

COMMUNICATION ARRANGEMENT AND METHOD OF OPERATING A DIGITALLY CONTROLLABLE SCATTERER

5 TECHNICAL FIELD

This application relates to the technical field of communication arrangements, more specifically to communication arrangements including digitally controllable scatterers, and to methods and computer programs for the operation thereof.

10 BACKGROUND

In the technical field of radio communication, a capacity of a radio channel between communication nodes (CNs) can be improved by providing multiple antennas in some or all of the communication nodes. Such techniques are denoted as Multiple-Input and Multiple-Output (MIMO) technologies. A CN can be, for example, a Base Station (BS) or a User Equipment (UE). MIMO technologies allow to
15 exploit a spatial diversity of the propagation channel of electromagnetic waves for improving channel capacity compared to Single-Input Single-Output (SISO) techniques, wherein a single antenna is provided at each communication node.

For further improving radio communication, it has been proposed to move from solutions where channel diversity that occurs due to the propagation of electromagnetic waves in the environment of the
20 communication nodes is exploited to solutions where the propagation channel can be manipulated and adapted to specific needs. This can be done by introducing programmable surfaces called Digitally Controllable Scatterers (DCS), wherein a large number of reflective or scattering elements is provided on large surfaces. DCS can, for example, be implemented in the form of so-called Reflective Intelligent
Surfaces (RIS), Intelligent Reflective Surfaces (IRS), or Large Intelligent Surfaces (LIS). The reflection
25 phase of each element composing the surface can be controlled on its own. This enables shaping the propagation channel by adapting to the requirement and the environment.

Fig. 1 schematically illustrates a DCS 100, a first CN 101, and a second CN102, which can be part of a set of CNs including further CNs which can have features similar to those of the first CN 101 and/or the second CN 102. In the following, in mathematical expressions, indices i and j will generally be used for
30 denoting quantities relating to two CNs which are sometimes referred to as CN_i and CN_j , wherein, for

example, for $i = 1$ and $j = 2$, CN_i can be the first CN 101 and CN_j can be the second CN 102 shown in Fig. 1.

The DCS 100 includes a plurality of scattering elements 103, one of which is exemplarily denoted by reference numeral 104 in Fig. 1. The scattering elements 103 are adapted such that incident electromagnetic radiation, in particular electromagnetic radiation in a particular frequency range that is used for radio communication, is reflected with a phase shift that can be electronically controlled. Examples of scattering elements include antennas connected to phase shifting circuitry and meta-materials.

In Fig. 1, electromagnetic radiation emitted by the first CN 101 is schematically illustrated by dotted arrows. Electromagnetic radiation from the first CN 101 that is reflected by the DCS 100 towards the second CN 102 is schematically illustrated by dashed arrows. The reflection of electromagnetic radiation at the DCS 100 contributes to a communication channel from the first CN 101 to the second CN 102, which is schematically denoted by arrow 105 in Fig. 1.

The overall communication channel can be decomposed into two main components, which are the direct channel 106, wherein electromagnetic radiation propagates from the first CN 101 to the second CN 102 without reflection at the DCS 100 and the channel 105. The channel 105 consists of two components: the channel between the DCS 100 and the first CN 101, and the channel between the DCS 100 and the second CN 102. Mathematically, the direct channel 106 can be denoted by a matrix $\mathbf{H}_0$ of complex numbers, whose number of rows and columns depends on the number of antennas at the first CN 101 and the second CN 102. This component of the communication channel can be estimated through direct estimation, as both components have active radio frequency (RF) chains.

The channel between the DCS 100 and the first CN 101 can be modeled by a matrix $\mathbf{H}_{DCS-CN_i}$, and the channel between the DCS 100 and the second CN 102 can be modeled by a matrix $\mathbf{H}_{DCS-CN_j}$. The numbers of rows and columns of each of the matrices $\mathbf{H}_{DCS-CN_i}$, $\mathbf{H}_{DCS-CN_j}$ depends on the number of the scattering elements of the DCS 100, and the number of antennas of the first CN 101 and the second CN 102, respectively. The cascade of these two channels can provide the channel 105 through the DCS 100. The channel 105 through the DCS 100 is denoted by a matrix $\mathbf{H}_{CN_i-DCS-CN_j}$, which can be obtained by multiplying the matrix $\mathbf{H}_{DCS-CN_i}$, a transfer function $\mathbf{F}(\boldsymbol{\phi})$ of the DCS 100, and the matrix $\mathbf{H}_{DCS-CN_j}^T$, where $\mathbf{A}^T$ stands for the transpose of matrix $\mathbf{A}$. The transfer function $\mathbf{F}(\boldsymbol{\phi})$ is a function of the reflection phase shifts of the scattering elements 103 of the DCS 100, which are represented by a matrix $\boldsymbol{\phi}$. Thus, by controlling the reflection phase shifts of the scattering elements 103 of the DCS 100, the communication channel between the first CN 101 and the second CN 102 can be manipulated.

The knowledge of the communication channel between the DCS 100 and a communication node $\mathbf{H}_{DCS-CN_i}$ and the overall communication channel through the DCS $\mathbf{H}_{CN_i-DCS-CN_j}$ between two communication nodes i, j such as the CNs 101, 102 can be of importance for the design of many algorithms in the communication chain, such as an optimization of $\mathbf{F}(\boldsymbol{\phi})$ for a given target performance metric (e.g. maximizing the Signal to Noise Ratio (SNR), or the rank of the channel matrix, i.e., the channel rank), user scheduling and beam construction in a multiuser scenario, as well as estimating the overall end-to-end channel between any transmitter and receiver while communicating through the DCS 100.

Nevertheless, manipulating the channel by controlling the reflection phase shifts of the scattering elements 103 of the DCS 100 requires the knowledge of the propagation properties and, more specifically, the propagation properties between the DCS and the various communicating components, e.g. transmitters (TX) and receivers (RX) of the CNs 101, 102. Several problems can arise, as not only a huge number of scattering elements 103 are present on the DCS 100, but also these elements are not active elements, since they do not have radio-frequency (RF) chains required for channel estimation. These constraints can render conventional channel estimation techniques unfeasible.

Known techniques for channel estimation with a DCS can have several drawbacks and limitations associated therewith, which can include requirements for complex additional hardware, high complexity of calculations performed and large processing time, in particular when scaling to a multiuser scenario, requirements to perform extensive calculations to fully recalculate the communication channel when there is a change of the position of a CN, and a poor quality of the calculated cascaded channel $\mathbf{H}_{CN_i-DCS-CN_j}$.

SUMMARY

The present disclosure provides communication arrangements, methods of operating a digitally controllable scatterer and computer programs which help to address some or all of the above-mentioned issues.

According to a first aspect, a communication arrangement is provided. The communication arrangement includes a digitally controllable scatterer (DCS). The DCS includes a plurality of scattering elements. At least a part of the plurality of scattering elements is adapted such that a reflection phase shift thereof is electronically controllable. The plurality of scattering elements includes a subset of active transmission elements configured to transmit electromagnetic radiation. The subset of active transmission elements includes at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements. The communication arrangement

further includes circuitry configured to control a transmission of the electromagnetic radiation by the active transmission elements so that each of the active transmission elements transmits a respective beacon signal.

5 In a possible implementation, the respective beacon signals of the active transmission elements include at least one of orthogonal signals and semi-orthogonal signals selected from a codebook of signals.

In a possible implementation, at least one of the respective beacon signals from the active transmission elements includes a tone having a single frequency.

10 In a possible implementation, the communication arrangement further includes circuitry for transmitting information representative of at least one of a respective frequency, code, and time used by the active transmission elements to at least one communication node (CN).

In a possible implementation, the communication arrangement further includes circuitry for obtaining reception information from at least one communication node (CN) in response to a reception of the respective beacon signals of the active transmission elements by the at least one CN.

15 In a possible implementation, the communication arrangement further includes circuitry for transmitting position estimation information including one or more of a first wave propagation model for a propagation of electromagnetic waves transmitted by the active transmission elements, a position of each of the active transmission elements, and a radiation pattern of each of the active transmission elements to the at least one CN. The reception information from a respective CN of the at least one CN is indicative of a position of the respective CN relative to the DCS.

20 In a possible implementation, the reception information includes at least one of an azimuth angle, an elevation angle, and a distance at which the respective CN is positioned with respect to a center of the DCS.

25 In a possible implementation, the communication arrangement further includes channel estimation circuitry for computing a respective channel estimate matrix for each communication channel between the DCS and the respective CN on the basis of the reception information.

30 In a possible implementation, the reception information from the respective CN is indicative of a position of the respective CN relative to the DCS, and the channel estimation circuitry is configured to compute the channel estimate matrix for the communication channel between the DCS and the respective CN on the basis of a second wave propagation model for the propagation of electromagnetic waves from the position of the respective CN to the DCS.

In a possible implementation, at least one of the first and second wave propagation models is representative of a propagation of spherical waves between the position of the respective CN and the DCS.

5 In a possible implementation, at least one of the first and second wave propagation models is further based on one or more of a number of the plurality of scattering elements of the DCS and a respective position of each scattering element of the plurality of scattering elements, a number of at least a subset of the active transmission elements of the DCS and a respective position of at least the subset of the active transmission elements of the plurality of active transmission elements, and a reflection phase shift of each scattering element of the plurality of scattering elements.

10 In a possible implementation, the reception information from the respective CN includes a sparse channel estimate matrix for the communication channel between the DCS and the respective CN. The sparse channel estimate matrix includes a subset of elements of the channel estimate matrix for the communication channel between the DCS and the respective CN that corresponds to the active transmission elements of the DCS. The channel estimation circuitry is configured to calculate, for the
15 respective CN, the channel estimate matrix for the communication channel between the DCS and the respective CN on the basis of the sparse channel estimate matrix for the communication channel between the DCS and the respective CN using a matrix completion technique.

In a possible implementation, the at least one CN includes a first CN and a second CN. The channel estimation circuitry is further configured to compute a channel estimate matrix for an overall
20 communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the DCS and the first CN, the channel estimate matrix for the communication channel between the DCS and the second CN, and the reflection phase shifts of the plurality of scattering elements.

In a possible implementation, the circuitry for obtaining the reception information and the channel
25 estimation circuitry are provided at the DCS.

In a possible implementation, the circuitry for obtaining the reception information and the channel estimation circuitry are provided at the first CN.

In a possible implementation, the first CN is a base station.

30 In a possible implementation, the plurality of scattering elements further includes a subset of active receiving elements. Each active receiving element is further adapted for receiving electromagnetic radiation. The subset of active receiving elements includes at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements. The at least one CN includes a first CN and a second CN. The communication arrangement further includes

circuitry for receiving, at the subset of active receiving elements, a beacon signal from the first CN. The channel estimation circuitry is configured to compute a channel estimate matrix for a communication channel between the first CN and the DCS on the basis of the beacon signal from the first CN received at the subset of active receiving elements and to compute a respective overall channel estimate matrix
5 for the communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the first CN and the DCS, the channel estimate matrix for the communication channel between the DCS and the second CN, and the reflection phase shifts of the plurality of scattering elements.

In a possible implementation, the first CN is a base station.

