



(51) International Patent Classification:
G05B 19/04 (2006.01)

(21) International Application Number:
PCT/CN2016/097830

(22) International Filing Date:
01 September 2016 (01.09.2016)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **HUIZHOU TCL MOBILE COMMUNICATION CO.,LTD** [CN/CN]; No.86, Hechang 7th West Road, ZhongKai Hi-tech Development, Huizhou, Guangdong 516006 (CN).

(72) Inventors: **CAI, Songfu**; No.86, Hechang 7th West Road, Zhong Kai Hi-tech Development, Hui Zhou, Guangdong 516006 (CN). **LAU, Kin Nang**; No.86, Hechang 7th West Road, Zhong Kai Hi-tech Development, Hui Zhou, Guangdong 516006 (CN). **LIU, An**; No.86, Hechang 7th West Road, Zhong Kai Hi-tech Development, Hui Zhou, Guangdong 516006 (CN).

(74) Agent: **CHINA WISPRO INTELLECTUAL PROPERTY LLP.**; Zhongdi Building, China University of Geosciences Base, No.8 Yuexing 3rd Road, High-Tech Industri-

al Estate, Room A806, Nanshan District, Shenzhen, Guangdong 518057 (CN).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: METHODS FOR PLANT STATE DATA TRANSMISSION AND ASSOCIATED SENSING AND CONTROL DEVICES

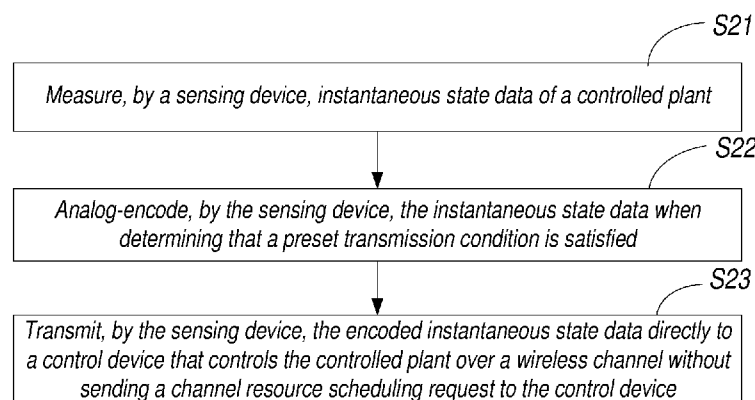


FIG. 2

(57) Abstract: Methods, sensing and control devices for plant state data transmission are disclosed. The method includes: measuring, by a sensing device (12), instantaneous state data of a controlled plant (11) (S21); analog-encoding the measured instantaneous state data when determining that a preset transmission condition is satisfied (S22); and transmitting the encoded instantaneous state data directly to a control device (13) that controls the controlled plant (11) over a wireless channel without sending a channel resource scheduling request to the control device (13) (S23). Thus, the data transmission overheads and the access latency can be significantly reduced.

Published:

— *with international search report (Art. 21(3))*

METHODS FOR PLANT STATE DATA TRANSMISSION AND ASSOCIATED SENSING AND CONTROL DEVICES

TECHNICAL FIELD

[0001] This disclosure relates generally to information transmission technology, and more particularly, to methods for plant state data transmission and associated sensing and control devices.

BACKGROUND

[0002] A Networked Control System (NCS) is a fully distributed, networked-based real-time feedback control system. A typical NCS may essentially consist of a dynamic plant, multiple sensors, a controller, and a communication network. Control loops of the NCS are closed through the communication network. Sensors may measure the instantaneous state of the dynamic plant and transmit the state data to the controller, so that the controller may produce a control command based on the state data and transfer the control command to the dynamic plant to stabilize the dynamic plant.

[0003] NCS has now gained enormous popularity due to its growing applications in industrial automation, smart transportation, remote robotic control, etc..An existing NCS may require a plurality of sensors to measure the state data at different positions of the dynamic plant. The sensors may digitally code the measured state data and upload the coded data to the controller.To avoid the data uploaded by different sensors from collision, sensors may need to send a scheduling request to the controller before uploading so that the controller can assign different channel resources for different sensors. However, each time before a sensor uploads its measured state data, it may need to send a scheduling request to the controller, resulting in remarkable data transmission overheads and access latency.

SUMMARY

[0004] In view of the above, methods for plant state data transmission and associated sensing and control devices are disclosed in the disclosure to reduce the data transmission overhead and access latency.

[0005] According to a first aspect of the disclosure, a method for plant state data transmission is disclosed that includes: Measuring, by a sensing device, instantaneous state data of a controlled plant; analog-encoding the instantaneous state data if a preset transmission condition is satisfied; and transmitting the encoded instantaneous state data directly to a control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device.

[0006] The block of transmitting the encoded instantaneous state data directly to the control device may comprise: transmitting the encoded instantaneous state data to the control device using a first preset time-frequency resource on uplink channel. All sensing devices wirelessly connected to the control device each may use the first preset time-frequency resource to transmit their measured instantaneous state data.

[0007] The first preset time-frequency resource may be specified by the control device.

[0008] The block of transmitting the encoded instantaneous state data directly to the control device may further comprise: transmitting a reference signal (RS) to the control device using a second preset time-frequency resource in the uplink channel, wherein the RS may be supplied to the control device for channel state estimation of the uplink channel. All sensing devices wirelessly connected to the control device each may use the second preset time-frequency resource to transmit RSs.

[0009] All sensing devices wirelessly connected to the control device each may transmit the same reference signal.

[0010] Sensing devices may perform wireless communication with the control device through a Long Term Evolution (LTE) network. The first preset time-frequency resource may be located on Physical Uplink Shared Channel (PUSCH), and the second preset time-frequency resource may comprise at least part of time-frequency resources on the PUSCH used to transmit uplink RSs.

[0011] The transmission condition may be interrelated with the instantaneous state

data measured by the sensing device.

[0012] The transmission condition may be expressed by $\|C_i x(n)\|^2 > \|C_i\|Ths$, where C_i is a measurement matrix of the i th sensing device, $C_i x(n)$ is the instantaneous state data matrix measured by the i th sensing device, and Ths is a preset threshold.

[0013] The method may further comprise: receiving the preset threshold Ths issued by the control device, wherein the preset threshold Ths may be determined according to the current demand of the control device for the state data of the controlled plant.

[0014] The block of analog-encoding the instantaneous state data may comprise: obtaining a quantized amplitude of the instantaneous state data, wherein the quantized amplitude may be loaded directly onto a carrier and thus transmitted to the control device.

[0015] The block of obtaining the quantized amplitude of the instantaneous state data may comprise: converting the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data, and taking the value represented by the bit stream as the quantized amplitude of the instantaneous state data.

[0016] The method may further comprise, after the block of converting the instantaneous state data from analog to digital to obtain the corresponding bit stream of the instantaneous state data: converting the instantaneous state data from serial to parallel.

[0017] The method may further comprise, after the block of the sensing device measuring the instantaneous state data of the controlled plant: limiting the amplitude of the measured instantaneous state data.

[0018] The method may further comprise, before the block of limiting the amplitude of the measured instantaneous state data: adjusting a dynamic range of the amplitude limitation according to a preset scalar value.

[0019] The method may further comprise, before the block of adjusting the dynamic range of the amplitude limitation according to the preset scalar value: receiving the

preset scalar value from the control device, wherein the preset scalar value may be determined based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

[0020] The method may further comprise: when the sensing device is newly added to the wireless network through which it communicates with the control device or when relevant communication parameters change, sending a synchronization request to the control device to obtain the network system information broadcast by the control device.

[0021] According to a second aspect of the disclosure, a method for plant state data transmission is also disclosed that comprises: receiving, by a control device, instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, wherein when each sensing device detects that a preset transmission condition is satisfied, it may analog-encode its measured instantaneous state data and transmit the encoded instantaneous state data over a wireless channel; analyzing the received instantaneous state data to obtain the instantaneous state data of the controlled plant; producing a control command in response to the obtained instantaneous state data of the controlled plant; and transferring the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[0022] The plurality of sensing devices each may transmit the instantaneous state data using a first preset time-frequency resource on uplink channel. And the block of receiving the instantaneous state data wirelessly transmitted from the plurality of sensing devices may comprise: receiving collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

[0023] The method may further comprise: receiving a collided reference signal (RS) produced from collision among RSs wirelessly transmitted from the plurality of sensing devices, wherein the plurality of sensing devices each may transmit RSs using a second preset time-frequency resource on the uplink channel. And the block of

analyzing the received instantaneous state data to obtain the instantaneous state data of the controlled plant may comprise: obtaining a collided effective channel $\sum_{i \in \Omega} H_i C_i$

based on the received collided reference signal $y_p(n)$ using the following equation (1):

$$[0024] \quad y_p(n) = \sum_{i \in \Omega} H_i C_i P + v(n) \quad (1); \quad \text{and}$$

[0025] obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$;

[0026] wherein, n identifies a serial number of a currently received frame or sub-frame, Ω represents the number of the sensing devices that currently connect to the network, H_i is the current channel state of the i th sensing device, P is a column vector consisting of RSs of all sensing devices currently connecting to the network, and $v(n)$ is the channel noise.

[0027] The block of obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$

may comprise: computing the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (2):

$$[0028] \quad y_d(n) = \sum_{i \in \Omega} H_i C_i \hat{x}(n) + z(n) \quad (2); \quad \text{where } z(n) \text{ is the channel noise.}$$

[0029] The block of obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$

may comprise: estimating the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using

Kalman filter algorithm.

[0030] The block of estimating the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$

using Kalman filter algorithm may comprise:

[0031] estimating the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the collided state data $y_d(n-1)$ of the received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (3):

$$[0032] \quad \hat{x}(n) = A\hat{x}(n-1) + AK(n-1)(y_d(n-1) - \sum_{i \in \Omega} H_i C_i \hat{x}(n-1)) \quad (3);$$

[0033] wherein $\hat{x}(n-1)$ is the instantaneous state data of the controlled plant that is estimated according to the received previous frame, A is a constant matrix, and K is Kalman gain.

[0034] According to a third aspect of the disclosure, a sensing device is disclosed that comprises: a measurement module configured to measure instantaneous state data of a controlled plant; an encoding module configured to analog-encode the instantaneous state data if a preset transmission condition is satisfied; and a transmission module configured to transmit the encoded instantaneous state data directly to a control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device.

[0035] According to a fourth aspect of the disclosure, a sensing device is also disclosed that comprises a measurement circuit, a processing circuit, and a radio frequency (RF) circuit group that are connected in series. The measurement circuit may be configured to measure and output the instantaneous state data of a controlled plant to the processing circuit. The processing circuit may be configured to analog-encode the instantaneous state data when a preset transmission condition is satisfied and output the encoded instantaneous state data to the RF circuit group. And the RF circuit group may be configured to transmit the encoded instantaneous state data directly to a control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device.

[0036] The RF circuit group may be configured to transmit the encoded instantaneous state data to the control device using a first preset time-frequency

resource on uplink channel. All sensing devices wirelessly connected to the control device each may use the first preset time-frequency resource to transmit their measured instantaneous state data.

[0037] The RF circuit group may further be configured to transmit a reference signal (RS) to the control device using a second preset time-frequency resource on the uplink channel, wherein the RS may be supplied to the control device for channel state estimation of the uplink channel. All sensing devices wirelessly connected to the control device each may use the second preset time-frequency resource to send RSs.

[0038] Each sensing device wirelessly connected to the control device may send the same RS.

[0039] The RF circuit group may be configured to perform wireless communication with the control device through a Long Term Evolution (LTE) network. The first preset time-frequency resource may be located on Physical Uplink Shared Channel (PUSCH), and the second preset time-frequency resource may comprise at least part of time-frequency resources on the PUSCH that are used to transmit uplink RSs.

[0040] The transmission condition may be interrelated with the instantaneous state data measured by the sensing device.

[0041] The transmission condition may be expressed by $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, wherein C_i is the measurement matrix of the i th sensing device, $C_i x(n)$ is the instantaneous state data measurement of the i th sensing device, and T_{hs} is a preset threshold.

[0042] The RF circuit group may further be configured to: receive the preset threshold T_{hs} issued by the control device that may be determined according to the current demand of the control device for the state data of the controlled plant.

[0043] The processing circuit may comprise an analog encoder configured to obtain a quantized amplitude of the instantaneous state data, wherein the quantized amplitude may be loaded directly onto a carrier and thus transmitted to the control device.

[0044] The analog encoder may comprise an analog-to-digital converter (ADC)

configured to convert the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data and take the value represented by the bit stream as the quantized amplitude of the instantaneous state data.

[0045] The analog encoder may further comprise a serial-to-parallel converter configured to convert the corresponding bit stream of the instantaneous state data from serial to parallel.

[0046] The processing circuit may further comprise an amplitude limiter configured to limit the amplitude of the measured instantaneous state data.

[0047] The processing circuit may further be configured to adjust a dynamic range of the amplitude limitation according to a preset scalar value.

[0048] The RF circuit group may further be configured to receive the preset scalar value from the control device that may be determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

[0049] According to a fifth aspect of the disclosure, a control device is also disclosed that comprises: a receiving module configured to receive instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, wherein when each sensing device detects that a preset transmission condition is satisfied, it may analog-encode its measured instantaneous state data and transmit the encoded instantaneous state data over a wireless channel; a computation module configured to obtain the instantaneous state data of the controlled plant by analyzing the received instantaneous state data; a generation module configured to produce a control command in response to the obtained instantaneous state data of the controlled plant; and a transmission module configured to transmit the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[0050] According to a sixth aspect of the disclosure, a control device is also disclosed that comprises a processing circuit, a radio frequency (RF) circuit group,

and an output, wherein the processing circuit is coupled to the RF circuit group and the output respectively. The RF circuit group may be configured to receive instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, and output the received instantaneous state data to the processing circuit. The processing circuit may be configured to obtain the instantaneous state data of the controlled plant by analyzing the received instantaneous state data, produce a control command in response to the obtained instantaneous state data of the controlled plant, and output the control command to the output. And the output may be configured to transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[0051] The plurality of sensing devices each may transmit the instantaneous state data using a first preset time-frequency resource on uplink channel. And the RF circuit group may be configured to receive collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

[0052] The RF circuit group may further be configured to: receive a collided reference signal (RS) produced from collision among RSs wirelessly transmitted from the plurality of sensing devices, wherein the plurality of sensing devices each may transmit RSs using a second preset time-frequency resource on the uplink channel. And the processing circuit may be configured to obtain a collided effective channel $\sum_{i \in \Omega} H_i C_i$ based on the received collided reference signal $y_p(n)$ using the following equation (1):

[0053] $y_p(n) = \sum_{i \in \Omega} H_i C_i P + v(n)$ (1); and

[0054] obtain the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$;

[0055] wherein, n identifies a serial number of a currently received frame or sub-frame, Ω represents a number of the sensing devices that currently connect to the

network, H_i is the current channel state of the i th sensing device, P is a column vector consisting of RSs of all sensing devices that currently connect to the network, and $v(n)$ is the channel noise.

[0056] The processing circuit may be configured to compute the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (2):

[0057] $y_d(n) = \sum_{i \in \Omega} H_i C_i \hat{x}(n) + z(n)$ (2); where $z(n)$ is the channel noise.

[0058] The processing circuit may be configured to estimate the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm.

[0059] The processing circuit may be configured to estimate the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n-1)$ of a received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (3):

[0060] $\hat{x}(n) = A\hat{x}(n-1) + AK(n-1)(y_d(n-1) - \sum_{i \in \Omega} H_i C_i \hat{x}(n-1))$ (3);

[0061] wherein $\hat{x}(n-1)$ is the instantaneous state data of the controlled plant that is estimated according to the previous frame, A is a constant matrix, and K is Kalman gain.