10 According to a second aspect, a communication arrangement is provided. The communication arrangement includes a digitally controllable scatterer (DCS). The DCS includes a plurality of scattering elements. At least a part of the plurality of scattering elements is adapted such that a reflection phase shift thereof is electronically controllable. The plurality of scattering elements includes a subset of active
15 receiving elements configured to receive electromagnetic radiation. The subset of active receiving elements includes at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements. The communication arrangement further includes circuitry configured to receive, at the subset of active receiving elements, a respective beacon signal from at least one communication node (CN) and channel estimation circuitry configured to
20 compute a channel estimate matrix for a respective communication channel between a respective CN of the at least one CN and the DCS, wherein, for the respective CN of the at least one CN. The computation of the channel estimate matrix includes at least one of: determining a position of the respective CN relative to the DCS on the basis of the respective beacon signal from the respective CN; and determining the channel estimate matrix on the basis of a wave propagation model for a propagation of
25 electromagnetic waves from the position of the respective CN to the DCS; and determining, on the basis of the respective beacon signal from the respective CN, a sparse channel estimate matrix including a subset of elements of the channel estimate matrix corresponding to the active receiving elements of the DCS, and determining the complete channel estimate matrix from the sparse channel estimate matrix using a matrix completion technique.

In a possible implementation, the respective beacon signals from the at least one CN include at least one
30 of orthogonal signals and semi-orthogonal signals selected from a codebook of signals.

In a possible implementation, at least one of the beacon signals from the at least one CN includes a tone having a single frequency.

In a possible implementation, the communication arrangement further includes circuitry for transmitting information representative of at least one of a respective frequency, code, and time of the beacon signals to the at least one CN.

5 In a possible implementation, the determined position of the respective CN includes at least one of an azimuth, an elevation, and a distance at which the respective CN is positioned with respect to a center of the DCS.

In a possible implementation, the wave propagation model is representative of a propagation of spherical waves between the position of the respective CN and the DCS.

10 In a possible implementation, the wave propagation model is further based on one or more of: a number of the plurality of scattering elements of the DCS and a respective position of each scattering element of the plurality of scattering elements; a number of the active receiving elements of the DCS and a respective position of each active receiving element of the plurality of active receiving elements; and a reflection phase shift of each scattering element of the plurality of scattering elements.

15 In a possible implementation, at least one CN includes a first CN and a second CN. The channel estimation circuitry is further configured to compute a channel estimate matrix for an overall communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the first CN and the DCS, the channel estimate matrix for the communication channel between the second CN and the DCS, and the reflection phase shifts of the plurality of scattering elements.

20 In a possible implementation, the channel estimation circuitry is provided at the DCS.

In a possible implementation, the channel estimation circuitry is provided at the first CN.

In a possible implementation, the first CN is a base station.

25 According to a third aspect, a method of operating a digitally controllable scatterer (DCS) is provided. The DCS includes a plurality of scattering elements. At least a part of the plurality of scattering elements is adapted such that a reflection phase shift thereof is electronically controllable. The plurality of scattering elements includes a subset of active transmission elements configured to transmit electromagnetic radiation. The subset of active transmission elements includes at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements. The method includes controlling a transmission of the electromagnetic radiation by
30 the active transmission elements so that each of the active transmission elements transmits a respective beacon signal.

According to a fourth aspect, a method of operating a digitally controllable scatterer (DCS) is provided. The DCS includes a plurality of scattering elements. At least a part of the plurality of scattering elements is adapted such that a reflection phase shift thereof is electronically controllable. The plurality of scattering elements includes a subset of active receiving elements configured to receive electromagnetic radiation. The subset of active receiving elements includes at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements. The method includes receiving, at the subset of active receiving elements, a respective beacon signal from at least one communication node (CN) and computing a channel estimate matrix for a respective communication channel between a respective CN of the at least one CN and the DCS. For the respective CN of the at least one CN, the computation of the channel estimate matrix includes at least one of: determining a position of the respective CN relative to the DCS on the basis of the respective beacon signal from the respective CN; and determining the channel estimate matrix on the basis of a wave propagation model for a propagation of electromagnetic waves from the position of the respective CN to the DCS; and determining, on the basis of the respective beacon signal from the respective CN, a sparse channel estimate matrix including a subset of elements of the channel estimate matrix corresponding to the active receiving elements of the DCS, and determining the complete channel estimate matrix from the sparse channel estimate matrix using a matrix completion technique.

According to a fifth aspect, a computer program including instructions which, when carried out on a computer, cause the computer to perform any of the methods described above is provided.

BRIEF DESCRIPTION OF DRAWINGS

In the following, embodiments will be described with reference to the drawings, wherein:

Fig. 1 shows a digitally controllable scatterer and two communication nodes according to the prior art;

Fig. 2 shows a communication arrangement according to an embodiment;

Fig. 3 shows a communication node in the communication arrangement of Fig. 2;

Fig. 4 shows a controller in the communication arrangement of Fig. 2;

Figs. 5 and 6 show flowcharts of estimation procedures according to embodiments;

Fig. 7 shows a communication arrangement according to an embodiment;

Fig. 8 and 9 show flowcharts of estimation procedures according to embodiments;

Fig. 10a and 10b show communication arrangements according to embodiments;

Fig. 11 shows a flowchart of an estimation procedure according to an embodiment;

Fig. 12 shows a communication arrangement according to an embodiment;

Fig. 13 shows a frame structure;

Fig. 14 shows a communication arrangement according to an embodiment;

5 Figs. 15 to 21 show flowcharts of estimation procedures according to embodiments; and

Figs. 22a-22c and 23 show DCS configurations.

DESCRIPTION OF EMBODIMENTS

The present disclosure proposes a solution for estimating the propagation channel matrix $\mathbf{H}_{DCS-CN_i}$ between any communication node i of a plurality of communication nodes and a DCS, in particular when they are situated in the near field of the DCS, so that the channel $\mathbf{H}_{DCS-CN_i}$ is a degenerate channel. A characteristic length scale for distinguishing between near field and far field conditions is the so-called Fraunhofer distance $d_F = 2 D^2 / \lambda$. Herein, D is the largest dimension of the DCS. For example, in the case of an approximately rectangular DCS, D is the length of the larger one of the sides of the DCS. λ is the wavelength of the electromagnetic radiation reflected by the DCS. For electromagnetic radiation employed for radio communication at a carrier frequency f_c , $\lambda = c / f_c$ with light speed c . For a CN, near field conditions are typically fulfilled when the distance between the CN and the DCS is less than or approximately equal to the Fraunhofer distance.

Through the channel estimation described herein, there is also provided a solution for estimating the overall channel $\mathbf{H}_{CN_i-DCS-CN_j}$ between two CNs i, j in the near field of the DCS for any state ϕ of the scattering elements of the DCS, i.e. for any selected transfer function $\mathbf{F}(\phi)$ at the DCS without the need for an extra specific estimation procedure. Here, ϕ represents the phase shifts applied by the scattering elements of the DCS and the transfer function $\mathbf{F}(\phi)$ represents the resulting scattering pattern.

In order to perform the channel estimation, a subset $\mathcal{D}$ of d low complexity low power consuming active elements (at least one element, for example, at least 3 elements) can be provided in the DCS, which are spread over the surface of the DCS i.e., they are not arranged close to each other. These active elements can be all active transmission elements or can also be active receiving elements, or they can be a mix of active transmission elements and active receiving elements.

The d active elements on the DCS can be used to enable estimation of the propagation channel between the DCS and the CN. When the active elements at the DCS are active transmission elements, the CN can

use its antennas as receiving elements. When the active elements at the DCS are active receiving elements, the CN can use its antennas as transmission elements. When the DCS has a mix of active transmission and active receiving elements, in some embodiments, the CN can use a subset of its antennas for transmission and another subset of its antennas for reception. In other embodiments, the CN can use all antennas for simultaneous transmission and reception in a full-duplex fashion, or multiplexed over time. For a CN having a number N of antennas, an estimation of the channel between the active elements in DCS and the N antennas at the CN can be performed to obtain an estimate of a subset of $N * d$ channel coefficients corresponding to the N antennas at the CN and d active elements at the DCS. In the following, this subset will be denoted as $\hat{\mathbf{H}}_{\mathcal{D}} = \{\hat{\mathbf{H}}_{l,m}, l \in 1..N, m \in \mathcal{D}\}$.

In embodiments described herein, a propagation model for the propagation of electromagnetic waves under near field conditions can be employed. The propagation model can be representative of a propagation of spherical waves between a position of a CN and the DCS. Using the propagation model as well as characteristics of the DCS such as the number of the scattering elements of the DCS and their respective positions, the number and position of all active transmission and receiving elements at the DCS, and/or a status of the DCS (i.e. the phase shifts ϕ applied to the various scattering elements), a proper channel model can be constructed and used in order to extrapolate and obtain the entire channel estimate $\hat{\mathbf{H}}_{DCS-CN}$ only based on the few Nd estimated components $\hat{\mathbf{H}}_{\mathcal{D}}$. For doing so, a sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}^S$ for the communication channel between the DCS and the CN can be provided which includes the Nd estimated components $\hat{\mathbf{H}}_{\mathcal{D}}$. An estimate of the entire channel matrix $\hat{\mathbf{H}}_{DCS-CN}$ can then be obtained by means of a matrix completion technique, wherein the components of the entire channel estimate matrix other than the $N * d$ estimated components are computed, for example on the basis of model assumptions for the channel estimate matrix. In other embodiments, a position of the CN relative to the DCS can be estimated, for example by estimating at least one of an azimuth, an elevation and a distance at which the CN is positioned with respect to the DCS, and the channel estimate matrix can be computed on the basis of the position of the CN relative to the DCS and a wave propagation model.

Furthermore, in embodiments described herein, an estimate $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ of the channel matrix $\mathbf{H}_{CN_i-DCS-CN_j}$ between two communication nodes CN_i, CN_j can be computed based on the estimated $\hat{\mathbf{H}}_{DCS-CN_i}$ and $\hat{\mathbf{H}}_{DCS-CN_j}$ for the two communication nodes and a transfer function $\mathbf{F}(\phi)$ of the DCS.

As will be detailed below, from a hardware point of view, the embodiments described herein can be implemented by a communication arrangement including a DCS having a plurality of scattering elements adapted such that a reflection phase shift thereof for electromagnetic radiation can be electronically controlled, wherein a subset of the plurality of scattering elements includes active transmission elements, active receiving elements or a mixture of both transmission and receiving

elements that may be collocated or not. The active elements disposed on the DCS can have a low complexity and low power consumption, and they can be distributed over the available surface of the DCS, so that they are provided at relatively large mutual distances. The active transmission elements and the active receiving elements provided in the DCS need not be fully equipped for data
5 communication. Instead, the active transmission elements of the DCS can be transmitters specifically configured for sending beacon signals, wherein the beacon signals can include tones which are signals with a single frequency. In some implementations, the beacon signals can be signals with a frequency approximately equal to a carrier frequency of electromagnetic radiation sent and received by the CNs. In other implementations, the beacons signals can have a different frequency. In other embodiments,
10 however, the active transmission elements of the DCS can be fully equipped transmitters or transceivers, so that the DCS can perform radio communication with the CNs. Similarly, in embodiments, the active receiving elements can be receivers specifically configured for receiving beacon signals including tones having a single frequency, although fully equipped receivers or transceivers can also be used.