[0062] According to the above solutions of the disclosure, sensing devices can directly transmit their measured instantaneous state data to the control device using analog transmission without needing to send resource scheduling requests, namely, the instantaneous state data would be transmitted after being analog-encoded. With analog transmission, even if collision happens, the collided data can still be able to be utilized to obtain state estimation, thus the reliability of data transmission can be

improved, and in turn the control device would be able to effectively control the controlled plant to be stabilized. Furthermore, because the sensing device may transmit state data only when the preset transmission condition is satisfied and there is no need to send a scheduling request, uplink data overheads can be dually reduced. Additionally, the simplification of the data uploading process and the increase of the data uploading speed can reduce the uplink access latency and thus can improve the data transmission efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0063] FIG. 1 illustrates a Networked Control system (NCS) according to an embodiment of the disclosure.

[0064] FIG. 2 is a flowchart illustrating a method for plant state data transmission according to an embodiment of the disclosure.

[0065] FIG. 3a illustrates the transmission of state data using analog encoding.

[0066] FIG. 3b illustrates the transmission of state data using digital encoding.

[0067] FIG. 4 is a flowchart illustrating a method for plant state data transmission according to another embodiment of the disclosure.

[0068] FIG. 5 is a block diagram illustrating a sensing device implementing the method shown in FIG. 4.

[0069] FIG. 6 is a block diagram of a control device configured to receive the state data transmitted using the method as shown in FIG. 4.

[0070] FIG. 7 illustrates an application scenario where transmitted state data collides using analog encoding.

[0071] FIG. 8 illustrates another application scenario where transmitted state data collides using analog encoding.

[0072] FIG. 9 illustrates the channel structure employed by sensing devices in an application scenario according to the disclosure.

[0073] FIG. 10 is a flowchart illustrating a method for plant state data transmission according to yet another embodiment of the disclosure.

[0074] FIG. 11 illustrates the frame structure used by sensing devices in

synchronization in Frequency Duplex Division (FDD) case according to the disclosure.

[0075] FIG. 12 illustrates the frame structure used by sensing devices in synchronization in Time Duplex Division (TDD) case according to the disclosure.

[0076] FIG. 13 illustrates the communication process in an NCS according to another embodiment of the disclosure.

[0077] FIG. 14 illustrates the system information mapping employed by sensing devices according to an embodiment of the disclosure.

[0078] FIG. 15 is a block diagram of a sensing device according to an embodiment of the disclosure.

[0079] FIG. 16 is a block diagram of a sensing device according to another embodiment of the disclosure.

[0080] FIG. 17 is a block diagram of a sensing device according to yet another embodiment of the disclosure.

[0081] FIG. 18 is a block diagram of a control device according to an embodiment of the disclosure.

[0082] FIG. 19 is a block diagram of a sensing device according to another embodiment of the disclosure.

[0083] This disclosure includes references to “one embodiment,” “a particular embodiment,” “some embodiments,” “various embodiments,” or “an embodiment.” The appearances of the phrases “in one embodiment,” “in a particular embodiment,” “in some embodiments,” “in various embodiments,” or “in an embodiment,” do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

[0084] Various modules, units, circuits, or other components may be described or claimed as “configured to” perform a task or tasks. In such contexts, “configured to” is used to connote structure by indicating that the modules/units/circuits/components include structure (e.g., circuitry) that performs those task or tasks during operation. As such, the modules/units/circuits/components can be said to be configured to

perform the task even when the specified module/unit/circuit/component is not currently operational (e.g., is not on). The modules/units/circuits/components used with the “configured to” language include hardware—for example, circuits, memory storing program instructions executable to implement the operation, etc. Reciting that a module/unit/circuit/component is “configured to” perform one or more tasks is expressly intended not to invoke 35 U.S.C. §112(f), for that module/unit/circuit/component. Additionally, “configured to” can include a generic structure (e.g., generic circuitry) that is manipulated by software and/or firmware (e.g., an FPGA or a general-purpose processor executing software) to operate in a manner that is capable of performing the task(s) at issue. “Configured to” may also include adapting a manufacturing process (e.g., a semiconductor fabrication facility) to fabricate devices (e.g., integrated circuits) that are adapted to implement or perform one or more tasks.

[0085] As used herein, the term “based on” describes one or more factors that affect a determination. This term does not foreclose additional factors that may affect the determination. That is, a determination may be solely based on those factors or based, at least in part, on those factors. Consider the phrase “determine A based on B.” While in this case, B is a factor affects the determination of A, such a phrase does not foreclose the determination of A from also being based on C. In other instances, A may be determined based solely on B.

DETAILED DESCRIPTION

[0086] For a thorough understanding of the disclosure, numerous specific details are set forth in the following description for purposes of illustration but not of limitation, such as particular system structures, interfaces, technologies, et cetera. However, it should be appreciated by those of skill in the art that, in absence of these specific details, the disclosure may also be realized by other implementations. In other instances, detailed descriptions for well-known devices, circuits, and methods are omitted, in order to avoid unnecessary details from hindering the description of the disclosure.

[0087] To better illustrate the disclosure, hereinbelow a description will first be rendered to the system on which methods of the disclosure are implemented.

[0088] Referring to FIG. 1, a schematic of a Networked Control System (NCS) according to an embodiment of the disclosure is depicted. The NCS may comprise a controlled plant 11, a plurality of sensing devices 12, and a control device 13. The plurality of sensing devices 12 may be distributed onto different physical positions of the controlled plant 13 to measure the state data of the controlled plant 13 at different positions. (FIG. 1 merely shows an illustrative structure of the NCS, which doesn't reflect the actual relative positions of the sensing devices and the controlled plant). Control device 13 may communicate signals with the controlled plant 11. For instance, a wired or wireless channel may be established between control device 13 and controlled plant 11. Likewise, sensing devices 12 can build up communication channels with the control device 13 for data transmission. The network formed by control device 13 and sensing devices 12 may be hereinafter referred to as an access network. Control device 13 may build up wireless MIMO (multiple input multiple output) channels with controlled plant 11 and sensing devices 12 respectively. Adoption of wireless MIMO channel can improve the efficiency and reliability of data transmission and thus can improve the system stability.

[0089] Sensing devices 12 may perform Machine-Type Communication (MTC) with control device 13, thus throughout the specification and claims a sensing device can also be interchangeably referred to as an MTC device, while the control device can be interchangeably called an MTC server. For instance, sensing devices 12 may communicate with the control device 13 through a wireless network such as Long Term Evolution (LTE), 3GPP, etc. without needing human intervention.

[0090] Sensing devices 12 may be configured to measure the state data of the controlled plant 11 periodically or when receiving a trigger-command, and transmit the measured state data to the control device through the established wireless channels. The state data may comprise multiple different portions of state data of the controlled plant 11.

[0091] Control device 13 may be configured to perform state estimation of the

controlled plant 11 based on the received state data and the channel condition, and produce a corresponding control command according to the state estimation result and transfer the control command to the controlled plant 11. In one particular implementation, the control device 13 may be a server.

[0092] Controlled plant 11 may be configured to execute the control command transferred from the control device 13, so that the control device 13 can achieve a corresponding control over the controlled plant 11. In one particular implementation, the controlled plant 11 may be a potentially unstable dynamic plant. Control device 13 may estimate the state of the controlled plant 11 using the received state data, and further control the controlled plant 11 according to the state estimation result, in order to stabilize the controlled plant 11. When equation $\limsup_{N \rightarrow \infty} \frac{1}{N} \sum_{n=1}^N E \left[\|x(n)\|^2 \right] < \infty$ is satisfied, the controlled plant 11 may be in a typical stabilized state. The current state of the controlled plant 11 may be expressed by $x(n+1) = Ax(n) + Bu(n) + w(n)$, where $x(n)$ represents the previous state of the controlled plant 11, $u(n)$ is the control command, and $w(n)$ is the device noise.

[0093] When a sensing device 12 is newly added to the wireless network over which it communicates with the control device 13 or when relevant communication parameters change, the sensing device 12 may send a synchronization request to the control device 13 to obtain the network system information broadcast by the control device 13. As such, time slot and frame synchronization between the sensing devices 12 and the control device 13 can be achieved.

[0094] After the time slot and frame synchronization, the sensing devices 12 and control device 13 can jointly conduct the methods of the following embodiments for data transmission.

[0095] Referring now to FIG. 2, a flowchart of a method for plant state data transmission according to an embodiment of the disclosure is depicted. The method can be applied on the NCS as illustrated in FIG. 1 and particularly executed by the sensing devices 12 shown in FIG. 1. For purposes of illustration, the method is

illustrated as being sequential. However, portions of the method may be performed in other orders or in parallel (e.g., simultaneously). The method may comprise the following blocks.

[0096] At S21, the sensing device may measure the instantaneous state data of the controlled plant.

[0097] For instance, the sensing device may be disposed over the controlled plant or in its vicinity, and may measure the instantaneous state data of the controlled plant using a suitable internally or externally built sensing circuit. The instantaneous state data may include the instantaneous temperature, velocity, location, etc. The “instantaneous” state data as described herein shall not be strictly limited to the state data obtained at the present moment, but the state data obtained at any moment that may affect the controlled plant, so “old” data may also be included.

[0098] At S22, when the sensing device determines a preset transmission condition is satisfied, it may perform analog encoding to the instantaneous state data.

[0099] To reduce data transmission overhead, the sensing device may not upload all its measured state data to the control device, but may determine whether to transmit the data depending on the preset transmission condition.

[00100] The transmission condition may be set by the control device and/or the sensing device. In some embodiments, the transmission condition may be set to correlate with the instantaneous state data measured by the sensing device. For example, the transmission condition may be set as that the difference of the instantaneous state data measured by the sensing device from the ideal state data is greater than a predetermined value, where the ideal state data can be the measured historical state data. And only when this transmission condition is satisfied, will the instantaneous state data be analog-encoded and prepared for uploading.

[00101] As to the analog encoding, the sensing device may directly obtain the quantized amplitude of the instantaneous state data and load the quantized amplitude onto a carrier for transmission. Because the quantized amplitude as a modulation signal can assume infinite states (the quantized amplitude of different-valued instantaneous state data may also be different), it is how analog encoding derives its

name. The quantized amplitude may be a numeral that can be recognized and processed by the sensing device. For example, suppose an instantaneous state data is 14.8012 and the sensing device can handle only one decimal point, then the instantaneous state data may become 14.8 after analog encoding.

[00102] Existing sensors all use digital encoding for data transmission. However, with digital encoding, the digital signal in the form of bit streams obtained through analog-to-digital conversion may further require transport block check, block segmentation, rate matching, etc., and may then be modulated and transmitted to the control device. The control device may receive the digital signal that may further require decoding and digital-to-analog conversion, and the obtained analog signal may further require additional processing. By contrast, with analog encoding, the amplitude value of an input analog signal can be directly modulated and thus transmitted. Hence, compared with digital encoding, analog encoding at least reduces the need of transport block check, block segmentation, rate matching, and the corresponding decoding process, thereby structure of the sensing devices and control device, as well as the transmission path, can be significantly simplified.

[00103] Furthermore, referring to FIG. 3b, if, during the process a sensing device transmits a digital signal to the control device over the wireless channel, another sensing device also releases a digital signal to the control device, then digital signals transmitted from different sensing devices may be likely to collide, so that the control device may receive an erroneous digital signal, causing the signal invalid. Whereas using analog encoding as shown in FIG. 3a, even if signals transmitted from multiple sensing devices are superimposed together, the control device can still correctly decode the superimposed signal, i.e., the collided signal is still valid. Therefore, by analog-encoding the instantaneous state data, the communication reliability can be improved such that even when multiple sensing devices in the NCS simultaneously transmit data to the same control device, the control device would not require channel resource scheduling.

[00104] At S23, the sensing device may transmit the encoded instantaneous state data directly to the control device that controls the controlled plant over a wireless channel

without sending a channel resource scheduling request to the control device.

[00105] Because unlike digital encoding, the analog-encoded data can always come to valid data even if collision happens, the NCS can adopt a new communication protocol, which is, when the sensing device determines to upload data, it transmits the analog-encoded instantaneous state data directly to the control device over the wireless channel, instead of first sending a channel resource scheduling request to the control device.

[00106] Reasonably, because sensing devices don't send channel resource scheduling requests, there may be the probability that multiple sensing devices in the NCS transmit their respective measured instantaneous state data using the same channel resource, causing data collision. Nevertheless, with analog encoding, even if the control device receives collided data, it can still demodulate the collided data to obtain valid state data, thus securing an effective control over the controlled plant without worrying about collision. Furthermore, because the sensing device may transmit state data only when the preset transmission condition is satisfied and there is no need to send a scheduling request, the uplink data overhead can be largely reduced. In addition, the data uploading process can be simplified, the data uploading time can be reduced, and the simplification of the data uploading process and the increase of data uploading speed can shorten the uplink access latency and can thus improve the data transmission efficiency.

[00107] Referring now to FIG. 4, a flowchart of a method for plant state data transmission according to another embodiment of the disclosure is depicted. The method can be applied on the NCS as illustrated in FIG. 1 and particularly executed by sensing devices 12 shown in FIG. 1. For purposes of illustration, the method is illustrated as being sequential. However, portions of the method may be performed in other orders or in parallel (e.g., simultaneously). The method may comprise the following blocks.

[00108] At S41, the sensing device may measure the instantaneous state data of the controlled plant.

[00109] Optionally, the method may further comprise, before S41, sending a

synchronization request to the control device to obtain the network system information broadcast by the control device when the sensing device is newly added to the wireless network over which it communicates with the control device or when relevant communication parameters change; see relevant description in other embodiments for particularities of synchronization.

[00110] At S42, the sensing device may limit the amplitude of the measured instantaneous state data.

[00111] For example, the sensing device may pass the measured instantaneous state data through an amplitude limiter to lower the amplitude of signals that is higher than the set amplitude consistently to the set amplitude, so as to constrain the peak transmission power of the sensing device.

[00112] The sensing device can adjust the dynamic range of the amplitude limitation according to a set scalar value, in order to maintain a small (target) probability of saturation. When saturated, the limiter can stop the sensing devices from transmitting any more data. In some embodiments, the dynamic range can also be called the amplitude limit value of the amplitude limiter. Particular configuration of the dynamic range can follow:

$$L(n) = \frac{1}{\sqrt{\varepsilon}} (1 + \|A - B\Psi A\| \theta) (\|B\Psi A\| \sqrt{\text{Tr}(\sum(n)) - \text{Tr}(W)} + \sqrt{\text{Tr}(W)}),$$

where

$$\theta = \frac{1}{\mu_{\min}(T)} \left(\left\| (A - B\Psi A)^T Q \right\| + \left(\left\| (A - B\Psi A)^T Q \right\|^2 + \mu_{\min}(T) \|Q\| \right)^{\frac{1}{2}} \right)$$

is a constant (Q and T are any positive definite symmetric matrices such that

$$(A - B\Psi A)^T Q (A - B\Psi A) - Q = -T).$$

[00113] The scalar value can be set by the sensing device or the control device. For instance, the sensing device can receive the set scalar value from the control device before S42. The preset scalar value may be determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state

data. The greater the state estimation error, the larger the set scalar value.

[00114] At S43, when the sensing device determines the preset transmission condition is satisfied, it may obtain the quantized amplitude of the instantaneous state data and load the quantized amplitude onto a carrier to produce a radio frame.

[00115] The transmission condition may be interrelated with the instantaneous state data measured by the sensing device. For instance, the transmission condition can be expressed as $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, wherein i represents a serial number of the sensing device, C_i is the measurement matrix of the i th sensing device, $x(n)$ is a column vector made up of all state data of the controlled plant, $C_i x(n)$ is the instantaneous state data measurement of the i th sensing device, and T_{hs} is a preset threshold.

[00116] The preset threshold T_{hs} can be determined by the control device. For instance, the sensing device may further receive, before S43, the preset threshold T_{hs} issued by the control device that may be determined according to the current demand of the control device for the state data of the controlled plant. The preset threshold T_{hs} may assume an inverse relationship with the current demand of the control device for the state data of the controlled plant, that is, the more state data that is needed to receive, the smaller the preset threshold T_{hs} should be set. For example, if the control device performs state estimation based on the received state data and produce a comparatively large state estimation error, it may require more state data and may then reduce the preset threshold by a set step and transmit it to the sensing devices in the system.

[00117] The quantized amplitude can be directly loaded onto a carrier and transmitted to the control device.

[00118] An example of the sensing device is illustrated in FIG. 5, wherein the analog encoder 50 may comprise an analog-to-digital converter 51. The sensing device obtaining the quantized amplitude of the instantaneous state data may comprise: passing the amplitude-limited instantaneous state data through the analog-to-digital converter 51 for analog-to-digital conversion to obtain a corresponding bit stream of

the instantaneous state data, wherein the value represented by the bit stream may be taken as the quantized amplitude of the instantaneous state data, that is, the sensing device can obtain the quantized amplitude of the instantaneous state data based on the bit stream.

[00119] For instance, suppose an instantaneous state data is 14.001, which after analog-to-digital conversion may give a corresponding bit stream 1110. Because an equivalent decimal value represented by the bit stream is 14, the quantized amplitude of the instantaneous state data would be 14. Alternatively, the sensing device can also quantize the state data in other ways other than analog-to-digital conversion. After the sensing device obtains the quantized amplitude of the instantaneous state data according to the value represented by the bit stream, it may process and load the quantized amplitude onto a carrier to generate a radio frame. For instance, the sensing device may sequentially pass the quantized amplitude through transform precoder 53 for precoding, resource element mapper 54 for resource block mapping, SC-FDMA signal generator 55 to generate a complex-valued time-domain SC-FDMA signal, and frame generator 56 to produce the resulting radio frame. The resulting radio frame may then be transmitted to the control device through the mapped resource block on the wireless channel.

[00120] Additionally, some sensing devices may implement two-way parallel transmission (e.g., the transmitted signals are complex-valued signals), thus to accommodate the transmission method, the analog encoder 50 may further comprise a serial-to-parallel converter 52. Specifically, after converting the instantaneous state data from analog to digital to obtain the corresponding bit stream of the instantaneous state data, the sensing device may further convert the corresponding bit stream of the instantaneous state data from serial to parallel using the serial-to-parallel converter 52. That is, when the sensing device needs to transmit multiple bits of instantaneous state data, it can convert the multiple bits of serial state data to parallel, so as to enable two-way parallel transmission to further improve the transmission efficiency. After serial to parallel conversion, the quantized amplitude represented by either of the two bit streams can be loaded onto a carrier to form a radio frame to be transmitted to the

control device.

[00121] After the control device receives the radio frame loaded with the quantized amplitude, it may convert the radio frame to a numeral that can be recognized and processed, then demodulate the quantized amplitude from the radio frame, and perform state estimation based on the quantized amplitude and channel condition and thereby further produce a corresponding control command. Specifically, as shown in FIG. 6, the control device may pass the received radio frame through the analog-to-digital converter 61 for analog-to-digital conversion to obtain a corresponding bit stream of the radio frame, and the bit stream that can be handled by the control device would be taken as the quantized amplitude of the received state data. Then, the bit stream of the radio frame may successively pass through frame synchronization module 62 for frame synchronization, Fast Fourier transformer 63 for demodulation to obtain the loaded quantized amplitude information, and then be outputted to channel estimation module 64 and state estimation module 65. The state estimation module 65 may perform state estimation based on the outputs of the Fast Fourier transformer 63 and channel estimation module 64.

[00122] It should be appreciated that, though in the analog encoding scheme proposed by the disclosure the bit stream is obtained through analog to digital conversion, the purpose of analog to digital conversion is not to transmit every bit of the data, but to provide a device processable amplitude information made up of multiple bits. Thus, compared with digital encoding scheme, the control device may perform state estimation based on the received amplitude information, but not gauge every information bit, thereby resulting in more effective and robust state estimation performance.

[00123] To better illustrate the advantages of the analog encoding scheme proposed by the disclosure, hereinafter a brief description will be rendered to digital encoding. Digital encoding may require the source signal to pass sequentially through analog-to-digital conversion, transport block check and block segmentation, and rate matching to be digitally encoded, and then through a transform precoder, resource element mapper, SC-FDMA signal generator, and frame generator, to be outputted to

the transport channel. Once the receiver side receives the signal frame, reversely the signal frame may need to sequentially pass through a demodulator, channel deinterleaver, channel and CRC decoder to be digitally decoded, after which the state estimation can be carried out. The signal receiving at the receiver side may be modeled as $y_d(n) = r(n)x(n) + Z_q(n)[1]$, where $Z_q(n)$ is the quantization noise, $x(n)$ is the state data, and $r(n) \in \{0,1\}$ is a binary random variable, where $r(n)=1$ if the corresponding $r(n)$ can be correctly decoded, and $r(n)=0$ if the received signal does not contain any information about $r(n)$ but only the quantization noise, hence the state estimation performance deteriorates.

[00124] Whereas with the analog encoding scheme proposed by the disclosure, the signal received by the control device can be modeled as $y_a(n) = H(n)x(n) + Z_c(n)$, where $H(n)$ denotes the wireless channel state, $Z_c(n)$ contains the channel noise and quantization noise, and $x(n)$ is the state data. Thus, the received signal would always contain the information of the state data $x(n)$, thereby effectively improving the state estimation performance.

[00125] Furthermore, the analog encoding scheme can be achieved by simply replacing the digital modulation modules in existing digital encoding scheme with the corresponding analog encoding modules and eliminating the existing digital decoding components. For example, the sensing device may only require to replace all modules for digital encoding prior to the transform precoder with the analog to digital converter and serial to parallel converter as discussed above, while the control device may only require to remove all demodulation-related modules after the FFT module. Because the remaining modules perform the same functions as they are applied for digital encoding, the analog encoding scheme may be in effect compatible to existing network physical layer, such as LTE physical layer. In addition, because the analog encoding scheme proposed by the disclosure does not require digital modulation and demodulation, structure of the devices can be further simplified.

[00126] Additionally, in existing digital encoding scheme the bit stream is uncoded or coded with very simple channel coding method such as repetition code. This will result in a very high bit error rate (BER) of the encoded signal, resulting in poor estimation performance. Whereas the analog encoding scheme does not require digital encoding of the bit stream, thus the above problem can be avoided. Additionally, the digital encoding scheme is not suitable for low transmission power devices, because a low transmission power sensing device cannot guarantee a sufficient signal noise ratio (SNR) for stable state estimation performance, in which a high bit error rate (BER) may be involved and in turn the coverage area may be vastly limited, whereas according to the analog encoding scheme, the received signal would always contain the state data information, leading to a far better coverage performance.

[00127] In a specific application example, the data processing in analog encoding scheme may be illustrated as follows: the source signal carrying the instantaneous

state data may contain two real numbers 6 and 15, i.e., $\begin{bmatrix} 6 \\ 15 \end{bmatrix}$. The source signal may

first be converted from analog to digital to obtain a corresponding bit stream 10101101, which may then be passed through a serial-to-parallel converter to obtain a repeated data symbol sequence $s: 5.8+i15.2$, because one resource block contains 84 symbols, so the data symbol sequence s is repeated 84 times in one resource block. This repeated data symbol sequence s may then be outputted to the transform precoder for suitable processing, and then be transmitted over the wireless channel to the control device. After the control device receives the signal, it may pass it sequentially through a DAC, frame synchronization module, and FFT module to obtain $12+i2.1$, and the state estimator may then calculate the state estimation data

$\begin{bmatrix} 6.1 \\ 15.1 \end{bmatrix}$ based on the output $12+i2.1$ of the FFT and the channel estimator output

$1.1+i2.6$. As can be seen, the state estimation performance is excellent.

[00128] Further, because in analog encoding scheme the data symbol sequence corresponds to the quantized amplitude, the data symbol sequence of each

instantaneous state data would contain only one symbol, such that the symbol can be repeated 84 times in one resource block. Whereas in the digital encoding scheme, each instantaneous state data may correspond to multiple bits, so the data symbol sequence would contain multiple symbols. For instance, the symbols would include $-1-i1, 1-i1, 1+i1, -1+i1$ in the above application example. Therefore, the set of data symbols can be repeated only 21 times in one resource block. As a result, the repetition times in analog encoding scheme is far greater than digital encoding scheme. When the control device receives such a resource block and performs processing based on the repeated data symbols in the resource block, for example, dividing the noise of the resource block by the repetition times, arguably, the more the repetition times, the more the noise of each data symbol sequence can be decreased, namely, the higher the SNR.

[00129] Additionally, based on experimental and algorithmic deduction it shows that by analog encoding the controlled plant can be more easily stabilized, and the more the collided data is, the easier the stability can be achieved.

[00130] At S44, the sensing device may transmit the encoded instantaneous state data to the control device using a first preset time-frequency resource on uplink channel, and transmit a reference signal (RS) to the control device using a second preset time-frequency resource on the uplink channel.

[00131] In the NCS all sensing devices wirelessly connected to the control device each may transmit their measured instantaneous state data to the control device using the first preset time-frequency resource. The RS (also referred to as a pilot signal) may be supplied to the control device for channel state estimation of the uplink channel. All sensing devices wirelessly connected to the control device may use the second preset time-frequency resource to transmit RSs. In one embodiment, the first and second preset time-frequency resources may be configured by the control device, so that information of the resources can be included in the synchronized network system information and transmitted to the sensing devices, or broadcast to the sensing devices after synchronization.

[00132] That is, all sensing devices that currently connect to the network may all use

the same time-frequency resource to transmit to the control device the radio frames carrying the quantized amplitudes of their respective measured instantaneous state data, and use another same time-frequency resource to transmit RSs to the control device.

[00133] So, sensing devices may directly transmit RSs and the instantaneous state data using the same time-frequency resources on wireless uplink channel without sending channel resource scheduling requests to the control device. Because all sensing devices use the same time-frequency resource to transmit state data, the present embodiment purposefully enables the state data transmitted from different sensing devices to collide, so that the control device can use the collided state data to derive state estimation with even higher precision.

[00134] For example, as shown in FIG. 7, the controlled plant may have three state data $X = (x_1 \ x_2 \ x_3)^T$, where X is a column vector. Sensing device 1 may measure two of the three state data, x_1 and x_2 , which can be expressed as $(x_1 \ x_2)^T = C_1 X$, where C_1 represents the measurement matrix of sensing device 1 and is $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$. While sensing device 2 may measure two of the three state data, x_2 and x_3 , which can be expressed as $(x_2 \ x_3)^T = C_2 X$, where C_2 represents the measurement matrix of sensing device 2 and is $\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$. The plant may be

unstable with state transition matrix $A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{pmatrix}$. The number of rows or columns

of the state transition matrix may usually be, but not limited to, the total amount of the plant's state data. The state transition matrix A may be a diagonal matrix, in which the diagonal elements increment progressively from 1 at the upper left to the lower right at steps of 1. If sensing devices 1 and 2 transmit their state data without collision, because (A, C_1) and (A, C_2) are both unobservable, (Observability is a

notion in control theory which states that a system with an initial state is observable if and only if the value of the initial state can be determined from the system output $y(t)$ that has been observed through the time interval $t_0 < t < t_f$, while if the initial state cannot be so determined, the system is unobservable. The more non-zero matrix elements in C , the larger probability the system is observable), the control device may obtain a state estimation with a relatively large error after performing state estimation based on the received collision-free state data. So the plant cannot be effectively controlled, hence still unstable. By contrast, if the state data transmitted from sensing devices 1 and 2 collides, for example, $(x_1 \ x_2)^T + (x_2 \ x_3)^T = (C_1 + C_2)X = C_3X$, then the measurement matrix of the collided data would be $C_3 = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix}$. Because (A, C_3) is observable, the control device can obtain a state estimation with higher precision based on the received collided state data. So, the plant can be effectively controlled, hence stabilized. Therefore, collision of state data can increase the probability of observability, and the collision following analog encoding can improve the stability of the plant.

[00135] In another example, as shown in FIG. 8, the controlled plant may have three state data $X = (x_1 \ x_2 \ x_3)^T$, where X is a column vector. Sensing device 1 may measure two of the three state data, x_1 and x_2 , which can be expressed as $(x_1 \ x_2)^T = C_1X$, where C_1 represents the measurement matrix of sensing device 1 and is

$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$. While sensing device 2 may measure the three state data of the plant, x_1, x_2 ,

and x_3 , which can be expressed as $(x_1 + x_2 \ x_3)^T = C_2X$, where C_2 represents the measurement matrix of sensing device 2 and is $\begin{pmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$. The plant may be

unstable with a state transition matrix $A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{pmatrix}$. If sensing devices 1 and 2

transmit state data without collision, because (A, C_2) is observable though (A, C_1) is unobservable, the control device can still control the controlled plant effectively based on the received collision-free state data, and so the controlled plant can be stabilized. By contrast, if the state data transmitted from sensing devices 1 and 2 collides, for example, $(x_1 \ x_2)^T + (x_2 \ x_3)^T = (C_1 + C_2)X = C_3X$, then the measurement matrix of the collided data would be $C_3 = \begin{pmatrix} 2 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix}$. Because (A, C_3) is observable, the control device can still control the plant effectively so that the controlled plant can also be stabilized. As can be concluded, collision will not destroy the observability of the state data, but instead enhance the stability of the controlled plant.

[00136] Typically, all sensing devices may use the same time-frequency resource to transmit RSs, so that RSs transmitted from multiple sensing devices may probably collide. The control device can utilize the collided RS to estimate the channel to obtain an equivalent channel, and further compute the state data of the controlled plant by taking the estimated equivalent channel as the channel state of the collided state data. Further, the state data of the controlled plant can be used to control the controlled plant accordingly.

[00137] To further save the processing overhead of the sensing devices, all sensing devices may transmit the same RS, so that the control device can perform estimation to obtain the equivalent channel based on the unique agreed RS to be transmitted and the received RS, without needing a series of processing to obtain the RSs transmitted from each sensing device.

[00138] In one application example in which sensing devices and the control device perform wireless communication over an LTE or 3GPP network, the aforementioned first preset time-frequency resource may be located on uplink PUSCH, while the sensing preset resource block may comprise at least part of time-frequency resources on the uplink PUSCH that are used to transmit RSs, as shown in FIG. 9. The first preset time-frequency resource can be configured by the control device via DCI format 0.

[00139] It can be appreciated that, the sensing devices may not be required to send RSs using the same time-frequency resource. The control device can estimate the current equivalent channel based on the channel over which data is received the last time, and further perform state estimation based on the estimated equivalent channel and the received collided data.

[00140] Referring now to FIG. 10, a flowchart of a method for plant state data transmission according to yet another embodiment of the disclosure is depicted. The method can be applied on the NCS as illustrated in FIG. 1 and particularly executed by the control device shown in FIG. 1. For purposes of illustration, the method is illustrated as being sequential. However, portions of the method may be performed in other orders or in parallel (e.g., simultaneously). The method may comprise the following blocks.