Additionally, the communication arrangement can include circuitry that is configured for performing
15 steps for the estimation of channel matrices disclosed herein, such as sending and receiving various signals and various types of information, as well as well as performing computations. Unless expressly stated otherwise, such circuitry need not be provided at a particular location and/or in a particular device. For example, circuitry for transmitting and receiving various types of information, and circuitry for performing computations can be provided at the DCS, at one or more CNs, or at any other location from
20 which communication with the DCS or the one or more CNs is possible over a communication network. For example, circuitry for performing computations can be provided at a data center. Furthermore, in some embodiments, components of the circuitry can be provided at different locations. For example, circuitry for transmitting and/or receiving information can include a transmitter and/or receiver provided at the DCS or one of the CNs, and processing equipment for processing the transmitted and/or received
25 information that can be provided at a different location and connected with the transmitter and/or receiver via a communication network. In particular, a CN being a base station can be connected to a backhaul communication network that can be employed for communication with processing equipment arranged at a different location such as, for example, a data center.

In the following, embodiments implementing the proposed approach, and solving various issues that
30 might appear, will be described in more detail with reference to the drawings.

Fig. 2 schematically illustrates a communication arrangement including a DCS 200, a controller 209 and a CN 201. The DCS 200 includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. The plurality of scattering elements 203 can be adapted such that a reflection phase shifts for electromagnetic radiation in a predetermined frequency range are
35 electronically controllable. In some embodiments, each of the scattering elements 203 can include an

antenna and phase shifting circuitry. The phase shift provided by the phase shifting circuitry can be electronically controlled so as to provide the reflection phase shift of the scattering element. In other embodiments, the scattering elements can include meta-material elements configured to provide a reflection phase shift for electromagnetic radiation in the predetermined frequency range that can be electronically controlled. The reflection phase shifts of the scattering elements 203 can be controlled by the controller 209 which is connected to the scattering elements 203. Further features of the scattering elements 203 and the controller 209 can correspond to those of scattering elements and controllers in known digitally controllable scatterers.

The scattering elements 203 can include a subset of active transmission elements 205, 206, 207, 208 that are further adapted for transmitting electromagnetic radiation. In some implementations, the active transmission elements can be adapted to transmit electromagnetic radiation in the predetermined frequency range. In other implementations, the active transmission elements can be adapted to transmit electromagnetic radiation outside the predetermined frequency range, for example at a higher frequency or a lower frequency. The active transmission elements 205-208 can be employed for transmitting beacon signals that can be used for providing an estimate of the channel matrix for the communication channel between the DCS 200 and the CN 201, as schematically illustrated by arrows in Fig. 2. For this purpose, circuitry for controlling the transmission of electromagnetic radiation by the active transmission elements 205-208 so that each of the active transmission elements 205-208 transmits a respective beacon signal can be provided. In embodiments, such circuitry can be provided in the controller 209.

In some embodiments, the number d of the active transmission elements 205-208 can be four, as shown in Fig. 2. In other embodiments, a different number of active transmission elements can be employed. The number of active transmission elements 205-208 can be at least one, and less than all of the plurality of scattering elements 203. In some embodiments, the number of active transmission element 205-208 can be at least three. The channel matrix for the communication channel between the DCS 200 and a CN such as, for example, the CN 201 shown in Fig. 2 depends on a position of the CN 201 relative to the DCS 200. The position of the CN 201 relative to the DCS 200 can be represented by three parameters, in accordance with the three dimensions of space. As will be detailed below, an example of a set of parameters representing the position of the CN 201 relative to the DCS 200 that can be employed in embodiments consists of an azimuth angle, an elevation angle, and a distance at which the CN 201 is positioned relative to the DCS 200. By providing at least three active transmission elements 205-208, it can be ensured that information for estimating the channel matrix can be obtained from the beacon signals transmitted by the active transmission elements 205-208.

By providing a greater number of active transmission elements 205-208, a precision of the estimation of the channel matrix for the communication channel between the DCS 200 and the CN 201 can be

improved, and a redundancy for ensuring the operation of the DCS 200 in the case of a failure of one more of the active transmission elements 205-208 can be provided.

The number d of the active transmission elements 205-208 can be a fraction of the total number of the scattering elements 203. While the total number of scattering elements 203 can, for example, be in a range from about 100 to about 10000, the number of the active transmission elements 205-208 can be substantially smaller, for example less than 20 or less than 10. By providing only a fraction of the scattering elements 203 as active transmission elements 205-208, the complexity and costs of the DCS 200 can be reduced.

The active transmission elements 205-208 can be distributed over the surface of the DCS 200. Thus, it can be ensured that the active transmission elements 205-208 are a representative sample of the scattering elements 203. In embodiments, three or four of the active transmission elements 205 can be provided in different quadrants of the DCS 200. For example, in the DCS 200 shown in Fig. 2, the active transmission element 205 is located in an upper left quadrant of the DCS 200, the active transmission element 206 is located in an upper right quadrant, the active transmission element 207 is located in a lower right quadrant and the active transmission element 208 is located in a lower left quadrant of the DCS 200. Furthermore, three or four of the active transmission elements 205-208 can be located in a vicinity of different corners of the DCS 200, or in a vicinity of the centers of different sides of the DCS 200. In further embodiments, three or more active transmission elements can be provided in each quadrant of the DCS 200. In such embodiments, an estimation of the channel can be performed separately for each of the quadrants of the DCS 200, which can help to increase the precision of the channel estimation, in particular when the CN is arranged at a steep elevation angle relative to the DCS.

Fig. 3 shows a schematic block diagram of the CN 201 according to an embodiment. The CN can be a user equipment (UE) or a base station (BS). The CN can include antennas 301, 302. The number of antennas can be two, as shown in Fig. 2. In other embodiments, a greater number of antennas can be provided. Providing two or more antennas can allow performing communication in accordance with MIMO technologies. In further embodiments, for example in embodiments wherein the CN 201 is a UE, a single antenna can be provided.

The CN 201 can include transmitter circuitry 303 and receiver circuitry 304, which are connected to the antennas 301, 302, and can be used for transmitting and/or receiving beacon signals and various types of information. Additionally, the CN 201 can include computation circuitry 305, which can include a processor 306 and memory 307. The computation circuitry 305 can be used for performing various computations at the CN, as described in detail below.

Fig. 4 shows a schematic block diagram of the controller 209 according to an embodiment. The controller 209 can include interface circuitry 401 for connecting the controller to the scattering elements

203 of the DCS 200 through a connection 405, and computation circuitry 402, which can include a processor 403 and a memory 404. The computation circuitry 402 can be used for performing various computations at the DCS 200, as will be detailed below.

Fig. 5 depicts a general flowchart for an estimation procedure that can be performed in embodiments wherein a communication arrangement as described above with reference to Fig. 2 is employed. At step S501, a channel estimation is requested. The channel estimation can be requested by the DCS 200, a communication node such as, for example, the CN 201 shown in Fig. 2, or by another network entity. The communication node requesting the channel estimation can be a base station or a user equipment.

In response to the request for channel estimation, at step S502, the active transmission elements 205-208 of the DCS 200 are activated so that each of the active transmission elements 205-208 transmits a respective beacon signal. The beacon signals are received at the CN 201. Then, at step S503, reception information related to the CN 201 is obtained in response to the reception of the beacon signals from the transmission elements 205-208 of the DCS by the CN 201. As will be detailed below, obtaining the reception information can include analyzing the beacon signals from the active transmission elements 205-208 of the DCS 200 at the CN 201 and/or receiving the reception information from the CN 201.

In embodiments, the reception information can include an estimate of the subset $\hat{\mathbf{H}}_D$ of the channel coefficients of the channel matrix for the communication channel between the DCS 200 and the CN 201 corresponding to the antennas at the CN 201 and the active transmission elements 205-208 at the DCS 200. Additionally and/or alternatively, the reception information can be indicative of a position of the CN 201 relative to the DCS 200. For example, the reception information can include results of measurements of timing delays between the transmission of the beacon signals by the active transmission elements 205-208 of the DCS 200 and the receipt of the beacons signals by the CN 201 and/or values of at least one of azimuth angle, elevation angle, and distance of the CN 201 relative to the center of the DCS 200.

Thereafter, at step S504, a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ for the communication channel between the DCS 200 and the CN 201 is computed. In some embodiments wherein the reception information includes an estimate of a subset $\hat{\mathbf{H}}_D$ of the channel coefficients of the channel matrix for the communication channel between the DCS 200 and the CN 201, the computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ can include an extrapolation of the channel coefficients of the subset $\hat{\mathbf{H}}_D$, for example by means of a matrix completion technique. In other embodiments, the computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ can be based on a computation of at least one of an azimuth angle, an elevation angle, and a distance at which the CN 201 is positioned with respect to the center of the DCS 200, and a computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ on the basis thereof. Embodiments of performing the computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ will be described below.

For performing the computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$, which is done at step S504, at steps S504a, S504b, S504c and S504d, various inputs can be provided. The inputs can include a configuration of the DCS, in particular number and positions of the scattering elements 203 (step S504a), a configuration of the active transmission elements 205-208, in particular number and positions thereof (step S504b), one or more propagation models for the propagation of electromagnetic waves between the DCS 200 and the CN 201 (step S504c), and a current status of the DCS, in particular values of the reflection phase shifts ϕ thereof (Step S504d). The inputs provided at steps S504a-S504c can be computed offline. They can also be computed as analytical or semi-analytical models. The input provided at step S504d, on the other hand, is a more dynamic input that needs to be updated as soon as there is a change or expected change of the reflection phase shifts of the scattering elements 203, as they dynamically affect the scattering pattern of the DCS 200.

Steps S504a-S504d need not be performed in a particular temporal order relative to each other, and relative to steps S501-S503, as long as the inputs required for the computation of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ are available when the computation of the channel estimate matrix is performed at step S504.

Steps S503 and S504 need not be performed at a particular entity. While in some embodiments, one or both of steps S503 and S504 can be performed at the DCS 200, in other embodiments, one or both of steps S503 and S504 can be performed at the DCS 201, or at any third party entity at the network. When step S503 is performed at the CN 201, the obtaining of the reception information can include analyzing the beacon signals from the active transmission elements 205-208 of the DCS 200 which are received at the CN 201. When step S503 is performed at the DCS 200 or a third party entity, step S503 can include receiving, at the DCS, the reception information from the CN 201.

After the computation of the channel estimate matrix at step S504, the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ can be provided at step S505. In particular, the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ can be provided to the entity that has requested the channel estimation at step S501. In some embodiments, providing the channel estimate matrix can include transmitting data corresponding to the channel estimate matrix over a radio communication network.

Fig. 6 shows a flow diagram illustrating the channel estimation process providing a channel estimation between two communication nodes CN_i and CN_j through a DCS including active transmission elements, for example the DCS 200 described above with reference to Fig. 2. Each of the communication nodes CN_i (denoted as “first CN” in the following) and CN_j (denoted as “second CN” in the following) can be a communication node similar to the CN 201 described above with reference to Fig. 1. For convenience, in Figs. 5 and 6, like reference numerals have been used to denote corresponding steps. Unless explicitly indicated otherwise, steps denoted by like reference numerals can have corresponding features.