[00141] At S101, the control device may receive instantaneous state data that is wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices. When the sensing device detects that a preset transmission condition is satisfied, it may perform analog encoding to its measured instantaneous state data and transmit the encoded instantaneous state data over a wireless channel.

[00142] Sensing devices may use the method of the previous embodiment to transmit their measured instantaneous state data; see relevant description in the previous embodiment for more details. Before the sensing devices transmit the instantaneous state data, the control device may not perform channel resource scheduling for the sensing devices, so that the sensing devices may autonomously select the channel resource to transmit the instantaneous state data.

[00143] At S102, the control device may analyze the received instantaneous state data to obtain the instantaneous state data of the controlled plant.

[00144] The control device may decode the instantaneous state data and perform state estimation accordingly, as shown in FIG. 6; see relevant description of the previous embodiment for more details.

[00145] In some embodiments, all sensing devices in the system each may use a first

preset time-frequency resource on uplink channel to transmit their measured instantaneous state data. For example, all sensing devices may use the first preset time-frequency resource as shown in FIG. 9 to transmit the state data. Specifically in S101, the control device may receive collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices. And in S102, the control device may estimate the state of the controlled plant using the collided state data and the estimated equivalent channel.

[00146] In some embodiments, all sensing devices in the system may further use a second preset time-frequency resource on the uplink channel to transmit RSs. For example, all sensing devices each may use the second preset time-frequency resource as shown in FIG. 9 to transmit RSs. Specifically in S101, the control device may further receive a collided RS produced from collision among RSs wirelessly transmitted from the plurality of sensing devices. And S102 may specifically comprise the following sub-steps.

[00147] In S1021, a collided effective channel $\sum_{i \in \Omega} H_i C_i$ may be obtained based on the received collided reference signal $y_p(n)$ using the following equation (11):

$$[00148] \quad y_p(n) = \sum_{i \in \Omega} H_i C_i P + v(n) \quad (11);$$

[00149] wherein, n represents a serial number of a currently received frame or sub-frame, Ω is a number of the sensing devices that currently connect to the network (i.e., can perform wireless communication with the control device in the NCS), H_i is the current channel state of the i th sensing device, P is a column vector consisting of RSs of all sensing devices currently connecting to the network, (typically, all sensing devices that currently connect to the network may transmit the same RS), and $v(n)$ represents the channel noise in transmission of the RS.

[00150] In the control device's computation of the collided effective channel $\sum_{i \in \Omega} H_i C_i$ based on the collided reference signals $y_p(n)$ using the above equation (11), standard channel estimation methods in LTE such as LMS and MMSE filtering

algorithms can be adopted.

[00151] Note, in other embodiments, the sensing devices may not send reference signals or may not sent RSs using the same time-frequency resource. And the control device may estimate the current collided effective channel based on the previous channel state or a combination of the previous channel state and the received RSs. In particular, Kalman filtering can be used for the channel estimation. For example it can use Least Square (LS) or Minimum Mean Square Error (MMSE) estimation for the channel estimation.

[00152] In S1022, the instantaneous state data of the controlled plant may be obtained based on the received collided state data and the collided effective channel.

[00153] For example, the instantaneous state data of the controlled plant $\hat{x}(n)$ can be computed based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (12):

[00154] $y_d(n) = \sum_{i \in \Omega} H_i C_i \hat{x}(n) + z(n)$ (12); where, $z(n)$ represents the channel noise in transmission of the instantaneous state data.

[00155] In another example, the control device can obtain the instantaneous state data using Kalman filtering. And step S1022 may comprise: estimating the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm. More

specifically, the control device may estimate the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the collided state data $y_d(n-1)$ of the received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (13):

[00156] $\hat{x}(n) = A\hat{x}(n-1) + AK(n-1)(y_d(n-1) - \sum_{i \in \Omega} H_i C_i \hat{x}(n-1))$ (13);

[00157] wherein $\hat{x}(n-1)$ is the state data of the controlled plant that is estimated according to the previous frame, A is a constant matrix, and K is Kalman gain.

[00158] It can be appreciated that, in other embodiments, there also can use the currently received state data to estimate the instantaneous state data.

[00159] At S103, the control device may produce a control command in response to the analyzed instantaneous state data of the controlled plant.

[00160] For example, the control device may produce a control command based on the computed instantaneous state data of the controlled plant at S122 and the control requirements over the controlled plant.

[00161] At S104, the control device may transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[00162] For example, the control device may produce and transfer a corresponding control command to the controlled plant over an MIMO channel, so that the controlled plant may execute the control command and may thus be stabilized accordingly.

[00163] For purposes of illustration, an example is given as follows. In the NCS as shown in FIG. 1, sensing devices and control device may communicate via an LTE network. First, when a sensing device is newly added to the wireless network over which it communicates with the control device or when relevant communication parameters change, the sensing device may send a synchronization request to the control device to obtain the network system information broadcast by the control device. As such, synchronization between the sensing device and the control device can be achieved.

[00164] For instance, when the sensing device is newly added to the wireless network through which it communicates with the control device or when relevant communication parameters change, it may first detect the primary synchronization signal (PSS), which can enable the sensing device to be synchronized on sub-frame level. In some embodiments, the sensing device may employ Frequency Division Dual (FDD) communication, the PSS may be located in the last Orthogonal Frequency Division Multiplexing (OFDM) symbol of first and eleventh slot of the first subframe (subframe 0) as illustrated in Figure 11. The PSS may be repeated in

subframe 5 which means the sensing device is synchronized on 5ms basis. In some embodiments, the sensing device may employ Time Division Duplexing (TDD) communication, the PSS may be in the third symbol of the 3rd and 13th slots as illustrated in FIG. 12.

[00165] The sensing device may then detect the secondary synchronization signal (SSS). In FDD embodiments, as illustrated in Figure 11, SSS symbols are located in the same subframe of PSS but in the symbol before PSS. In TDD embodiments, as illustrated in Figure 12, SSS may be transmitted three symbols earlier than the PSS. The SSS may provide the sensing device with information about frame timing properties and etc..The synchronization between sensing devices and the control device thus can enable each sensing device to derive system information (MIB and SIBs) of the network. The system information may be periodically broadcast in the network and this information is needed for each sensing device to be able to connect to the network. The control device may periodically broadcast the network system information, so that sensing devices can achieve time slot and frame synchronization and further connect to the network relying on the network system information. Note that the disclosure is also totally compatible to Filter Bank-Orthogonal Frequency Division Multiple Access (FB-OFDMA).

[00166] After the sensing device synchronization with the control device and the sensing device acquisition of the network system information (Master Information Block (MIB) and multiple System Information Blocks (SIBs)), each sensing device may be ready to access the network. The communication protocol between the sensing device and the control device is discussed in some depth with reference to FIG. 13, and hereinafter MTC device refers to the sensing device, while the MTC server refers to the control device.

[00167] **1. Initialization**

[00168] The MTC server broadcasts the RRC (Radio Resource Control) Connection Reconfiguration Message to all the MTC devices to configure the parameters of DCI Format 0 configurations. The MTC server also broadcasts a scalar value L and a threshold Ths to all the MTC devices using PDSCH.

[00169] **2. Grant free analog asynchronous network access at the MTC devices**

[00170] Each MTC device sets the dynamic range of its limiter to the value of L . Each MTC device determines whether to transmit its state data and reference signal (pilots) or shut down the transmitter based on the state data (partial state observation) and threshold Ths . Specifically, the i -th MTC device is active for transmission if the condition $\|C_i x(n)\|^2 > \|C_i\| Ths$ is satisfied, where C_i is the i -th MTC device's state measurement matrix, and $C_i x(n)$ is the partial state data of the i -th MTC device; otherwise, the i -th MTC device is turned off or enters a sleep state so that no transmission is performed. If an MTC device is active for transmission, it transmits its encoded state data on the specified data field of PUSCH as configured by MTC server, and reference signals (pilots) on the RS field of PUSCH. Each active MTC device transmits the same reference signal (pilots) on the same RS field on PUSCH. Depending on the partial state observation and threshold Ths at each sensor, the proposed protocol promotes data collision of unobservable plant states, which encourages the unobservable states to become observable and therefore, substantially enhances the system stability.

[00171] **3. Collided effective channel estimation at the MTC server**

[00172] The MTC server estimates the collided effective channel from the collided reference signals (pilots) on the RS field of the received PUSCH.

[00173] **4. Plant state estimation at the MTC server**

[00174] The MTC server calculates the plant state estimate based on the received collided state data on the data field of the received PUSCH and the collided effective channel estimation. The MTC server then generates plant control action and the actuator uses the control action for plant actuation.

[00175] **5. Periodical feedback of the MTC server**

[00176] The MTC server updates the scalar value L and the threshold Ths and broadcasts the updated values via PDSCH to all the MTC devices periodically with a period of T .

[00177] The MTC device may periodically receive the messages broadcast by the

MTC server. More specifically, as shown in FIG. 14, Each MTC device is periodically turned on to receive the system information broadcast by the MTC server. The system information (MIB and SIBs) is periodically broadcast in the network by the MTC server and the system information is needed for each MTC device to be able to connect to the network. The system information mapping is illustrated in Figure 13. Specifically, each MTC device is turned on every 40ms to receive the MIB on BCH carried by PBCH. Each MTC device is turned on every 80ms, 160ms, 320ms and 640ms to receive the SIB-1, SI-1, SI-2, and SI-3, respectively, on the DL-SCH carried by PDSCH. Each MTC device is periodically turned on with the period of T to receive the scalar value L and the threshold Ths broadcast by the MTC server on PDSCH.

[00178] The advantages of the above communication protocol can be summarized as follows.

[00179] **1) PHY Layer (L1) Link Budget Advantage**

- a. No notion of “packet error” in analog transmission.
- b. Simpler and cheaper PHY data path.
- c. Better link Budget compared with uncoded digital datapath.

[00180] **2) MAC Layer (L2) Benefits**

- a. All the existing digital multi-MTC access schemes in 3GPP cannot handle collision and avoid collision by either contention resolution or scheduling.
- b. The proposed analog transmission embraces and welcomes collision.
- c. Robust to Collisions.

Under analog transmission, collided measurements are very useful

No need for contention resolution or collision resolution

- d. Grant-Free Access

No need for UL (uplink) scheduling leading to low access latency. The proposed protocol is grant-free and completely uncoordinated which results in short access latency and therefore, substantially enhances the performance of MTC control type applications.

Unlike grant-free access solutions in digital transmission, the receiver datapath in

the proposed solution is very simple. No need for complicated collision resolution signal processing.

e. Collision Enhances “Observability”.

Observable measurements promote system stability.

Collided unobservable measurements between multi-MTC may become observable, leading to enhanced stability.

f. Collision will not destroy “Observability”.

Observable measurements are still observable after collision, leading to enhanced stability.

g. No Contention Resolution or Collision Resolution is needed.

The proposed protocol can utilize collided data measurements for remote state estimation and control.

[00181] **3) Decentralized Event-driven Transmission based on Local State**

a. Efficient use of Radio Resource Block (RB).

b. No need to have centralized MTC device scheduling at all, which thus substantially simplifies the MAC layer.

[00182] **4) Promote Collision to Enhance Stability**

Unlike conventional MAC protocol which avoids collision, the proposed MAC protocol promotes collision of localized MTC state measurements, so that unobservable states become observable, which substantially enhances system stability.

[00183] **5) Low Overhead**

All MTC devices just need to share common pilot symbols which ensures the protocol to have low overhead.

[00184] The above state estimation method used by the control device may have the following advantages:

[00185] **1) Exploiting Collision via Collided Effective Channel Estimation**

a. Allow all the MTC devices to share the same reference signals (Pilots) (Instead of orthogonal pilots as in existing 3GPP multi-MTC), leading to high resource efficiency.

b. Effective channel condition can be exploited by MTC server even if collision happens, which enhances robustness to collision.

2) Low Complexity State Estimation Algorithm for Exploiting Collided Analog Data Measurements from Multiple MTC devices

a. The MTC server adopted state estimation algorithm can accommodate the collided data measurements of multiple active MTC devices.

b. More information about the plant state can be exploited from the collided data measurements by the adopted state estimation algorithm, so it welcomes collision.

[00186] Referring now to FIG. 15, a block diagram of a sensing device according to an embodiment of the disclosure is depicted.

[00187] The sensing device may be sensing device 12 as illustrated in FIG. 1. The sensing device may comprise a measurement module 151, an encoding module 152, and a transmission module 153.

[00188] Measurement module 151 may be configured to measure the instantaneous state data of the controlled plant.

[00189] Encoding module 152 may be configured to analog-encode the instantaneous state data when determining that a preset transmission condition is satisfied.

[00190] And transmission module 153 may be configured to transmit the encoded instantaneous state data directly to the control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device. The control device may be control device 13 illustrated in FIG. 1.

[00191] Specifically, the transmission module 153 may be configured to transmit the encoded instantaneous state data to the control device using a first preset time-frequency resource on uplink channel, wherein all sensing devices wirelessly connected to the control device each may use the first preset time-frequency resource to transmit their measured instantaneous state data. The first preset time-frequency may be specified by the control device.

[00192] Specifically, the transmission module 153 may further be configured to transmit a reference signals (RS) to the control device using a second preset

time-frequency resource on the uplink channel. The RS may be supplied to the control device for performing channel state estimation of the uplink channel, and all sensing devices wirelessly connected to the control device each may use the second preset time-frequency resource to send RSs. Typically, all sensing devices wirelessly connected to the control device may send the same RS.

[00193] In one embodiment, the sensing devices and the control device may perform wireless communication over an LTE network, and the aforementioned first preset time-frequency resource may be located on uplink PUSCH, while the second preset time-frequency resource may comprise at least part of time-frequency resources on the uplink PUSCH that are used to transmit RSs, as shown in FIG. 9.

[00194] Optionally, the transmission condition may be interrelated with the instantaneous state data measured by the sensing device. For example, the transmission condition may be expressed by relation $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, where C_i is a measurement matrix of an i th sensing device, $C_i x(n)$ is the instantaneous state data measurement of the i th sensing device, and T_{hs} is a preset threshold. The preset threshold T_{hs} can be determined by the control device.

[00195] Referring now to FIG. 16, a block diagram of a sensing device according to another embodiment of the disclosure is depicted. In addition to the modules illustrated in the embodiment shown in FIG. 15, the sensing device 160 may further comprise a receiving module 164, amplitude limitation module 165, adjustment module 166, and synchronization module 167.

[00196] The transmission condition adopted in this embodiment can be expressed as $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$. Receiving module 164 may be configured to receive the preset threshold T_{hs} issued by the control device. The preset threshold T_{hs} may be determined according to the current demand of the control device for the state data of the controlled plant. For example, the preset threshold T_{hs} may assume an inverse relationship with the current demand of the control device for the state data of the controlled plant.

[00197] Encoding module 152 may be configured to obtain the quantized amplitude

of the instantaneous state data. The quantized amplitude may be directly loaded onto a carrier and so transmitted to the control device.

[00198] Optionally, encoding module 152 may comprise an analog-to-digital conversion unit 1521 and a serial-to-parallel conversion unit 1522.

[00199] Analog-to-digital conversion unit 1521 may be configured to convert the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data. The value represented by the bit stream may be taken as the quantized amplitude of the instantaneous state data.

[00200] Serial-to-parallel conversion unit 1522 may be configured to convert the corresponding bit stream of the instantaneous state data from serial to parallel.

[00201] Amplitude limitation module 165 may be configured to limit the amplitude of the measured instantaneous state data.

[00202] And adjustment module 166 may be configured to adjust the dynamic range of the amplitude limitation according to a preset scalar value. The preset scalar value may be set by the control device. For instance, the receiving module 164 may further be configured to receive the preset scalar value transmitted from the control device. The preset scalar value may be determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

[00203] Synchronization module 167 may be configured to, when the sensing device is newly added to the wireless network over which it communicates with the control device or when relevant communication parameters change, send a synchronization request to the control device to obtain the network system information broadcast by the control device.

[00204] It can be appreciated that, in other embodiments, the sensing device can also selectively include part of the newly added modules as shown in FIG. 16 according to different functional requirements. For example, the sensing device may include only the receiving module and synchronization module, or only the amplitude limitation module, adjustment module, and synchronization module, etc.

[00205] Various modules of the sensing device may be configured to execute the

corresponding steps of the method of the previous embodiment; see the description of corresponding method embodiment for more details.

[00206] Referring now to FIG. 17, a block diagram of a sensing device according to yet another embodiment of the disclosure is depicted. The sensing device may be sensing device 12 as illustrated in FIG. 1. The sensing device 170 may comprise a measurement circuit 171, a processing circuit 172, and a radio frequency (RF) circuit group 173 that are connected in series.

[00207] Specifically, RF circuit group 173 may comprise an RF circuit 1731 and an antenna 1732. The antenna 1732 may be an MIMO antenna, and the RF circuit 1732 may transmit the signals out through the antenna 1732.

[00208] Measurement circuit 171 may be configured to measure the instantaneous state data of the controlled plant and output it to the processing circuit 172.

[00209] Processing circuit 172 may be configured to analog-encode the instantaneous state data when determining that a preset transmission condition is satisfied, and output the encoded instantaneous state data to the RF circuit group 173.

[00210] And RF circuit group 173 may be configured to transmit the encoded instantaneous state data directly to the control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device. The control device may be control device 13 illustrated in FIG. 1.

[00211] Optionally, RF circuit group 173 may be configured to transmit the encoded instantaneous state data to the control device using a first preset time-frequency resource on uplink channel. All sensing devices wirelessly connected to the control device each may use the first preset time-frequency resource to transmit their measured instantaneous state data. The first preset time-frequency resource may be specified by the control device.

[00212] In some embodiments, RF circuit group 173 may further be configured to transmit a RS to the control device using a second preset time-frequency resource on the uplink channel. The RS may be supplied to the control device for performing channel state estimation of the uplink channel, and all sensing devices wirelessly connected to the control device each may use the second preset time-frequency

resource to send RSs.

[00213] In some embodiments, all sensing devices wirelessly connected to the control device may transmit the same RS.

[00214] In a specific embodiment, RF circuit group 173 and the control device may perform wireless communication over an LTE network, and the first preset time-frequency resource may be located on uplink PUSCH, while the second preset resource block may comprise at least part of time-frequency resources on the uplink PUSCH that are used to transmit RSs, as illustrated in FIG. 9.

[00215] Optionally, the transmission condition may be interrelated with the instantaneous state data measured by the sensing device 170. For example, the transmission condition may be expressed by $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, where C_i is a measurement matrix of an i th sensing device, $C_i x(n)$ is the instantaneous state data measured by the i th sensing device, and T_{hs} is a preset threshold.

[00216] Optionally, RF circuit group 173 may further be configured to receive the preset threshold T_{hs} issued by the control device. The preset threshold T_{hs} may be determined by the control device according to the current demand of the control device for the state data of the controlled plant.

[00217] Optionally, processing circuit 172 may comprise an analog encoder 1721 configured to obtain a quantized amplitude of the instantaneous state data. The quantized amplitude may be directly loaded onto a carrier and so transmitted to the control device.

[00218] Specifically, analog encoder 1721 may be configured to convert the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data. The value represented by the bit stream may be taken as the quantized amplitude of the instantaneous state data. Furthermore, analog encoder 1721 may further be configured to convert the corresponding bit stream of the instantaneous state data from serial to parallel. In one particular implementation, the analog encoder 1721 may comprise at least modules 51 and 52 in structure as illustrated in FIG. 5.

[00219] Optionally, processing circuit 172 may further comprise an amplitude limiter 1722 coupled to measurement circuit 171 and analog encoder 1721 respectively and configured to limit the amplitude of the measured instantaneous state data.

[00220] Optionally, processing circuit 172 may further be configured to adjust the dynamic range of the amplitude limitation according to the preset scalar value. For example, processing circuit 172 may further comprise a controller configured to adjust the dynamic range of the amplitude limitation according to the preset scalar value, or the amplitude limiter 1722 may further be configured to adjust the dynamic range of the amplitude limitation according to the preset scalar value.

[00221] Optionally, RF circuit group 173 may further be configured to receive the preset scalar value transmitted from the control device. The preset scalar value may be determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

[00222] Optionally, RF circuit group 173 may further be configured to, when the sensing device 170 is newly added to the wireless network over which it communicates with the control device or when relevant communication parameters change, send a synchronization request to the control device to obtain network system information broadcast by the control device.

[00223] Alternatively, processing circuit 172 may include the structure as illustrated in FIG. 5.

[00224] It can be appreciated that, the method performed by the sensing device that is illustrated in the present embodiment can be applied to or implemented by the processing circuit 172. Processing circuit 172 can be an integrated circuit chip with signal processing capabilities. In the implementation process, various steps of the method can be accomplished by the processing circuit 172's hardware integrated logic circuits or software commands. Processing circuit 172 may also be a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), or other programmable logic devices, discrete gates, transistor logic devices, discrete hardware

components. Processing circuit 172 can execute the various methods, steps, and logic diagrams as disclosed herein. The general-purpose processor can be a microprocessor or any conventional processor. Steps of the methods disclosed by the disclosure can be directly executed by a hardware decoding processor, or by a combination of hardware or software modules in the decoding processor. The software modules may reside in any storage medium familiar to the art such as a random access memory (RAM), flash memory, programmable read-only memory (ROM), or electrically erasable programmable memory or register. Processing circuit 172 may read the program stored in the storage medium and carry out the steps of the above methods.

[00225] Referring now to FIG. 18, a block diagram of a control device according to an embodiment of the disclosure is depicted. The control device may be control device 13 as illustrated in FIG. 1. The control device may comprise a receiving module 182, a computation module 183, a generation module 183, and a transmission module 184.

[00226] Receiving module 181 may be configured to receive instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices. When the sensing device detects that a preset transmission condition is satisfied, it may analog-encode the measured instantaneous state data and transmit the encoded instantaneous state data over a wireless channel. The sensing device may be that discussed in the preceding embodiments.

[00227] Computation module 182 may be configured to analyze the received instantaneous state data to obtain the instantaneous state data of the controlled plant.

[00228] Generation module 183 may be configured to produce a control command in response to the analyzed instantaneous state data of the controlled plant.

[00229] And the transmission module 184 may be configured to transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[00230] Optionally, the plurality of sensing devices each may transmit the instantaneous state data using a first preset time-frequency resource on uplink channel.

And the receiving module 181 may be configured to receive collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

[00231] Optionally, receiving module 181 may be configured to receive a collided reference signal (RS) produced from collision among RSs wirelessly transmitted from the plurality of sensing devices. The plurality of sensing devices each may transmit RSs using a second preset time-frequency resource on the uplink channel.

[00232] Computation module 182 may be configured to obtain the collided effective channel $\sum_{i \in \Omega} H_i C_i$ based on the received collided state data $y_p(n)$ using the above equation (11), and further obtain the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$.

[00233] Optionally, the computation module 182 may be configured to compute the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the above equation (12).

[00234] Optionally, the computation module 182 may further be configured to estimate the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm.

[00235] For example, the computation module 182 may be configured estimate the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n-1)$ of the received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the above equation (13).

[00236] Referring now to FIG. 19, a block diagram of a control device according to another embodiment of the disclosure is depicted. The control device may be control device 13 as illustrated in FIG. 1. The control device 190 may comprise a processing circuit 191, an RF circuit group 192, and an output 193. The processing

circuit 191 may be coupled to the RF circuit group 192 and output 193 respectively.

[00237] The RF circuit group 192 may specifically comprise an RF circuit 1921 and an antenna 1922. The antenna 1922 may be an MIMO antenna, and the RF circuit 1922 may transmit the signals out through the antenna 1921.

[00238] RF circuit group 192 may be configured to receive instantaneous state data that is wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, and output the received instantaneous state data to the processing circuit 191. The sensing devices may be those discussed in the above embodiments.

[00239] Processing circuit 191 may be configured to analyze the received instantaneous state data to obtain the instantaneous state data of the controlled plant, and produce a control command in response to the analyzed instantaneous state data of the controlled plant and output the control command to the output 193.

[00240] Output 193 may be configured to transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

[00241] It can be appreciated that the RF circuit group 192 and output 193 may be implemented as a same circuit. Or, output 193 can be implemented as another RF circuit group.

[00242] Optionally, the plurality of sensing devices each may transmit the instantaneous state data using a first preset time-frequency resource on uplink channel. And the RF circuit group 192 may be configured to receive collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

[00243] Optionally, the RF circuit group 192 may be configured to receive a collided reference signal (RS) produced from collision among RSs wirelessly transmitted from the plurality of sensing devices. The plurality of sensing devices each may transmit RSs using a second preset time-frequency resource on the uplink channel.

[00244] Processing circuit 191 may be configured to obtain the collided effective

channel $\sum_{i \in \Omega} H_i C_i$ based on the received collided state data $y_p(n)$ using the above equation (11), and further obtain the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$.

[00245] In some embodiments, the processing circuit 191 may be configured to compute the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the above equation (12).

[00246] In some embodiments, the processing circuit 191 may be configured to estimate the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm.

[00247] For example, the processing circuit 191 may be configured to estimate the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the collided state data $y_d(n-1)$ of the received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the above equation (13).

[00248] The method performed by the control device that is illustrated in the present embodiment can be applied to or implemented by the processing circuit 191.

[00249] Processing circuit 191 can be an integrated circuit chip with signal processing capabilities. In the implementation process, various steps of the method can be accomplished by the processing circuit 191's hardware integrated logic circuits or software commands. Processing circuit 191 may also be a general purpose processor, digital signal processor (DSP), application specific integrated circuit (ASIC), field programmable gate array (FPGA), or other programmable logic devices, discrete gates, transistor logic devices, discrete hardware components. Processing circuit 191 can execute the various methods, steps, and logic diagrams as disclosed herein. The general purpose processor can be a microprocessor or any conventional processor. Steps of the methods disclosed by the disclosure can be directly executed

by a hardware decoding processor, or by a combination of hardware or software modules in the decoding processor. The software modules may reside in any storage medium familiar to the art such as a random access memory (RAM), flash memory, programmable read-only memory (ROM), or electrically erasable programmable memory or register. Processing circuit 191 may read the program stored in the storage medium and implement the steps of the above methods.

[00250] According to the above solutions, the sensing devices can transmit their measured instantaneous state data directly to the control device by analog transmission without sending resource scheduling requests to the control device, that is, the measured instantaneous state data would be transmitted after being analog encoded. With analog transmission, even if collision happens, the collided data can still be able to be utilized to obtain state estimation, thereby the reliability of data transmission can be improved, and the control device can thus achieve an effective control over the controlled plant without worrying about data collision. Furthermore, because the sensing device may transmit state data only when the preset transmission condition is satisfied and there is no need to send a scheduling request, the uplink data overhead can be dually reduced. In addition, the simplification of the data uploading process and the increase of data uploading speed can effectively shorten the uplink access latency and thus improve the data transmission efficiency.

[00251] The elements, in different embodiments, with the same name but labeled by different reference numerals, may denote the same element and have same configuration and function.

[00252] It shall be appreciated that the disclosed systems, devices, and methods can also be implemented in other forms. Actually, the devices as described are merely illustrative. For example, the division of modules or units is only a division based on logic functions, thus in actual implementations there may be other division methods--for instance, multiple units or components may be combined or integrated onto another system, or some features may be ignored or simply not executed.

[00253] In addition, the displayed or discussed mutual couplings, direct couplings or communication connections may be achieved through some interfaces, devices or

units, and may be achieved electrically, mechanically or in other forms.

[00254] Separated units as described may or may not be physically separated. Components displayed as units may or may not be physical units, and they may reside at one location or may be distributed to multiple networked units. Part or all of the units may be selected according to actual requirements to achieve objectives of various embodiments of the disclosure.

[00255] In addition, various functional units as discussed in the disclosure may be integrated into one processing unit, or may be presented as various physically separated units. Two or more units may be integrated into one. The integrated units may be implemented by hardware, or may be implemented as software functional units.

[00256] If the integrated units are implemented as software functional units and sold or used as standalone products, they can be stored in a computer readable storage medium. As such, all or part of technical solutions of the disclosure may be embodied as software products. Computer software products can be stored in storage medium and can include multiple instructions enabling a computing device (e.g., a personal computer, a server, a network device, etc.) or a processor to execute all or part of steps of the methods as described in various embodiments of the disclosure. The storage medium may include all kinds of media that can store program codes, such as a USB flash disk, mobile hard drive, read-only memory (ROM), random access memory (RAM), magnetic disk, or optical disk.

What is claimed is:

1. A method for plant state data transmission, comprising:
measuring, by a sensing device, instantaneous state data of a controlled plant;
analog-encoding the instantaneous state data when a preset transmission
condition is satisfied; and
transmitting the encoded instantaneous state data directly to a control device that
controls the controlled plant over a wireless channel without sending a channel
resource scheduling request to the control device.
2. The method according to claim 1, wherein the block of transmitting the
encoded instantaneous state data directly to the control device over the wireless
channel comprises:
transmitting the encoded instantaneous state data to the control device using a
first preset time-frequency resource on uplink channel, wherein all sensing devices
wirelessly connected to the control device each use the first preset time-frequency
resource to transmit their measured instantaneous state data.
3. The method according to claim 2, wherein the first preset time-frequency
resource is specified by the control device.
4. The method according to claim 2, wherein the block of transmitting the
encoded instantaneous state data directly to the control device over the wireless
channel further comprises:
transmitting a reference signal (RS) to the control device using a second preset
time-frequency resource on the uplink channel, wherein the RS is supplied to the
control device for performing channel state estimation of the uplink channel, and all
sensing devices wirelessly connected to the control device each use the second preset
time-frequency resource to transmit RSs.
5. The method according to claim 4, wherein all sensing devices wirelessly
connected to the control device transmit a same RS.
6. The method according to claim 4, wherein the sensing devices and the
control device perform wireless communication over an LTE network, the first preset
time-frequency resource is located on Physical Uplink Shared Channel (PUSCH), and

the second preset time-frequency resource comprises at least part of time-frequency resources on the uplink PUSCH that are used to transmit RSs.

7. The method according to claim 1, wherein the transmission condition is interrelated with the instantaneous state data measured by the sensing device.

8. The method according to claim 7, wherein the transmission condition is expressed as $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, wherein C_i is a measurement matrix of an i th sensing device, $C_i x(n)$ is the instantaneous state data measurement of the i th sensing device, and T_{hs} is a preset threshold.

9. The method according to claim 8, further comprising:

receiving the preset threshold T_{hs} issued by the control device, wherein the T_{hs} preset threshold is determined by the control device according to its current demand for state data of the controlled plant.

10. The method according to claim 1, wherein the block of analog-encoding the instantaneous state data comprises:

obtaining an quantized amplitude of the instantaneous state data, wherein the quantized amplitude is to be loaded directly onto a carrier and so transmitted to the control device.

11. The method according to claim 10, wherein the block of obtaining the quantized amplitude of the instantaneous state data comprises:

converting the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data, and taking a value represented by the bit stream is as the quantized amplitude of the instantaneous state data.