At step S601, an estimation of the communication channel $\mathbf{H}_{CN_i-DCS-CN_j}$ from the first CN to the second CN is requested. The request can be made by the DCS 200, by one of the CNs, or by another network entity. Then, the active transmission elements 205-208 at the DCS 200 are activated so that they transmit beacon signals (step S502), reception information in response to a reception of the beacon signals is received by each of the CNs (step S503), and a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ is computed for each of the CNs (S504), using information provided at steps S504a-S504d. Steps S503 and S504 can be performed independently for each of the communication nodes and collected later.

At step S602, an overall channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the communication channel from the first CN to the second CN via the DCS 200 is computed, taking into account the status of the DCS 200 and the applied phase shifts ϕ . This can be done by performing a matrix multiplication of the channel estimate matrix for the communication channel from the DCS to the first CN, the transfer function $\mathbf{F}(\phi)$ and the channel estimate matrix for the communication channel from the DCS to the second CN, as will be explained in more detail below. The computed overall channel estimate matrix is provided to the entity that has requested the estimation at step S603.

Fig. 7 schematically illustrates a communication arrangement according to another embodiment that includes a DCS 700, a controller 209 and a CN 201. For convenience, in Fig. 2, on the one hand, and in Fig. 7, on the other hand, like reference numerals have been used to denote like components. Unless explicitly indicated otherwise, components of the communication arrangement shown in Fig. 7 can have features corresponding to those of components denoted by like reference numerals in Fig. 2.

The DCS 700 includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. A reflection phase shift of the scattering elements 203 for electromagnetic radiation in a predetermined frequency range is electronically controllable, for example by means of the controller 209.

The scattering elements 203 can include a subset of active receiving elements 705, 706, 707, 708, which are further adapted for receiving electromagnetic radiation. The active receiving elements can be adapted for receiving electromagnetic radiation in the predetermined frequency range and/or for receiving electromagnetic radiation at a frequency above or below the predetermined frequency range. In embodiments, the number d of active receiving elements in the DCS 700 can be four, as shown in Fig. 7. In other embodiments, a different number d of active receiving elements can be provided, wherein the number of active receiving elements is at least one and less than all of the scattering elements 203. In some embodiments, three or more active receiving elements can be provided. The number of active receiving elements in the DCS 700, and the arrangement of the active receiving elements in the DCS 700 can have features corresponding to the number and arrangement of the active transmission elements in the embodiments described above with reference to Fig. 2.

The active receiving elements 705-708 can be used for receiving a respective beacon signal from each of one or more CNs, for example a beacon signal from the CN 201. In embodiments, circuitry for receiving, at the active receiving elements 705-708, a respective beacon signal from the one or more CNs can be provided in the controller 209.

- 5 In embodiments wherein a communication arrangement as shown in Fig. 7 is used, the processing diagram can be as illustrated in Fig. 8. For convenience, in Figs. 5 and 8, like reference numerals have been used to denote like method steps. Unless explicitly described otherwise, steps denoted by corresponding reference numerals can have corresponding features.

- At step S501, a channel estimation is requested. Then, at step S801, each of one or more communication nodes, for example, the CN 201 shown in Fig. 7, is activated so as to transmit a beacon signal. At step S802, the beacon signals from the CNs are received by the active receiving elements 705-708 of the DCS 700. For mitigating potential interference between the beacon signals from the individual CNs, a unique CN identification signal can be inserted either through orthogonal frequencies, orthogonal codes, or any other technique providing the possibility to separate beacon signals from the CNs when they are received. Then, at step S503, reception information is obtained, wherein, different from embodiments wherein a DCS 200 having active transmission elements is used, as described above with reference to Fig. 5, the reception information is obtained from the beacons received by the active receiving elements 705-708 of the DCS 700 instead of being obtained from beacons received by one or more CNs. Other features of the reception information can correspond to those described above with reference to Fig. 5.
- 10 Thereafter, at step S504, a respective channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ is computed for the communication channel between the DCS 700 and each CN, which is provided at step S505, for example to the entity that has requested the channel estimation at step S501.

- Similar to the embodiments described above with reference to Fig. 5, at steps S504a-S504d, inputs required for the processing for step S504 are provided. The inputs provided at steps S504a-S504c can be computed offline. They can also be computed as analytical or semi-analytical models. The input provided at step S504d is a more dynamic input that needs to be updated as soon as the reflection phases ϕ of the scattering elements 203 change, as they directly affect the scattering pattern of the DCS 700.
- 25

- Fig. 9 shows a flow diagram illustrating the channel estimation process providing a channel estimation between a first communication node (denoted CN_i) and a second communication node (denoted CN_j) through the DCS 700. For convenience, in Figs. 5, 6, 8 and 9, like reference numerals have been used to denote corresponding steps. Unless explicitly indicated otherwise, steps denoted by like reference numerals can have corresponding features.
- 30

At step S601, an estimation of the communication channel $\mathbf{H}_{CN_i-DCS-CN_j}$ from the first CN to the second CN is requested. Then, at step S801, the first CN and the second CN are activated so that each of the CNs transmits a beacon signal. At step S802, the beacon signals from the CNs are received by the active receiving elements of the DCS 700. Then, step S503, wherein reception information in response to a reception of the beacon signals from the first CN and the second CN, respectively, by the active receiving elements 705-708 of the DCS 700 is received, and step S504, wherein a respective channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ is computed for the communication channels between the DCS 700 and the first and second CNs are performed separately for the first CN and the second CN. Inputs for the computation of the channel estimate matrices is provided at steps S504a-S504d. Then, at step S602, the overall channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the communication channel from the first CN to the second CN via the DCS is computed. At step S603, the overall channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the communication channel from the first CN to the second CN via the DCS is provided to the entity that has requested the estimation of the communication channel.

Fig. 10a schematically illustrates a communication arrangement including a DCS 1001, a controller 209 and a CN 201 according to an embodiment. For convenience, in Figs. 4 and 7, on the one hand, and in Fig. 10a, on the other hand, like reference numerals have been used to denote like components. Unless explicitly described otherwise, components of the DCS 1001 shown in Fig. 10a can have features corresponding to those of components denoted by like reference numerals in Figs. 4 and 7.

The DCS 1001 includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. A reflection phase shift of the scattering elements 203 for electromagnetic radiation in a predetermined frequency range is electronically controllable, for example by means of a controller 209.

The scattering elements 203 include a subset of active transmission elements 205, 206, 207, 208 that are further adapted for transmitting electromagnetic radiation. The active transmission elements 205-208 can be employed for transmitting beacon signals that can be used for providing an estimate of the channel matrix for the communication channel between the DCS 200 and the CN 201. Circuitry for controlling the transmission of electromagnetic radiation by the active transmission elements so that the active transmission elements transmit the beacon signals can be provided by interface circuitry 401 and computation circuitry 402 in the controller 209. The number of the active transmission elements 205-208 can be at least one (for example, at least three), and less than all of the scattering elements 203.

The scattering elements 203 further include a subset of active receiving elements 705, 706, 707, 708. Each of the active receiving elements is further adapted for receiving electromagnetic radiation. The active receiving elements 705-708 can be used for receiving a respective beacon signal from each of one

or more CNs, for example from the CN 201. Circuitry for controlling the reception of beacon signals at the active receiving elements 705-708 can be provided in the controller 209.

In Fig. 10a, arrows schematically illustrate beacon signals transmitted from the active transmission elements 205-208, and beacon signals from the CN 201 that are received by the active receiving elements 705-708.

Fig. 10b schematically illustrates a communication arrangement including a DCS 1002, a controller 209 and a CN 201 according to an embodiment. For convenience, in Figs. 4, 7, 10a and 10b, like reference numerals have been used to denote like components. Unless explicitly indicated otherwise, components of the DCS 1001 shown in Fig. 10b can have features corresponding to those of components denoted by like reference numerals in Figs. 4, 7 and 10a.

The DCS 1002 includes a plurality of scattering elements 203, wherein the scattering elements 203 include a subset of active transmission elements 205-208 and a subset of active receiving elements 705-708. Different from the embodiment of Fig. 10a, wherein the active transmission elements 205-208 and the active receiving elements 705-708 are disjoint subsets of the scattering elements 203, in the embodiment of Fig. 10b, the active transmission elements 205-208 and the active receiving elements 705-708 are co-located, so that there is a subset of the scattering elements 203 wherein the scattering element of the subset provides one of the active transmission elements 205-208 and one of the active receiving elements 705-708. For this purpose, the scattering elements in the subset include both transmission and reception circuitry, in addition to circuitry that is provided in the scattering elements 203 for controlling the reflection phase shifts thereof.

The active transmission elements 205-208 and the active receiving elements 705-708 provided in the DCS 1001 of Fig. 10a and the DCS 1002 of Fig. 10b can be used either to enhance the estimation of the channel between the DSC and a CN and/or to estimate the reciprocal channel. This can be useful in case of big mismatch in terms of transmitter and receiver chains hindering the channel from being reciprocal. This double estimation can therefore provide an estimation of the impact of imperfections in the RF chains electronics. The estimation can be used later for compensation.

Another application of a DCS 1001 according to Fig. 10a and a DCS 1002 according to Fig. 10b wherein both active transmission elements 205-208 and active receiving elements 705-708 are provided is the estimation of the channel between a first CN and a second CN when reciprocity assumptions do not hold. In this case, the active transmission elements 205-208 and the active receiving elements 705-708 on the DCS 1001, 1002 can be dedicated each to a different CN, as will be explained in the following with reference to Fig. 11.

Fig. 11 shows a flow diagram illustrating the channel estimation process for providing a channel estimation between a first communication node and a second communication node through a DCS including active transmission elements 205-208 and active receiving elements 705-708. The DCS can be a DCS 1001 as shown in Fig. 10a, or a DCS 1002 as shown in Fig. 10b. For convenience, in Figs. 5, 6, 8, 9, and 11, like reference numerals have been used to denoted corresponding steps. Unless explicitly indicated otherwise, steps denoted by like reference numerals can have corresponding features.

At step S601, an estimation of the communication channel $\mathbf{H}_{CN_i-DCS-CN_j}$ from the first CN to the second CN is requested. The following step S1102, and steps S503 and S504 are performed separately for the first CN (denoted as CN_i) and the second CN (denoted as CN_j).

At step S1101, the active transmission elements 705-708 of the DCS are activated to transmit beacon signals. The beacon signals from the active transmission elements 205-208 of the DCS are received by at least the first CN, and step S503 of obtaining receive information is performed for the first CN. In doing so, reception information in response to the reception of the beacon signals from the active transmission elements 205-208 of the DCS by the first CN is obtained. Then, step S504 is performed for the first CN, wherein a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ for the communication channel from the DCS to the first CN is computed on the basis of the reception information from the first CN.

At step S1102, the second CN is activated so that the second CN transmits a beacon signal that is received by the active receiving elements 705-708 of the DCS. At step S1103, the active receiving elements 705-708 of the DCS are activated. The beacon signal from the second CN is received at the DCS, and step S503 of obtaining receive information is performed for the DCS, wherein reception information is obtained in response to the reception of the beacon signal from the second CN by the active receive elements 705-708 of the DCS. Then, step S504 is performed for the second CN, wherein a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_j}$ for the communication channel from the DCS to the second CN is computed on the basis of the reception information from the second CN. Input for the computation of the channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}$, $\hat{\mathbf{H}}_{DCS-CN_j}$ at step S504 is provided at steps S504a-S504d.