12. The method according to claim 11, further comprising, after the block of converting the instantaneous state data from analog to digital to obtain the corresponding bit stream of the instantaneous state data:

converting the corresponding bit stream of the instantaneous state data from serial to parallel.

13. The method according to claim 1, further comprising, after the block of measuring by the sensing device the instantaneous state data of the controlled plant:

limiting an amplitude of the measured instantaneous state data.

14. The method according to claim 13, further comprising, before the block of limiting the amplitude of the measured instantaneous state data:

adjusting a dynamic range of the amplitude limitation according to a preset scalar value.

15. The method according to claim 14, further comprising, before the block of adjusting the dynamic range of the amplitude limitation according to the preset scalar value:

receiving the preset scalar value transmitted from the control device, wherein the preset scalar value is determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

16. The method according to claim 1, further comprising:

sending a synchronization request to the control device to obtain network system information broadcast by the control device when the sensing device is newly added to the wireless network over which it communicates with the control device or when relevant communication parameters change.

17. A method for plant state data transmission, comprising:

receiving, by a control device, instantaneous state data that is wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, wherein each sensing device analog-encodes its measured instantaneous state data and transmits the encoded instantaneous state data over a wireless channel when detecting that a preset transmission condition is satisfied;

analyzing the received instantaneous state data to obtain the instantaneous state data of the controlled plant;

producing a control command in response to the analyzed instantaneous state data of the controlled plant; and

transferring the control command to the controlled plant to enable the controlled plant to operate according to the control command.

18. The method according to claim 17, wherein the plurality of sensing devices each transmit their measured instantaneous state data using a first preset time-frequency resource on uplink channel; and the block of receiving the instantaneous state data wirelessly transmitted from the plurality of sensing devices comprises:

receiving collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

19. The method according to claim 18, further comprising:

receiving a collided reference signal (RS) produced from collision among the RSs wirelessly transmitted from the plurality of sensing devices, wherein the plurality of sensing devices each transmit their RSs using a second preset time-frequency resource on the uplink channel; and the block of analyzing the received instantaneous state data to obtain the instantaneous state data of the controlled plant comprises:

obtaining a collided effective channel $\sum_{i \in \Omega} H_i C_i$ based on the received collided RS

$y_p(n)$ using the following equation (1):

$$y_p(n) = \sum_{i \in \Omega} H_i C_i P + v(n) \quad (1);$$

obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$;

wherein, n represents a serial number of a currently received frame or sub-frame, Ω denotes a number of the sensing devices that currently connect to the network, H_i represents a current channel state of an i th sensing device, P is a column vector consisting of RSs of all the sensing devices currently connecting to the network, and $v(n)$ is channel noise.

20. The method according to claim 19, wherein the block of obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ comprises:

computing the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (2):

$$y_d(n) = \sum_{i \in \Omega} H_i C_i \hat{x}(n) + z(n) \quad (2); \text{wherein } z(n) \text{ is channel noise.}$$

21. The method according to claim 19, wherein the block of obtaining the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ comprises:

estimating the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm.

22. The method according to claim 21, wherein the block of estimating the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the Kalman filter algorithm comprises:

estimating the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the collided state data $y_d(n-1)$ of a received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (3):

$$\hat{x}(n) = A \hat{x}(n-1) + AK(n-1)(y_d(n-1) - \sum_{i \in \Omega} H_i C_i \hat{x}(n-1)) \quad (3);$$

wherein $\hat{x}(n-1)$ is the instantaneous state data of the controlled plant that is estimated according to the previous frame, A is a constant matrix, and K is Kalman gain.

23. A sensing device, comprising:
- a measurement module configured to measure instantaneous state data of a controlled plant;
 - an encoding module configured to analog-encode the instantaneous state data when determining that a preset transmission condition is satisfied; and
 - a transmission module configured to transmit the encoded instantaneous state data directly to a control device that controls the controlled plant over a wireless channel without sending a channel resource scheduling request to the control device.
24. A sensing device, comprising a measurement circuit, processing circuit, and radio frequency (RF) circuit group that are connected in series, wherein
- the measurement circuit is configured to measure instantaneous state data of a controlled plant and output it to the processing circuit;
 - the processing circuit is configured to analog-encode the instantaneous state data when determining that a preset transmission condition is satisfied, and output the encoded instantaneous state data to the RF circuit group; and
 - the RF circuit group is configured to transmit the encoded instantaneous state data directly to a control device that controls the controlled plant over a wireless channel without sending a resource scheduling request to the control device.
25. The sensing device according to claim 24, wherein the RF circuit group is configured to transmit the encoded instantaneous state data to the control device using a first preset time-frequency resource on uplink channel, wherein all sensing devices wirelessly connected to the control device each use the first preset time-frequency resource to transmit their measured instantaneous state data.
26. The sensing device according to claim 25, wherein the RF circuit group is further configured to:
- transmit a reference signal (RS) to the control device using a second preset time-frequency resource on the uplink channel, wherein the RS is supplied to the control device for performing channel state estimation of the uplink channel, and all sensing devices wirelessly connected to the control device each use the second preset time-frequency resource to transmit RSs.

27. The sensing device according to claim 26, wherein all sensing devices wirelessly connected to the control device transmit a same RS.

28. The sensing device according to claim 26, wherein the RF circuit group and the control device perform wireless communication over an LTE network, the first preset time-frequency resource is located on Physical Uplink Shared Channel (PUSCH), and the second preset resource block comprises at least part of time-frequency resources on the uplink PUSCH that are used to transmit RSs.

29. The sensing device according to claim 24, wherein the transmission condition is interrelated with the instantaneous state data measured by the sensing device.

30. The sensing device according to claim 29, wherein the transmission condition is expressed as $\|C_i x(n)\|^2 > \|C_i\| T_{hs}$, where C_i is a measurement matrix of the i th sensing device, $C_i x(n)$ is the instantaneous state data measurement of the i th sensing device, and T_{hs} is a preset threshold.

31. The sensing device according to claim 30, wherein the RF circuit group is further configured to:

receive the preset threshold T_{hs} issued by the control device, wherein the preset threshold T_{hs} is determined by the control device according to its current demand for state data of the controlled plant.

32. The sensing device according to claim 24, wherein the processing circuit comprises an analog encoder configured to obtain a quantized amplitude of the instantaneous state data, wherein the quantized amplitude is to be loaded directly onto a carrier and so transmitted to the control device.

33. The sensing device according to claim 32, wherein the analog encoder comprises an analog-to-digital converter (ADC) configured to convert the instantaneous state data from analog to digital to obtain a corresponding bit stream of the instantaneous state data take a value represented by the bit stream as the quantized amplitude of the instantaneous state data.

34. The sensing device according to claim 33, wherein the analog encoder further comprises a serial-to-parallel converter configured to convert the corresponding bit stream of the instantaneous state data from serial to parallel.

35. The sensing device according to claim 24, wherein the processing circuit further comprises an amplitude limiter configured to limit amplitude of the measured instantaneous state data.

36. The sensing device according to claim 35, wherein the processing circuit is further configured to:

adjust a dynamic range of the amplitude limitation according to a preset scalar value.

37. The sensing device according to claim 36, wherein the RF circuit group is further configured to receive the preset scalar value transmitted from the control device, wherein the preset scalar value is determined by the control device based on magnitude of state estimation error produced in state estimation of the controlled plant that is carried out by the control device according to its received instantaneous state data.

38. A control device, comprising:

a receiving module configured to receive instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the sensing devices, wherein each sensing device analog-encodes its measured instantaneous state data and transmits the encoded instantaneous state data over a wireless channel when determining that a preset transmission condition is satisfied;

a computation module configured to analyze the received instantaneous state data to obtain the instantaneous state data of a controlled plant;

a generation module configured to produce a control command in response to the analyzed instantaneous state data of the controlled plant; and

a transmission module configured to transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

39. A control device, comprising a processing circuit, radio frequency (RF) circuit group, and output, the processing circuit being coupled to the RF circuit group and the output respectively, wherein

the RF circuit group is configured to receive instantaneous state data wirelessly transmitted from a plurality of sensing devices without performing channel resource scheduling for the plurality of sensing devices, and output the received instantaneous state data to the processing circuit;

the processing circuit is configured to analyze the received instantaneous state data to obtain the instantaneous state data of a controlled plant, and produce a control command in response to the analyzed instantaneous state data of the controlled plant and output the control command to the output; and

the output is configured to transfer the control command to the controlled plant to enable the controlled plant to operate according to the control command.

40. The control device according to claim 39, wherein the plurality of sensing devices each transmit their instantaneous state data using a first preset time-frequency resource on uplink channel, and the RF circuit group is configured to receive collided state data produced from collision among the instantaneous state data wirelessly transmitted from the plurality of sensing devices.

41. The control device according to claim 40, wherein the RF circuit group is further configured to receive a collided reference signal (RS) produced from collision among the RSs wirelessly transmitted from the plurality of sensing devices, wherein the plurality of sensing devices each transmit their RSs using a second preset time-frequency resource on the uplink channel; and the processing circuit is configured to:

obtain a collided effective channel $\sum_{i \in \Omega} H_i C_i$ based on the received collided RS

$y_p(n)$ using the following equation (1):

$$y_p(n) = \sum_{i \in \Omega} H_i C_i P + v(n) \quad (1);$$

obtain the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$;

wherein, n represents a serial number of a currently received frame or sub-frame, Ω denotes a number of the sensing devices that currently connect to the network, H_i represents a current channel state of the i th sensing device, P is a column vector consisting of RSs of all of the sensing devices that currently connect to the network, and $v(n)$ is channel noise.

42. The control device according to claim 41, wherein the processing circuit is configured to compute the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the received collided state data $y_d(n)$ and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (2):

$$y_d(n) = \sum_{i \in \Omega} H_i C_i \hat{x}(n) + z(n) \quad (2); \text{ wherein } z(n) \text{ is channel noise.}$$

43. The control device according to claim 41, wherein the processing circuit is configured to estimate the instantaneous state data of the controlled plant based on the received collided state data and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using Kalman filter algorithm.

44. The control device according to claim 43, wherein the processing circuit is configured to estimate the instantaneous state data $\hat{x}(n)$ of the controlled plant based on the collided state data $y_d(n-1)$ of a received previous frame and the collided effective channel $\sum_{i \in \Omega} H_i C_i$ using the following equation (3):

$$\hat{x}(n) = A \hat{x}(n-1) + AK(n-1)(y_d(n-1) - \sum_{i \in \Omega} H_i C_i \hat{x}(n-1)) \quad (3);$$

wherein $\hat{x}(n-1)$ is the instantaneous state data of the controlled plant that is estimated according to the received previous frame, A is a constant matrix, and K is Kalman gain.

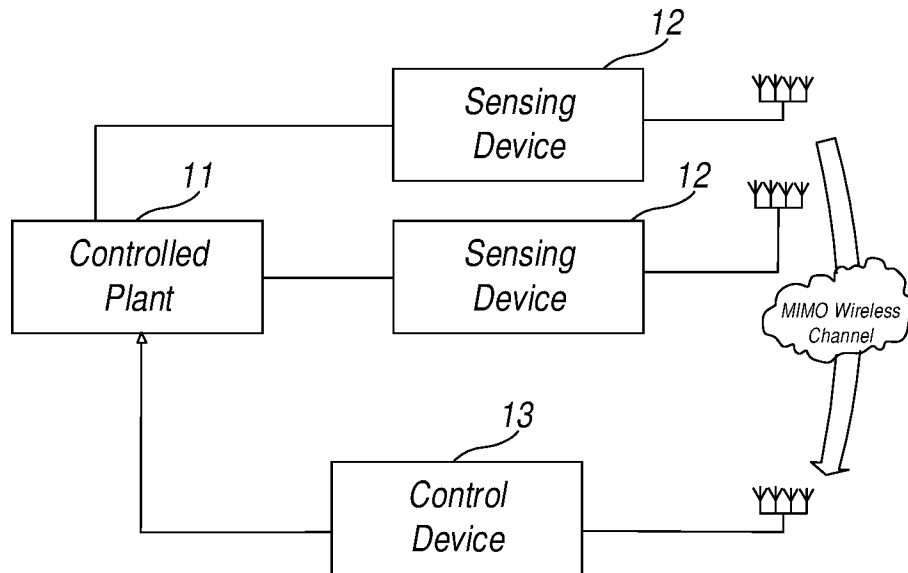


FIG. 1

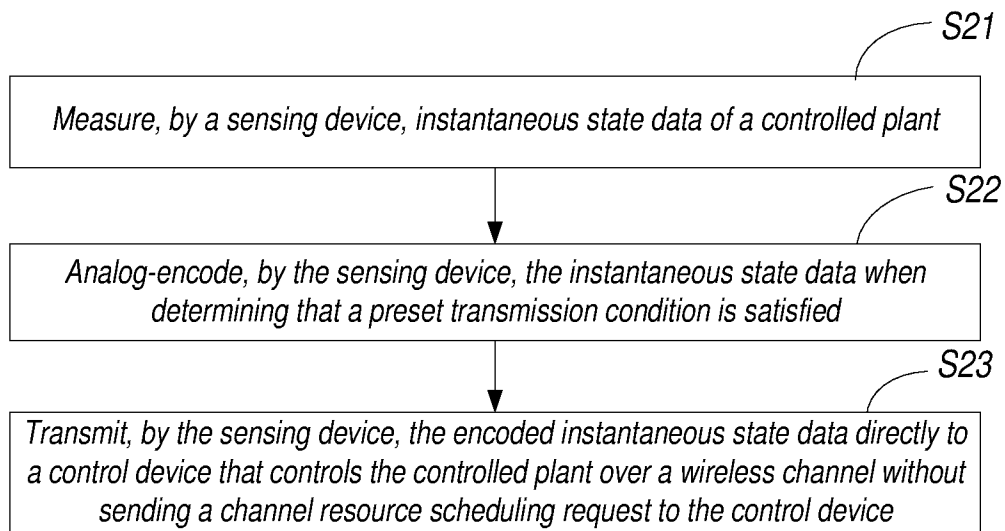


FIG. 2

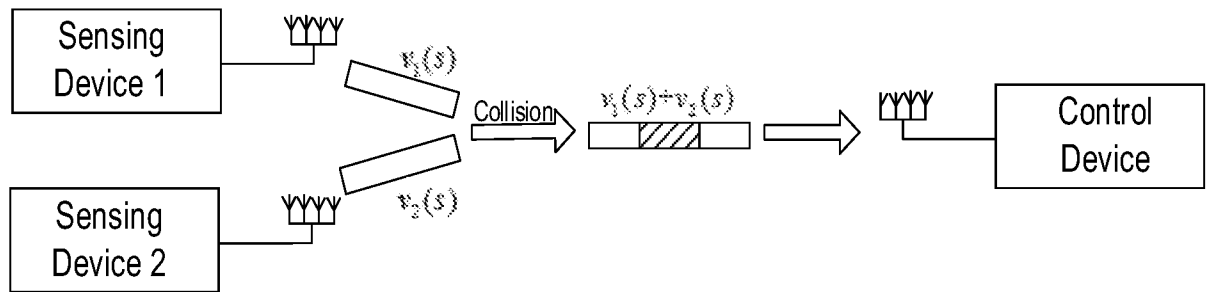


FIG. 3a

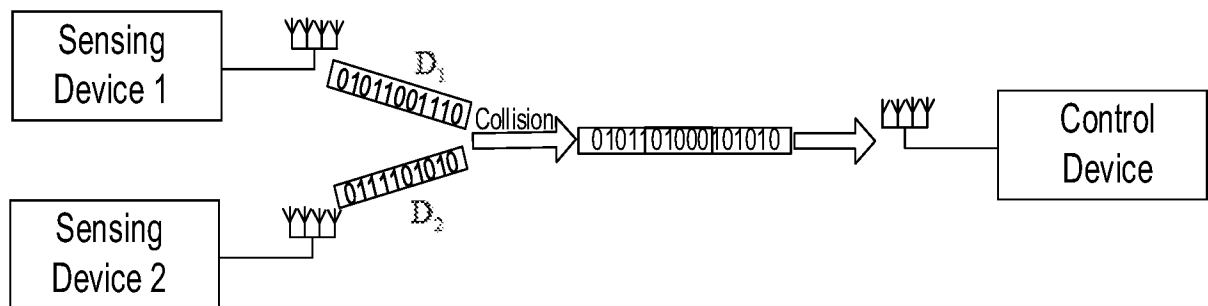


FIG. 3b

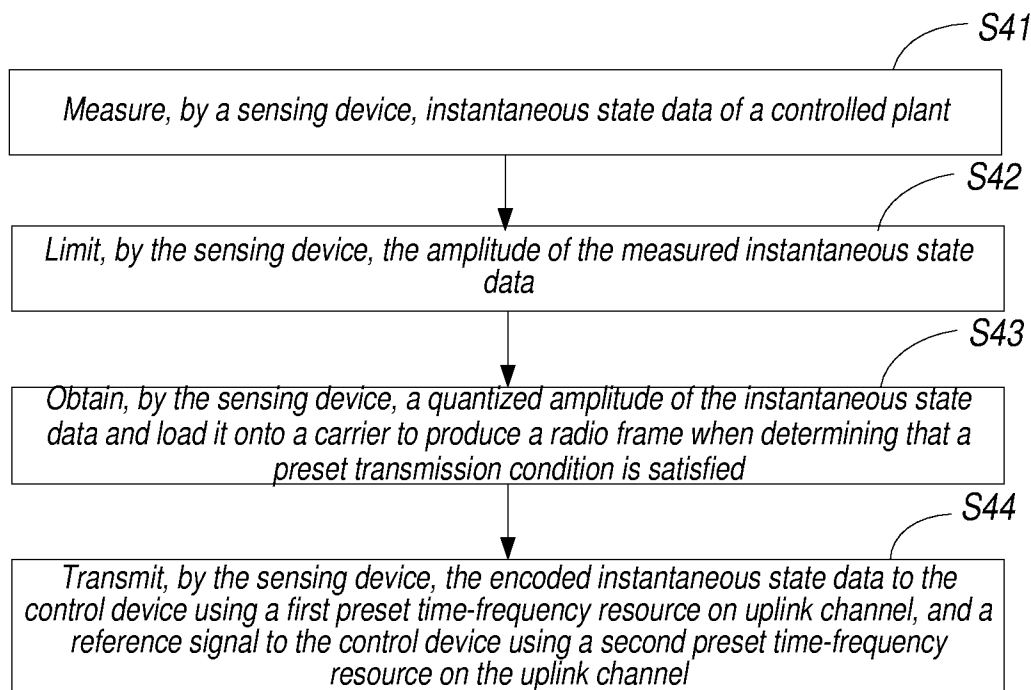


FIG. 4

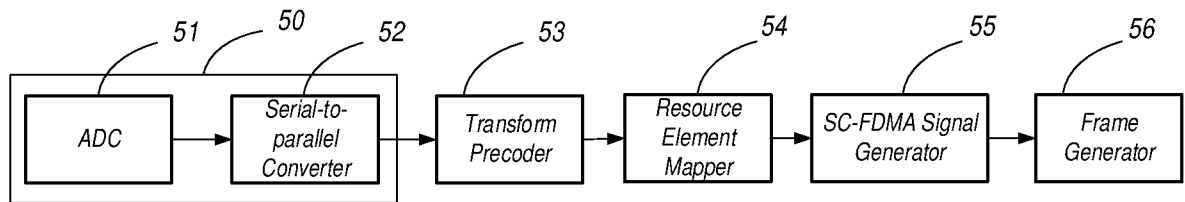


FIG. 5

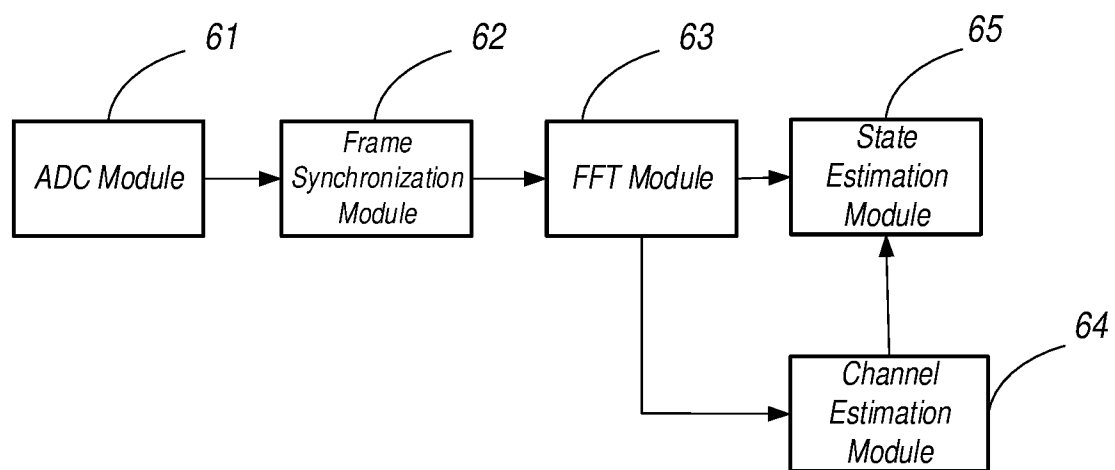


FIG. 6

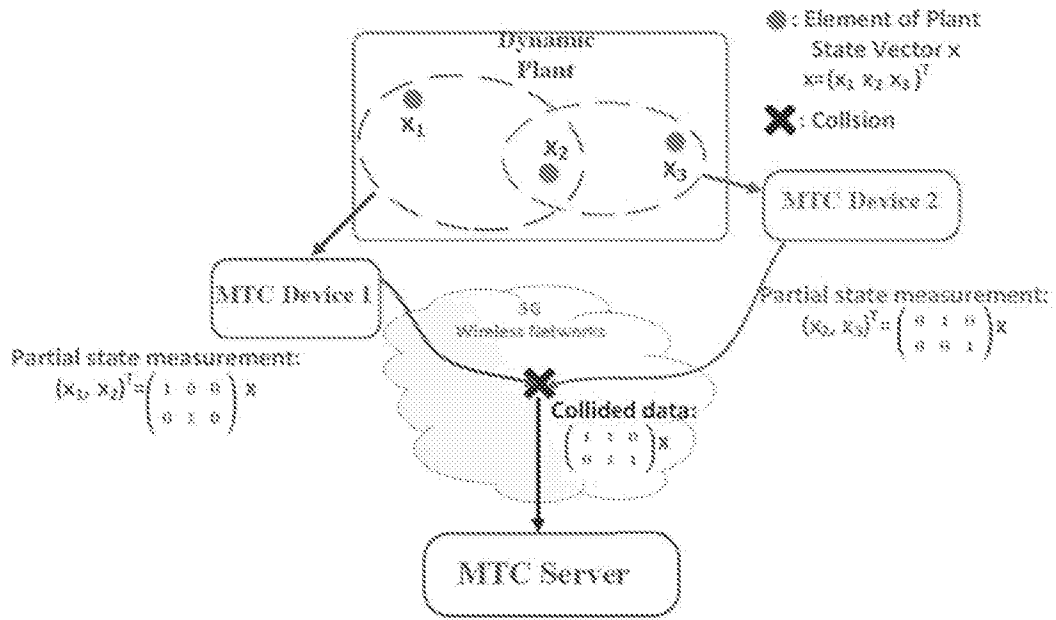


FIG. 7

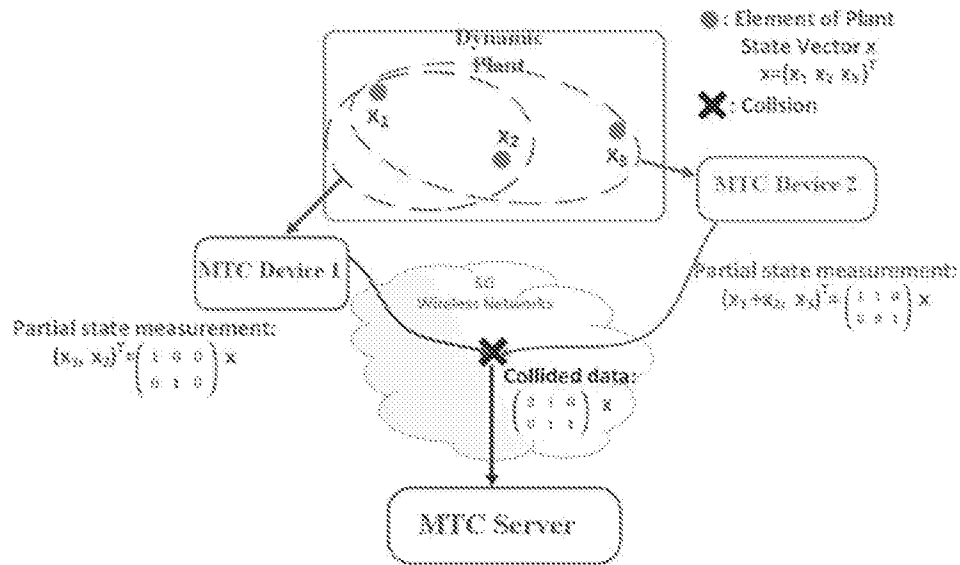


FIG. 8

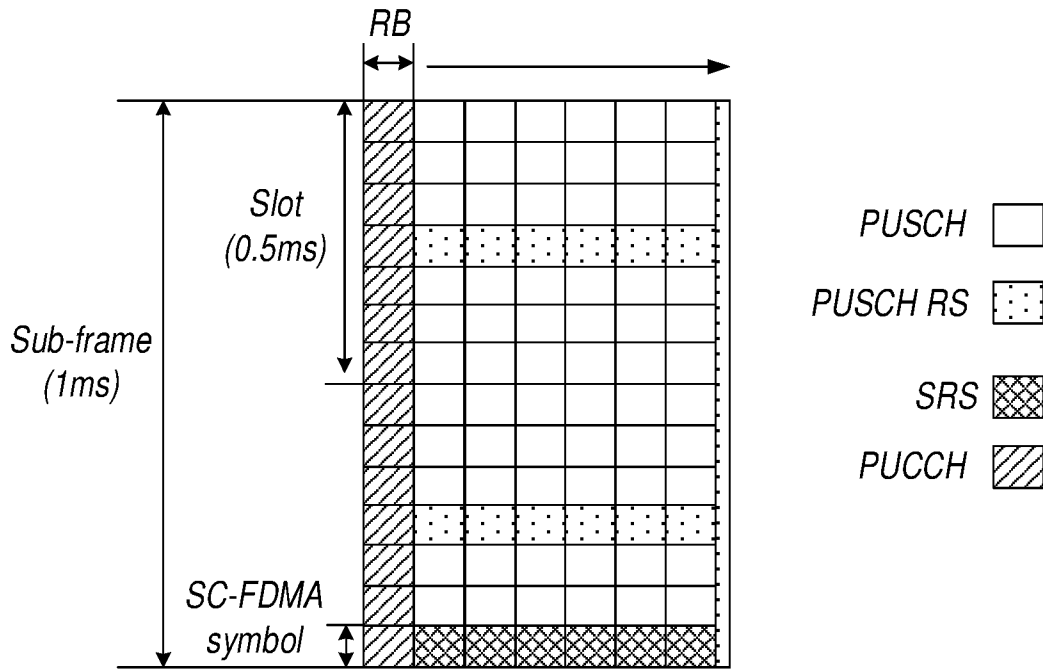


FIG. 9

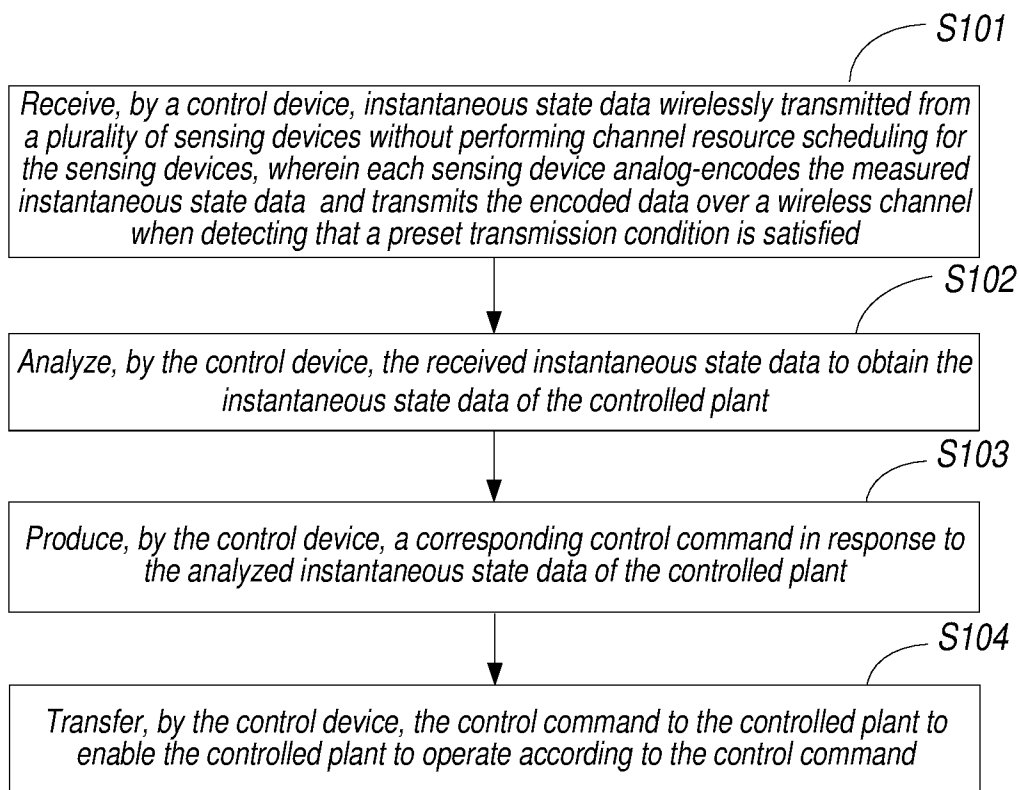
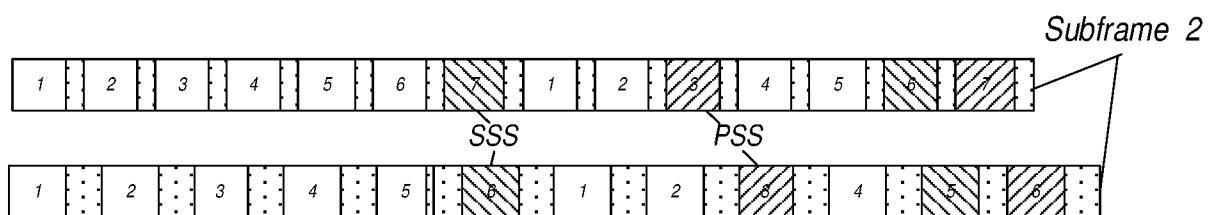
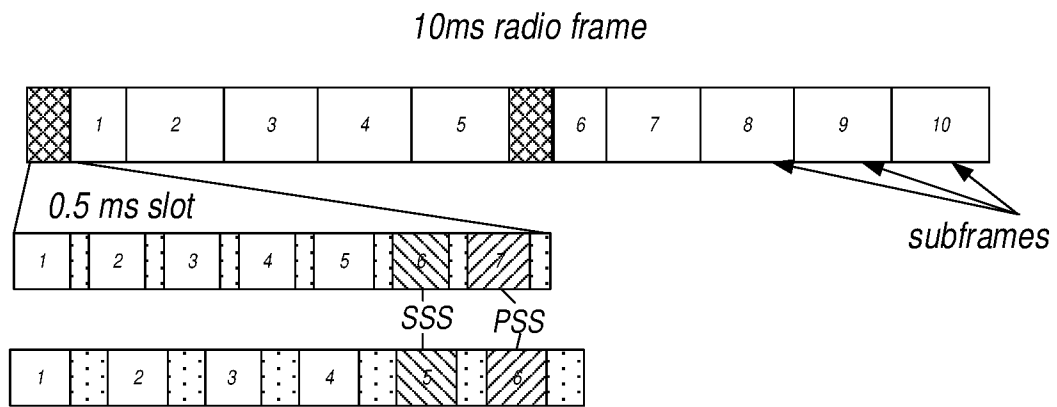