Then, at step S602, the overall channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the communication channel from the first CN to the second CN via the DCS is computed. At step S603, the overall channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the communication channel from the first CN to the second CN via the DCS is provided to the entity that has requested the channel estimation.

Communication arrangements, methods of operating a DCS and computer programs as disclosed herein allow to estimate communication channels in the presence of a DCS using only a few measurements based on the few active elements. The active elements can include active transmission elements, active receiving elements or a combination of active transmission elements and active receiving elements. The

few measurements can be performed using conventional tools for channel sounding based on transmission or receive radio frequency chains. As the active elements can be specifically designed for channel estimation, the signaling can be selected not to interfere with the communication bands. Since relatively simple signals are sent at short ranges, very high signal-to-noise ratios and, thus, very accurate estimates can be obtained.

In techniques disclosed herein, very few sparsely distributed active elements with low complexity and low consumption on the DCS are required. Very simple signals can be used, for example simple tones, which are signals with a single frequency. Using very few active elements can reduce the estimation to a small set of parameters.

Techniques disclosed herein can exploit that the propagation channel $\mathbf{H}_{DCS-CN}$ between a communication node CN and a DCS is well structured and can be modelled fairly well in a near field situation. The channel is in fact governed by a low number of parameters.

Techniques disclosed herein can take into account the structure and model of radiation patterns (amplitude and phase distribution) of the DCS, and can use spherical waves to model the near field communication. This is more realistic and better reflects the propagation environment than the models used in state-of-the-art solutions for channel estimation in DCS scenarios.

Techniques disclosed herein can enable not only the reconstruction of a communication channel $\mathbf{H}_{DCS-CN}$ between a DCS and a communication node but also the channel $\mathbf{H}_{CN_i-DCS-CN_j}$ between two communication nodes. The reconstruction can be performed on the basis of the low rank estimated components based on the knowledge of an accurate model and state of the DCS. Use can be made of a precomputed propagation model based on the available information, i.e. the structure and properties of the DCS under line-of-sight (LoS) and/or non-line-of-sight (NLoS) information (NLoS when available). Extrapolation is possible to complete the entire channel components and deduce an estimate of the entire channel matrix between two communication nodes $\mathbf{H}_{CN_i-DCS-CN_j}$.

In the following, further embodiments will be described with reference to Figs. 15-21.

Embodiment 1

This embodiment, which will be described with reference to Fig. 12 provides an example of how to compute, at each CN, a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ for the communication channel between the DCS and the CN by means of position information computed at the CN based on the signals sent from the few active elements of the DCS, and how to use $\hat{\mathbf{H}}_{DCS-CN}$ to compute $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ between two CNs. In this embodiment, the active transmission elements are acting as transmitters sending beacon signals that can be received by the various CNs in the vicinity (near field of the DCS) with high signal-

to noise ratio (SNR). Based on these signals, the CN can perform relative position estimation with respect to the DCS.

Fig. 12 shows a DCS 200, which can have features as described above with reference to Fig. 2. The DCS 200 includes a plurality of scattering elements 203, a subset of which is provided as active transmission elements 205-208 that are adapted for transmitting beacon signals. As an alternative to the DCS 200, a DCS 1001 as described above with reference to Fig. 10a, or a DCS 1002 as described above with reference to Fig. 10b can be used, which includes active transmission elements 205-208. Furthermore, a controller similar to the controller 209 described above (not shown) can be provided. Additionally, Fig. 12 exemplarily shows a first CN 1201, a second CN 1202, a third CN 1203, a fourth CN 1204. Beacon signals from the active transmission elements 205-208 are schematically illustrated by dashed arrows from the active transmission elements 205-208 to the CNs 1201-1204, wherein different types of dashing have been used for the beacon signals from the individual communication nodes.

The number of CNs and active transmission elements 205 need not be four, as shown in Fig. 12. In general, a number N of CNs can be considered. The number of scattering elements 203 in the DCS 200 is denoted as N_{DCS} elements, among which d are active transmission elements identified in a set $\mathcal{D}$. The placement of all of the scattering elements 203, in particular the placement of the active transmission elements 205-208 in the DCS 200 is known.

Each of the d active transmission elements 205-208 in set $\mathcal{D}$ ($d \in 1..D$) sends a beacon signal that is selected from a codebook $\mathcal{S}^\perp$ of orthogonal or semi-orthogonal signals. The signals can be orthogonal or semi-orthogonal with respect to a least one of frequency, code, time and waveform.

The active transmission element 205-208 (four elements in the example) can simultaneously transmit their respective beacon signals. The transmission can either be continuous or triggered. The beacons are received at each of the CNs 1201-1204. The various versions of the beacon signals received are combined to estimate a relative position of the CN with respect to the DCS, estimating $(\hat{\theta}_k, \hat{\phi}_k, \hat{D}_k)$ for each of the CNs 1201-1204, wherein $\hat{\theta}_k$, $\hat{\phi}_k$ and $\hat{D}_k$ are respectively the azimuth angle, elevation angle and distance at which the CN is positioned with respect to the center of the DCS 200, the index k being used to denote the individual CNs 1201-1204. The azimuth angle, elevation angle, and distance can be provided in a spherical coordinate system whose center is at the center of the DCS 200.

The estimation of the position of each of the CNs 1201-1204 can be performed by measuring a signal propagation delay between the transmission of the beacon signals emitted by the individual active transmission elements 205-208 and the receipt of the beacons signals by the respective CN. From the signal propagation delays, distances between the respective CN and each of the active transmission

elements 205-208 can be determined. From these distances, the azimuth angle, elevation angle, and distance at which the CN is positioned with respect to the center of the DCS can then be calculated, using the positions of the active transmission elements 205-208 of the DCS.

- 5 Additionally and/or alternatively, in some implementations, for estimating the positions of the CNs 1201-1204, further features of the beacon signals from the active transmission elements 205-208 that are received at the CNs 1201-1204 can be used, for example an intensity and/or a phase thereof. In some implementations, the relative positions of the CNs 1201-204 relative to the center of the DCS 200 can be calculated by means of a wave propagation model $\mathcal{T}$. The wave propagation model $\mathcal{T}$ can model the propagation of electromagnetic waves transmitted by the active transmission elements 205-208 of the DCS and/or radiation patterns of the active transmission elements 205-208. The radiation patterns can be precomputed as semi-analytical functions and stored in a table for various values of phase shifts ϕ that can be used at the scattering elements of the DCS 200. Additionally, the wave propagation model $\mathcal{T}$ can model the propagation of electromagnetic waves transmitted by a communication node and/or radiation patterns of the antennas of the communication node.
- 10 The wave propagation model $\mathcal{T}$ can be provided by using spherical waves to model the propagation of electromagnetic waves under near field conditions. In some implementations, the wave propagation model can be provided in the form of a model for the superposition of spherical waves. For providing the model for the superposition of spherical waves, for each of the active transmission elements 205-208 of the DCS 200, the electromagnetic radiation emitted from the respective active transmission element 205-208 is modeled as a spherical wave. Electromagnetic radiation emitted by the antennas of a communication node can also be modeled as a spherical wave. The wave propagation model $\mathcal{T}$ for the propagation of electromagnetic waves can be provided in the form of a superposition of spherical waves emitted by the active transmission elements 205-208 and/or antennas of the communication node. The wave propagation model $\mathcal{T}$ can be computed offline specifically for the DCS 200.
- 15 The estimated position is used jointly with the wave propagation model $\mathcal{T}$ in order to compute a respective estimate of the communication channel $\hat{\mathbf{H}}_{DCS-CN_k} = \mathcal{T}(\hat{\theta}_k, \hat{\phi}_k, \hat{D}_k, f_c)$ between the DCS 200 and each of the CNs 1201-1204, wherein the index k denotes the respective CN, $\hat{\theta}_k$, $\hat{\phi}_k$, $\hat{D}_k$ are the estimates of azimuth angle, elevation angle, and distance for the CN, and f_c is the carrier frequency used by the CN.
- 20 The above-described procedure is applied independently for each CN, and it can either be applied at the CN, the DCS or any other entity of the network involved in the channel estimation procedure.
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Based on the estimates of the channel matrices $\hat{\mathbf{H}}_{DCS-CN_i}$ and $\hat{\mathbf{H}}_{DCS-CN_j}$ for the communication channels between the DCS and two of the CNs (denoted by indices i, j), a channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS-CN_j}$ for the overall communication channel between the CNs via the DCS can then be computed as

$$\hat{\mathbf{H}}_{CN_i-DCS-CN_j} = \hat{\mathbf{H}}_{DCS-CN_i}^T(\hat{\theta}_i, \hat{\phi}_i, \hat{D}_i, f_c) \mathbf{F}(\boldsymbol{\phi}, f_c) \hat{\mathbf{H}}_{DCS-CN_j}(\hat{\theta}_j, \hat{\phi}_j, \hat{D}_j, f_c)$$

- 5 Here, $\mathbf{F}(\boldsymbol{\phi}, f_c)$ is the transfer function of the DCS computed based on its status at instant t depending on the phase configuration $\boldsymbol{\phi}$ and the operating carrier frequency f_c .

Embodiment 2

This embodiment, which will also be described with reference to Fig. 12, provides an example of how to compute $\hat{\mathbf{H}}_{DCS-CN}$ at each of the CNs 1201-1204 by obtaining first a few components of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ at the respective communication node based on the signals sent by the active transmission elements 205-208 of the DCS 200, and then computing the channel estimate matrix from the few components obtained based on the signals sent by the active transmission element 205-208.

The active transmission elements 205-208 are acting as transmitters, sending beacon signals that can be received by the various CNs 1201-1204 in the vicinity of the DCS 200 (in the near field of the DCS 200) with a high signal-to noise ratio (SNR). Based on the beacon signals, each of the CNs 1201-1204 can obtain those components $\hat{\mathbf{H}}_{\mathcal{D}}$ of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ at the respective communication node which correspond to the active transmission elements 205-208 of the DCS.

We consider here N CNs 1201-1204 with one DCS 200 than is equipped with N_{DCS} scattering elements 203, among which the d active transmission elements 205-208 are identified in a set $\mathcal{D}$. The placement of all the active transmission elements 205-208 and passive scattering elements 203 in the DCS are known. Radiation patterns of the active transmission elements 205-208 can be precomputed as semi-analytical functions and stored in a table $\mathcal{T}$ for various values of phase shifts $\boldsymbol{\phi}$ that can be used at the DCS to provide a wave propagation model.

Each of the active transmission elements 205-208, which are considered as elements d in set $\mathcal{D}$ ($d \in 1..D$) is operated so that it emits a respective beacon signal from a codebook $\mathcal{S}^\perp$ of semi-orthogonal or orthogonal signals that is orthogonal to the beacon signals emitted by the other active transmission elements. In some implementations, the active transmission elements 205-208 (four elements in the example) can simultaneously transmit their assigned beacon signals. The transmission can either be continuous or triggered. The beacons are then received at each of the CNs 1201-1204. For each of the CNs 1201-1204, the various versions of the beacon signals received are combined in order to obtain the subset $\hat{\mathbf{H}}_{\mathcal{D}}$ of the channel coefficients of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ for the communication channel from the DCS 200 which corresponds to the antennas of the respective CN and the active

transmission elements of the DCS 200. This can be done by means of known channel estimation techniques.