FIG. 10



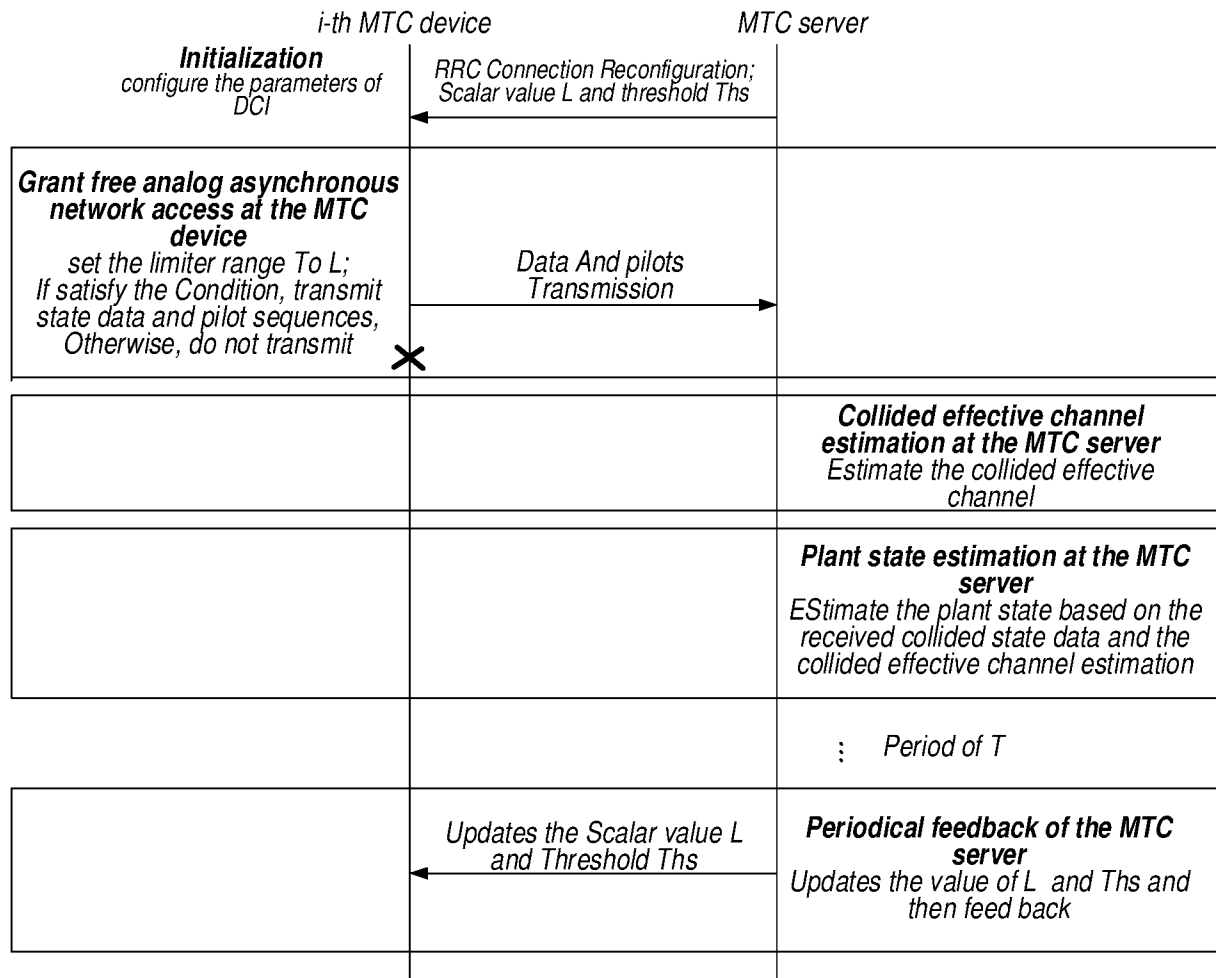


FIG. 13

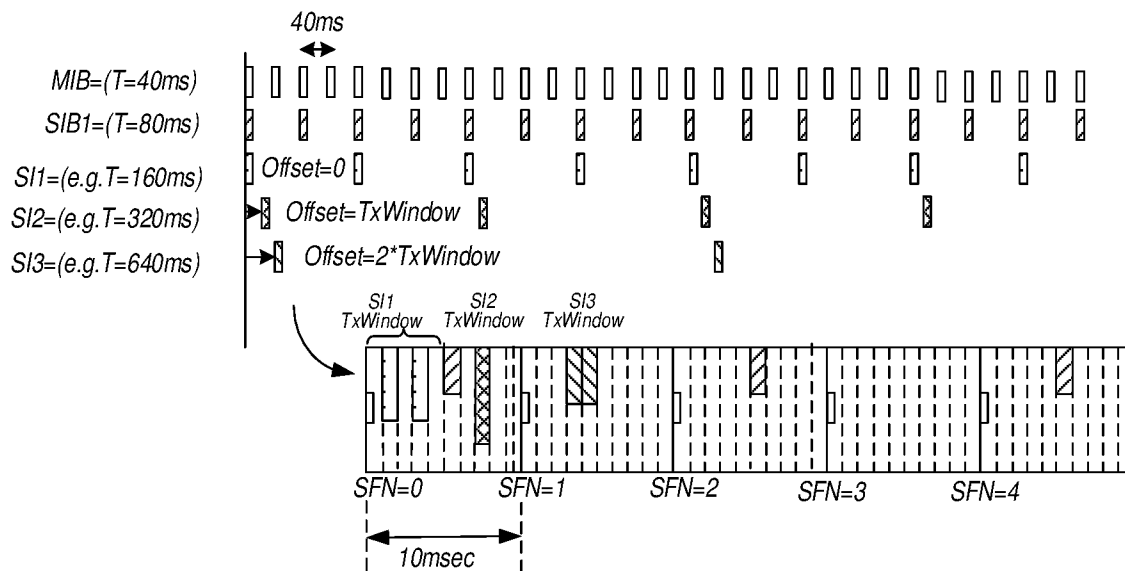


FIG. 14

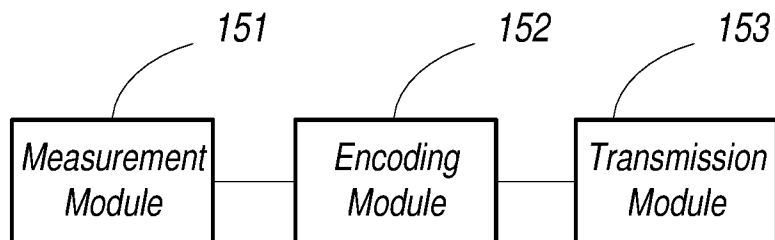


FIG. 15

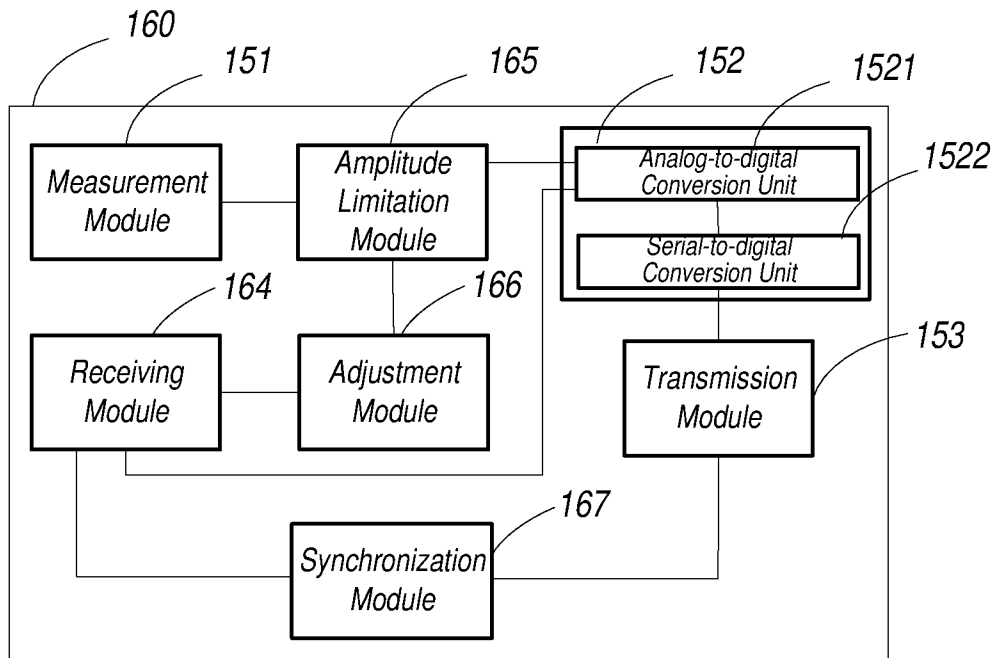


FIG. 16

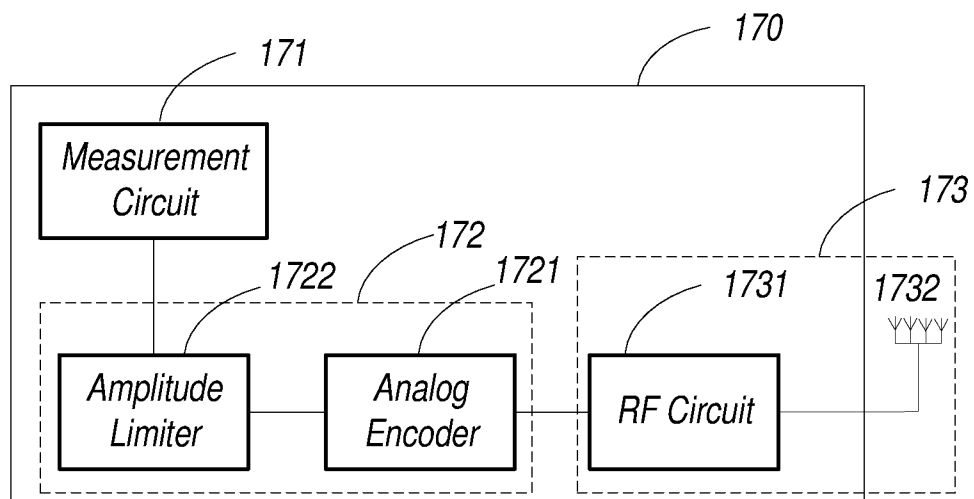


FIG. 17

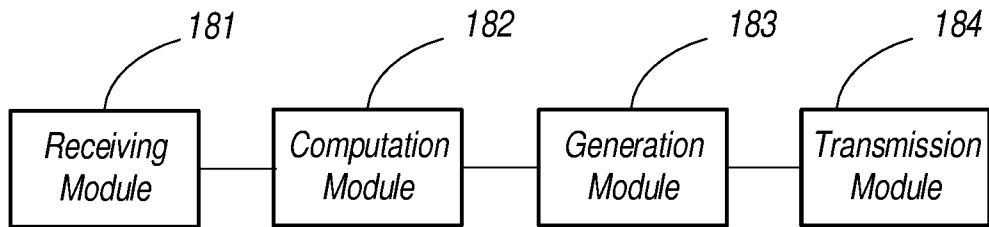


FIG. 18

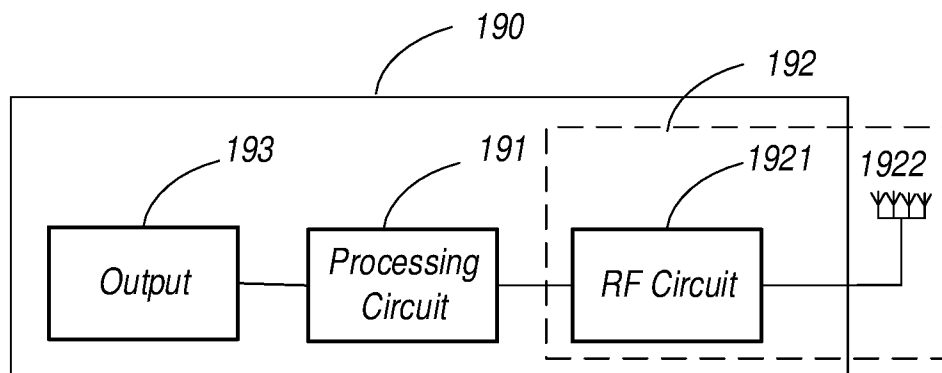


FIG. 19

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/097830

A. CLASSIFICATION OF SUBJECT MATTER G05B 19/04(2006.01)i 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) G05B19/-; H04L27/-; H04L12/- 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) CNKI,CNPAT,EPODOC,WPI:data,transmiss+,sens+,networked,control,system,NCS,plant,analog,encod+,instantaneous,data,reference,signal,preset,threshold,quantiz+		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012045013 A1 (CHEN,QIJUN ET AL.) 23 February 12 (2012-02-23) paragraphs [0026]-[0043], [0076]-[0084] and figure 1	1-3, 10-12, 16-18, 23-25, 32-34, 38-40
Y	US 2012045013 A1 (CHEN,QIJUN ET AL.) 23 February 12 (2012-02-23) paragraphs [0026]-[0043], [0076]-[0084] and figure 1	7-9, 29-31
Y	CN 105334888 A (JIANGSU UNIVERSITY OF SCIENCE AND TECHNOLOGY) 17 February 2016 (2016-02-17) claims 1-3	7-9, 29-31
A	CN 103812633 A (SOUTHWEST UNIVERSITY) 21 May 2014 (2014-05-21) the whole document	1-44
A	CN 102651641 A (TONGJI UNIVERSITY) 29 August 2012 (2012-08-29) the whole document	1-44
A	CN 101374082 A (ZHEJIANG GONGSHANG UNIVERSITY) 25 February 2009 (2009-02-25) the whole document	1-44
☒ Further documents are listed in the continuation of Box C. ☒ 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 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "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 05 May 2017	Date of mailing of the international search report 27 May 2017	
Name and mailing address of the ISA/CN STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088 China Facsimile No. (86-10)62019451	Authorized officer HUANG,Bin Telephone No. (86-10)62413654	

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/097830

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 202331173 U (BEIJING LONGDINGYUAN TECHNOLOGY CO., LTD.) 11 July 2012 (2012-07-11) the whole document	1-44

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2016/097830

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2012045013	A1	23 February 2012	CN	102375442	A	14 March 2012
CN	105334888	A	17 February 2016	None			
CN	103812633	A	21 May 2014	None			
CN	102651641	A	29 August 2012	CN	102651641	B	04 March 2015
CN	101374082	A	25 February 2009	None			
CN	202331173	U	11 July 2012	None			