The subset $\hat{\mathbf{H}}_{\mathcal{D}}$ of the channel coefficients provides a sparse version $\hat{\mathbf{H}}_{DCS-CN_i}^S$ of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ for each of the CNs 1201-1204 wherein only the entries corresponding to the active transmission elements 205-208 are present. Different from the full channel estimate matrix, the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$ does not include entries corresponding to those scattering elements 203 of the DCS which are not active transmission elements.

Based on the sparse channel estimate matrices, matrix completion and/or adaptive sampling techniques can be applied in order to recover the missing information, thus providing a complete channel matrix estimate $\hat{\mathbf{H}}_{DCS-CN_i}$.

In some implementations, matrix completion techniques as described, for example, in S. Chouvardas, S. Valentin, M. Draief and M. Leconte, "A method to reconstruct coverage loss maps based on matrix completion and adaptive sampling," *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Shanghai, China, 2016, pp. 6390-6394, doi: 10.1109/ICASSP.2016.7472907 and Jian-Feng Cai, Emmanuel J Candès, and Zuowei Shen, "A singular value thresholding algorithm for matrix completion," *SIAM Journal on Optimization*, vol. 20, no. 4, pp. 1956-1982, 2010 can be used. In such implementations, the complete channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ can be obtained by computing a matrix which is equal to the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$ in those entries which correspond to the active transmission elements 205-208. The other entries, which correspond to those scattering elements 203 that are not active transmission elements can be estimated on the basis of the assumption that the complete channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ has a low rank by minimizing the rank of $\hat{\mathbf{H}}_{DCS-CN_i}$:

$$\min_{\hat{\mathbf{H}}_{DCS-CN_i}} \text{rank}(\hat{\mathbf{H}}_{DCS-CN_i})$$

The minimization is performed subject to the condition that those entries of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ which correspond to the active transmission elements 205-208 are equal to the entries of the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$.

The minimization of the rank can have difficulties associated therewith, since it is NP-hard. However, the problem can be relaxed, solved efficiently via convex optimization and the resulting solution will be close enough to the solution of the rank minimization problem for providing a practically sufficient channel estimate matrix. The relaxation of the rank minimization problem can include a minimization of the nuclear norm of the channel estimate matrix:

$$\min_{\hat{\mathbf{H}}_{DCS-CN_i}} \|\hat{\mathbf{H}}_{DCS-CN_i}\|_*$$

- wherein $\|\hat{\mathbf{H}}_{DCS-CN_i}\|_*$ denotes the nuclear norm of the channel estimate matrix. The minimization is performed subject to the condition that those entries of the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ which correspond to the active transmission elements 205-208 are equal to the entries of the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$. For performing the minimization of the nuclear norm, an iterative algorithm as described in the above-cited articles of S. Chouvardas et. al. and Jian-Feng Cai et. al. can be used. In other implementations, other known matrix completion techniques can be employed. In some implementations, the computation of the channel estimate matrix can be driven by the available precomputed wave propagation models derived specifically for the DCS configuration and properties.
- 10 The channel estimate matrices for the communication channels between the DCS 200 and the individual CNs 1201-1204 can then be used for computing a channel estimate matrix for an overall communication channel from a first one of the CNs 1201-1204 to a second one of the CNs 1201-1204. This can be done as described above in the context of embodiment 1.

Embodiment 3

- 15 This embodiment, which will be described with reference to Fig. 13, provides an implementation of an integration of beacon signals from the active transmission elements 205-208 of the DCS with the obtaining of channel state information (CSI). The beacon signals can be provided as tone transmissions. In implementations wherein carrier aggregation is used, the beacon signals can be provided in only a part of the carrier frequencies. In further implementations, the beacon signals can be integrated into guard frequency bands. The transmission of the beacon signals can be integrated into actual communication systems such as 5G New Radio (NR). The DCS can be a DCS 200 including only active transmission elements, as described above with reference to Fig. 2, or a DCS 1001, 1002 including active receiving elements in addition to active transmission elements, as described above with reference to Figs. 10a and 10b.
- 20 NR is an orthogonal frequency division multiplexing (OFDM) based communication system that is based on a specific frame structure. The frame structure of NR can be maintained, and within these frames a tone transmission dedicated for CSI acquisition for the DCS can be as depicted on Fig. 13, which schematically illustrates a frame structure 1300. The frame structure 1300 includes DCS CSI acquisition tones 1301, 1302, 1303 provided by the beacon signals from the active transmission elements 205-208, in addition to the other frames of the NR frame structure.
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In this manner the acquisition of the CSI for the DCS can be aggregated, and can be done at the same time for several CNs (these nodes can be user equipment (UEs) or base stations (BSs)). Thus a solution

that avoids both contaminating and being contaminated by the regular pilots used to acquire the first part of the channel, namely the direct channel without the presence of the DCS denoted by $\mathbf{H}_0$, can be provided.

5 In the case of a cellular communication system where a base station (BS) is involved, the acquisition procedure can start with a request from the BS for Channel State Information (CSI) feedback from a CN. The CSI feedback from the CN to the BS is then the steering vector observed at the CN due to the transmission of the CSI acquisition tones 1301, 1302, 1303 by active transmission elements 205-208 of the DCS 200. The BS is required through proper Radio Resource Management (RRM) to ensure that the tones 1301, 1302, 1303 are not contaminated. Based on the tones received at the CN and the related
10 steering vector information feedback to the BS, the BS can compute estimates for azimuth angle, elevation angle, and distance ($\hat{\theta}$, $\hat{\phi}$, $\hat{D}$) of the CN, and can calculate the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ for the CN as described above in the context of the description of embodiment 1. This can be done similarly for a plurality of CNs, in order to construct the channel estimates $\mathbf{H}_{DCS-CN_i}$ and $\mathbf{H}_{DCS-CN_j}$ for several links between the DCS and CNs i, j .

15 In other embodiments, matrix completion techniques as described above in the context of embodiment 2 can be used for the calculation of the channel estimate matrices.

If a previous estimation exists, this procedure can be used for refining the available estimation and enhancing the channel estimates.

Embodiment 4

20 In this embodiment, which will be described with reference to Fig. 14, the active elements in the DCS of the communication arrangement are provided as receivers rather than transmitters. Fig. 14 shows a DCS 700 and a plurality of CNs 1401, 1402, 1403. The DCS 700 can have features as described above with reference to Fig. 7, wherein the scattering elements 206 include a subset of active receiving elements. Alternatively, a DCS 1001, 1002 including active receiving elements as described above with
25 reference to Fig. 10a and 10b can be used, wherein active transmission elements are provided in addition to the active receiving elements. In Fig. 14, as an example of a DCS wherein the number of active receiving elements is different from four, three active receiving elements 706, 707, 708 are shown. In other implementations, the number of active receiving elements can be different from three.

In Fig. 14, three CNs denoted by reference numerals 1401, 1402, 1403 are exemplarily shown. However,
30 there can be a number of CNs other than three. Generally, there is a set $\mathcal{K}$ of K communication nodes in the near field of the DCS 700, wherein each communication node can be a communication node similar to the CN 201 shown in Figs. 7, 10a and 10b. Parameters of the DCS 700 such as structure, composition and properties, as well as the positions of the active receiving elements 706-708 of the DCS

700 are provided. Based on the parameters of the DCS and the positions of the active receiving elements 706-708, information about wave distribution in space and frequency can be calculated. This can be done using a wave propagation model $\mathcal{T}$ for the propagation of electromagnetic waves from the communication nodes 1401-1403 to the DCS 700. The wave propagation model can be representative
 5 of a propagation of spherical waves from the CNs 1401-1403, and can, for example, be provided in form of precomputed tables, charts, radiation patterns or even analytically/semi-analytically computed expressions or models.

The communication arrangement includes a codebook of orthogonal or semi-orthogonal signals (tones) that can be used by the CNs 1401, 1402, 1403 in order to avoid cross-interference at the receiving
 10 elements. In order to perform the estimation, each of the K communication nodes 1401-1403 sends a beacon signal with its assigned code from the codebook. In Fig. 14, the beacon signals from the CNs 1401-1403 are illustrated by arrows from the CNs 1401-1403 to the DCS 700.

Then, the DCS 700 combines the various received signals on the active receiving elements 706-708 in order to assess the position of the various CNs 1401-1403. Separating the signals from the various CNs
 15 1401-1403 is possible due to the orthogonality property of the elements in the codebook. Based on these high SNR signals, the DCS 700, or a third-party network function can compute the position estimation $(\hat{\theta}_k, \hat{\phi}_k, \hat{D}_k)$ of each of the communication nodes, which are generally referred to as CN_k , $k \in \mathcal{K}$ in the mathematical expressions provided herein, based on the measured signal propagation delays and/or the wave propagation model $\mathcal{T}$, wherein the position can be provided in form of estimates of values of
 20 azimuth angle, elevation angle, and distance for each CN 1401-1403 relative to the DCS, similar to embodiment 1. From this information, the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_k} = \mathcal{T}(\hat{\theta}_k, \hat{\phi}_k, \hat{D}_k, f_c)$ for the communication channel between the DCS and each of the CNs 1401-1403 is then extrapolated and reconstructed using the wave propagation model.

Alternatively, the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_k}$ can be computed using a matrix completion
 25 technique as described above in the context of embodiment 2. For this purpose, for each of the CNs 1401-1403, the beacons received at the DCS 700 can be combined to obtain a subset $\hat{\mathbf{H}}_{\mathcal{D}}$ of the channel coefficients for the communication channel between the DCS 700 and the CN, which corresponds to the antennas of the respective CN and the active receiving elements of the DCS 700, and provides a sparse version $\hat{\mathbf{H}}_{DCS-CN_k}^S$ of the channel estimate matrix. Then, the full channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_k}$ can
 30 be computed from the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_k}^S$ by means of a matrix completion technique as described above in the context of embodiment 2.

After determining the channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_k}$ for the communication channels between the DCS 700 and the CNs 1401, 1402, 1403, the overall channel estimate matrix for the communication

channel between two communication nodes through the DCS 700 can be computed. The channel estimate matrix for the channel linking two communication nodes i and j can be computed as the cascade

$$\hat{\mathbf{H}}_{CN_i-DCS-CN_j} = \hat{\mathbf{H}}_{DCS-CN_i}^T(\hat{\theta}_i, \hat{\phi}_i, \hat{D}_i, f_c) \mathbf{F}(\boldsymbol{\phi}, f_c) \hat{\mathbf{H}}_{DCS-CN_j}(\hat{\theta}_j, \hat{\phi}_j, \hat{D}_j, f_c)$$

Where $\mathbf{F}(\boldsymbol{\phi}, f_c)$ is the transfer function of the DCS given its phase configuration $\boldsymbol{\phi}$ and the operating carrier frequency f_c .

Embodiment 5

In this embodiment, we consider a combination of both configurations of active elements of the DCS (active receiving elements and active transmission elements), wherein the accuracy of the estimates can be enhanced, as both information obtained by means of active transmission elements and information obtained by means of active receiving elements can be combined to enable estimation of non-reciprocal propagation channels wherein the communication channel from the DCS to a communication node is different from to communication channel from the communication node to the DCS, i.e., expressed in terms of channel matrices:

$$\mathbf{H}_{DCS-CN_i} \neq \mathbf{H}_{CN_i-DCS}^T$$

$\mathbf{A}^T$ being the matrix transpose operation. In this situation, a DCS 1001 as described above with reference to Fig. 10a, or a DCS 1002 as described above with reference to Fig. 10b can be employed.

A channel estimate matrix $\hat{\mathbf{H}}_{CN_i-DCS}$ for the communication channel between the DCS and a first communication node CN_i is calculated using techniques as described above for embodiments 1 and 2, wherein the active transmission elements of the DCS are used. Additionally, a channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_j}$ for the communication channel between the DCS and a second communication node CN_j is calculated using techniques as described above for embodiment 4. Then, the channel estimate matrix for the overall communication channel from the first communication node CN_i to the second communication node CN_j via the DCS 1001, 1002, can be calculated in accordance with

$$\hat{\mathbf{H}}_{CN_i-DCS-CN_j} = \hat{\mathbf{H}}_{CN_i-DCS} \mathbf{F}(\boldsymbol{\phi}, f_c) \hat{\mathbf{H}}_{DCS-CN_j}$$

Here, $\mathbf{F}(\boldsymbol{\phi}, f_c)$ is the transfer function of the DCS given its phase shift configuration $\boldsymbol{\phi}$ and the operating carrier frequency f_c .

In the following, further embodiments will be described with reference to Figs. 15-21, wherein signaling and information exchange between the different involved entities will be explained in detail.

Embodiment 6: Standalone DCS and CN, CN requests channel estimation, scenario 1

Fig. 15 illustrates exchanges between a DCS and a communication node (CN) in order to perform the estimation of the channel matrix for the communication channel between the DCS and the CN in a near field situation, wherein the DCS uses active transmission elements and the CN performs a position estimation.

At step S1501, the channel estimation is requested, wherein the channel estimation can be triggered either by the CN, as exemplarily shown in Fig. 15 or, alternatively, by the DCS or any third party entity in the network.

Then, at step S1502, the DCS activates its active transmission elements in order to transmit the beacon signals and, at step S1503, informs the CN of the frequencies or codes that are used by the various active transmission elements of the DCS. At step S1504, the CN collects the beacon signals from the active transmission elements of the DCS. As, in this embodiment, the CN is the entity that is going to perform the position estimation, at step S1505 the DCS provides extra information to the CN that will be needed for position estimation, for example one or more of a propagation model, positions of the active transmission elements of the DCS, or a radiation pattern of the active transmission elements of the DCS.

At step S1506, the CN combines the beacon signals from the active transmission elements of the DCS based on the information that was provided by the DCS at step S1505 to generate a position estimation $(\hat{\theta}_k, \hat{\phi}_k, \hat{D}_k)$ that it feeds back to the DCS at step S1507. At step S1508, the DCS computes the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ for the communication channel from the DCS to the CN based on the position estimation and a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . The generation of the position estimation and the computation of the channel estimation matrix can be performed as described above in the context of embodiment 1.

Finally, at step S1509, the channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN}$ is provided to the entity that triggered the request, for example to the CN.

Embodiment 7: Standalone DCS and CN, CN or DCS requests channel estimation, scenario 2

Fig. 16 illustrates exchanges between a DCS and a CN in order to perform the channel estimation in a near field situation, wherein the DCS uses active transmission elements, and the CN performs an estimation of the channel matrix for the communication channel between the DCS and the CN on the basis of a sparse channel estimate matrix including a subset of the elements of the channel matrix that it perceives.

At step S1601, the channel estimation can be triggered either by the CN or, alternatively, by the DCS or any third party entity in the network. At step S1602, the DCS then activates its active transmission

elements in order to transmit the beacon signals and, at step S1603, informs the CN of the frequencies or codes that are used by the active transmission elements of the DCS.

At step S1604, the CN then collects the beacon signals from the active transmission elements of the DCS and performs a channel estimation for the $N * d$ links it perceives (N being the number of antennas at the CN and d the number of active transmission elements at the DCS). At step S1605, the CN then forwards back to the DCS these estimates of the received signals (including but not restricted to enhanced, filtered versions of the received signals), which are the elements of the sparse channel estimate matrix. At step S1606, the DCS then computes the channel estimate matrix from the sparse channel estimate matrix using a matrix completion technique. This can be done as described above in the context of embodiment 2.

In some embodiments, the computation of the channel estimate matrix can be based on a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . A technique that can be applied is model-driven matrix completion.

Finally, at step S1607, the channel estimate matrix is provided to the entity that triggered the request.

Embodiment 8: Channel estimation at the DCS with active transmission elements at the DCS between two CN through the DCS

Fig. 17 illustrates exchanges between a DCS and two CNs in order to perform the channel estimation in a near field situation between a first CN (denoted as CN_i in Fig. 17), a second CN (denoted as CN_j in Fig. 17) and a DCS, wherein the DCS uses active transmission elements. Fig. 17 shows a process wherein sparse channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-CN_j}^S$ are computed, as detailed above in the context of embodiment 2. Nevertheless, any of the above described procedures can also be applied by adding the required associated signaling.

At step S1701, the channel estimation is requested. This can be done either by one of the CNs, for example by the first CN as shown in Fig. 17, or the DCS or any third party element in the network. At step S1702, the DCS activates its active transmission elements in order to transmit beacon signals.

At step S1703, the DCS informs each of the CNs of the frequencies or codes that are used by the various active transmission elements of the DCS.

At step S1704, each of the CNs collects the beacon signals from the various active transmission elements of the DCS and performs a channel estimation for the $N_i * d$ links it perceives (N_i being the number of antennas at CN_i and d the number of active transmission elements at the DCS). At step S1705, the CNs feed back to the DCS their respective channel estimates or the received signals (including but not restricted to enhanced, filtered versions of the received signals) to provide the sparse channel estimate

matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S, \hat{\mathbf{H}}_{DCS-CN_j}^S$. At steps S1706 and S1707, the DCS computes separately each of the full channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}, \hat{\mathbf{H}}_{DCS-CN_j}$ using a matrix completion technique. This can be done as described above in the context of embodiment 2. In some embodiments, the computation of the channel estimate matrix can be based on a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . A technique that can be applied is model-driven matrix completion.

Assuming channel reciprocity, at step S1708, the DCS computes the cascaded channel

$$\hat{\mathbf{H}}_{CN_i-DCS-CN_j} = \hat{\mathbf{H}}_{DCS-CN_i}^T \mathbf{F}(\phi, f_c) \hat{\mathbf{H}}_{DCS-CN_j}$$

Finally, at step S1709, the estimated channel can be provided to the entity that triggered the request which, in the example shown in Fig. 17, is the first CN.

Embodiment 9: Channel estimation at the BS with active transmission elements at the DCS

Fig. 18 illustrates exchanges between a DCS a CN and a base station BS in order to perform the channel estimation in a near field situation between the CN and the BS and where the DCS uses active transmission elements. Fig. 18 shows a process wherein sparse channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S, \hat{\mathbf{H}}_{DCS-BS}^S$ are computed, as detailed above in the context of embodiment 2. Nevertheless, any of the above described procedures can also be applied by adding the required associated signaling. As detailed in the following, computations can be done at the BS.

At step S1801, the channel estimation can be requested. This can be done either by the CN, the BS, the DCS or any third party entity in the network.

At step S1802, the DCS activates its active transmission elements in order to transmit the beacon signals and, at step S1803, informs the CN and the BS of the frequencies or codes that are used by the various active transmission elements it uses. In addition, at step S1804, it can provide the BS with its properties and configuration as well as its actual status ϕ .

A step S1805, the CN and the BS collect the various signals from the various active transmission elements of the DCS and perform channel estimation for the $N_i * d$ and $N_{BS} * d$ links, respectively, they perceive (N_i being the number of antennas at CN_i , N_{BS} being the number of antennas at the BS and d the number of active transmission elements at the DCS). At step S1806, the CN then feeds back its estimates of the received signals to the BS, either directly or through the DCS (including but not restricted to enhanced, filtered versions of the received signals) to provide the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$. At steps S1807, S1808, the BS then computes separately each of the full channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}, \hat{\mathbf{H}}_{DCS-BS}$ using a matrix completion technique. For the calculation of

$\hat{\mathbf{H}}_{DCS-CN_i}$, the BS used the sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$ from the CN. For the calculation of $\hat{\mathbf{H}}_{DCS-BS}$, the BS uses a sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-BS}^S$ that includes the channel estimation coefficients from the channel estimation performed by the BS. The computation of the channel estimate matrices can be performed as detailed above in the context of embodiment 2. In some embodiments, the computation of the channel estimate matrices can be based on a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . A technique that can be applied is model-driven matrix completion.

Assuming channel reciprocity, at step S1809, the BS computes the cascaded channel

$$\hat{\mathbf{H}}_{CN_i-DCS-BS} = \hat{\mathbf{H}}_{DCS-CN_i}^T \mathbf{F}(\phi, f_c) \hat{\mathbf{H}}_{DCS-BS}$$

Finally, at step S1810, the estimated channel is provided to the entity that triggered the request.

Embodiment 10: Channel estimation at the BS with active receiving elements

Fig. 19 depicts the required exchanges between a DCS, a CN and a base station BS in order to perform the channel estimation in a near field situation between the CN, the BS and the DCS when the DCS uses active receiving elements. Fig. 19 shows a process wherein channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-BS}^S$ are computed. Nevertheless, any of the other above described procedures can also be applied by adding the required associated signaling. As detailed in the following, computations can be done at the BS.

At step S1901, the channel estimation is requested, which can be done either by the CN, the BS, the DCS or any third party entity in the network.

At step S1902, the DCS activates its active receiving elements and, at step S1903, requests from the BS and the CN to send their beacon signals by specifying a different frequency/code for each one. In addition, at step S1904, the DCS provides the BS with its properties and configuration in terms of active receiving elements and non-active scattering elements, as well as its actual phase shift configuration ϕ .

At step S1905, the CN and the BS activate their channel estimation mode and, at step S1906, transmit their respective beacon signals that are collected at the DCS on the active receiving elements. The DCS performs channel estimation for the $N_i * d$ and $N_{BS} * d$ links, respectively, it perceives (N_i being the number of antennas at CN_i , N_{BS} being the number of antennas at the BS and d the number of active receiving elements at the DCS). At step S1907, the DCS then provides its estimates of the received signals to the BS (including, but not restricted to, enhanced, filtered versions of the received signals) to provide the sparse channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-BS}^S$. At steps S1908, S1909, the BS then computes separately each of the channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}$, $\hat{\mathbf{H}}_{DCS-BS}$ using a matrix

completion technique. This can be done as detailed above in the context of embodiment 2. In some embodiments, the computation of the channel estimate matrices can be based on a propagation model specifically computed based on the characteristics of the DCS and his actual phase shift configuration ϕ . A technique that can be applied is model driven matrix completion.

- 5 Assuming channel reciprocity, at step S1910, the BS computes the cascaded channel

$$\hat{\mathbf{H}}_{BS-DCS-CN_i} = \hat{\mathbf{H}}_{DCS-BS}^T \mathbf{F}(\phi, f_c) \hat{\mathbf{H}}_{DCS-CN_i}$$

Finally, at step S1911, the estimated channel is provided to the entity that triggered the request.

Embodiment 11: Channel estimation at the DCS with active receiving elements

- Fig. 20 illustrates exchanges between a DCS, a CN and a base station BS in order to perform the channel estimation in a near field situation between the CN, the BS and the DCS, when the DCS uses active receiving elements. Fig. 20 shows a process wherein sparse channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-BS}^S$ are used. Nevertheless, any of the above described procedures can also be applied by adding the required associated signaling. As detailed in the following, computations can be done at the DCS.
- 10

- At step S2001, the channel estimation is requested. This can be done either by the CN, the BS, the DCS or any third party entity in the network.
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At step S2002, the DCS activates its active receiving elements and, at step S2003, requests from the BS and the CN to send their beacon signals by specifying a different frequency/code for each one.

- At step S2004, the CN and the BS active their channel estimation mode and, at step S2005, transmit their respective beacon signals that are collected at the active receiving elements of the DCS. The DCS performs channel estimation for the $N_i * d$ and $N_{BS} * d$ links, respectively, they perceive (N_i being the number of antennas at CN_i , N_{BS} being the number of antennas at the BS and d the number of active receiving elements at the DCS) to obtain the channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-BS}^S$. At steps S2006, S2007, the DCS then computes separately each of the channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}$, $\hat{\mathbf{H}}_{DCS-BS}$ using a matrix completion technique. This can be done as described above in the context of embodiment 2. In some embodiments, the computation of the channel estimate matrices can be based on a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . A technique that can be applied is model driven matrix completion.
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Assuming channel reciprocity, at step S2008, the DCS computes the cascaded channel

$$\hat{\mathbf{H}}_{BS-DCS-CN_i} = \hat{\mathbf{H}}_{DCS-BS}^T \mathbf{F}(\phi, f_c) \hat{\mathbf{H}}_{DCS-CN_i}$$

Finally, at step S2009, the estimated channel is provided to the entity that triggered the request.

Embodiment 12: Channel estimation at the DCS with active receiving elements and active transmission elements

Fig. 21 illustrates exchanges between a DCS, a CN and a base station BS in order to perform the channel estimation in a near field situation between the CN, the BS and the DCS when the DCS uses both active receiving elements and active transmission elements. This can be useful for many situations, especially when the communication channel between the DCS and the CN and/or the communication channel between the DCS and the BS is not reciprocal. We assume here that the processing is performed at the DCS, but any case described previously can also be implemented by using the corresponding signaling. Also, the case of a BS is considered, but it can also be generalized to any kind of CN or a set of nodes.

Fig. 21 shows a process wherein channel estimate matrices $\hat{\mathbf{H}}_{DCS-CN_i}^S$, $\hat{\mathbf{H}}_{DCS-BS}^S$ are computed. Nevertheless, any of the above described procedures can also be applied by adding the required associated signaling.

At step S2101, the channel estimation is requested. This can be done either by the CN, the BS, the DCS or any third party entity in the network.

At step S2102, the DCS activates its active receiving elements, and, at step S2103, requests from the BS to send its beacon signals by specifying a frequency and/or code. Furthermore, at step S2104, the DCS activates its active transmission elements and, at step S2105, informs the CN of the frequency/code for each of its active transmission elements.

At step S2106, the BS activates its channel estimation mode, and at step S2107, the BS sends its beacon signal that is collected at the DCS on the active receiving elements.

At step S2108, the DCS sends its beacon signal, which is collected by the CN.

At step S2109, the DCS performs channel estimation for the $N_{BS} * d_R$ links it perceives (N_{BS} being the number of antennas at the BS and d_R the number of active receiving elements at the DCS) to provide a sparse channel estimate matrix $\hat{\mathbf{H}}_{BS-DCS}^S$ for the communication channel from the DCS to the BS and computes a full channel estimate matrix $\hat{\mathbf{H}}_{DCS-BS}^S$ for the communication channel from the DCS to the BS from the sparse channel estimate matrix $\hat{\mathbf{H}}_{BS-DCS}^S$.

The beacon signal sent by the DCS is collected at the CN, which listens to the beacon signals from the active transmission elements of the DCS, and performs channel estimation for the $N_{CN} * d_T$ links it perceives (N_{CN} being the number of antennas at the CN and d_T the number of active receiving elements at the DCS) to provide a sparse channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}^S$ for the communication channel from

the DCS to the CN at step S2110. The CN then feeds back the estimate $\hat{\mathbf{H}}_{DCS-CN_i}^S$ to the DCS at step S2111.

At step S2112, the DCS then computes a full channel estimate matrix $\hat{\mathbf{H}}_{DCS-CN_i}$ for the communication channel from the DCS to the CN, and computes the cascaded channel estimate matrix for the communication channel from the BS to the CN via the DCS:

$$\hat{\mathbf{H}}_{BS-DCS-CN_i} = \hat{\mathbf{H}}_{BS-DCS}^T \mathbf{F}(\phi, f_c) \hat{\mathbf{H}}_{DCS-CN_i}$$

The computation of the channel estimate matrices $\hat{\mathbf{H}}_{DCS-BS}$ and $\hat{\mathbf{H}}_{DCS-CN_i}$ can be performed separately, using a matrix completion technique as described above in the context of embodiment 2. In some embodiments, the computation of the channel estimate matrices can be based on a propagation model specifically computed based on the characteristics of the DCS and its actual phase shift configuration ϕ . A technique that can be applied is model driven matrix completion.

Finally, at step S2113, the estimated channel is provided to the entity that triggered the request.

The present disclosure is not limited to embodiments wherein the DCS is substantially planar and provided in a single piece. In the following, alternative DCS configurations will be described with reference to Figs. 22a-22c and 23. DCS configurations as described with reference to Figs. 22a-22c and 23 can be employed as alternatives to configurations as described with reference to Figs. 2, 7, 10a, 10b, 12 and 14 in any of the preceding embodiments. For convenience, in Figs. 2, 7, 10a, 10b, 12, 14, 22a, 22b, 22c, and 23, like reference numerals have been used to denote like components. Unless explicitly indicated otherwise, components denoted by like reference numerals can have corresponding features.

Embodiment 13: Non-planar DCS configurations

Figs. 22a, 22b and 22c show DCS configurations wherein the DCS is non-planar.

Fig. 22a schematically illustrates a communication arrangement including a DCS 2200a and a CN 201. The DCS 2200a includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. The scattering elements 203 include a subset of active elements 2201, 2202, 2203, 2204, 2205, 2206, 2207. The active elements 2201-2207 can be active transmission elements similar to the active transmission elements 205-208 described above with reference to Fig. 2 or active receiving elements similar to the active receiving elements 705-708 described above with reference to Fig. 7. In further implementations, the active elements 2201-2207 can include both active transmission elements and active receiving elements, which can be provided as disjoint subsets of the scattering elements 203, as described above with reference to Fig. 10a, or co-located, as described above with reference to Fig. 10b. The DCS 2200a can be connected to a controller 209, as described above with

reference to Figs. 2, 7, 10a and 10b (not shown). The DCS 2200a has a non-planar configuration, wherein a front surface of the DCS 2200a facing the CN 201 is convex.

Fig. 22b schematically illustrates a communication arrangement including a DCS 2200b and a CN 201. The DCS 2200b includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. The scattering elements 203 include a subset of active elements 2201, 2202, 2203, 2204, which can include active transmission elements and/or active receiving elements. The DCS 2200b can be connected to a controller (not shown). The DCS 2200b has a non-planar configuration, wherein a front surface of the DCS 2200b facing the CN 201 is concave.

Fig. 22c schematically illustrates a communication arrangement including a DCS 2200c and a CN 201. The DCS 201 includes a plurality of scattering elements 203, one of which is exemplarily denoted by reference numeral 204. The scattering elements 203 include a subset of active elements 2201, 2202, 2203, 2204, which can include active transmission elements and/or active receiving elements. The DCS 2200c can be connected to a controller (not shown). The DCS 2200c has a non-planar configuration, wherein a front surface of the DCS 2200c facing the CN 202 includes portions having a different curvature. In particular, the front surface of the DCS 2200c can include convex portions, concave portion and/or saddle-shaped portions.

The number of active elements shown in Figs. 22a, 22b and 22c is exemplary only. Generally, the subset of active elements can include at least one and less than all of the scattering elements 203. In some implementations, three or more active elements can be provided.

20 Embodiment 14: Distributed DCS configuration

Fig. 23 schematically illustrates a communication arrangement including a DCS 2300 and a CN 201. The DCS 2301 includes a plurality of DCS blocks 2301, 2302, 2303, 2304 which can be distributed. Thus, the DCS 2300 is not provided as a single piece.

The DCS 2300 includes a plurality of scattering elements, wherein each of the DCS blocks 2301-2304 includes a subset of the scattering elements. The DCS blocks 2301-2304 can have a non-planar configuration, as shown in Fig. 23. In other implementations, some or all of the DCS blocks 2301-2304 can be planar. In some implementations, each of the DCS blocks can have features corresponding to those of the DCSs described above, wherein the scattering elements of the DCS blocks 2301-2304 are operated in a coordinated manner, so that the DCS 2300 is provided as a virtual DCS.

The scattering elements of the DCS 2300 include a subset of active elements 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, which can include active transmission elements and/or active receiving elements. In some implementations, in each of the DCS blocks 2301-2304, a subset of the active elements 2201-2212 can be provided, wherein the number of active elements in the DCS

blocks 2301-2304 need not be equal. For example, the DCS block 2301 can include active elements 2201, 2202, 2203, the DCS block 2302 can include active elements 2204, 2205, 2206, 2207, the DCS block 2303 can include active elements 2208, 2209, 2210 and the DCS block 2304 can include active elements 2211, 2212. In other implementations, only a subset of the DCS blocks 2301-2304 includes
5 active elements, and one or more of the DCS blocks 2301-2304 do not include active elements. In further implementations, the number of active elements in the DCS blocks 2301-2304 can be equal.

The foregoing descriptions are merely specific implementations of this application, but are not intended to limit the scope of protection of this application. Any variation or replacement readily figured out by a person skilled in the art within the technical scope disclosed in this application shall fall within the
10 scope of protection of this application. Therefore, the scope of protection of this application shall be subject to the scope of protection of the claims.

CLAIMS

1. A communication arrangement, comprising:
- 5 a digitally controllable scatterer, DCS, comprising a plurality of scattering elements, at least a part of the plurality of scattering elements being adapted such that a reflection phase shift thereof is electronically controllable,
- wherein the plurality of scattering elements comprises a subset of active transmission elements configured to transmit electromagnetic radiation, the subset of active transmission elements comprising at least one scattering element of the plurality of scattering elements and less than all scattering elements
- 10 of the plurality of scattering elements; and
- circuitry configured to control a transmission of the electromagnetic radiation by the active transmission elements so that each of the active transmission elements transmits a respective beacon signal.
2. The communication arrangement according to claim 1, wherein the respective beacon signals of the active transmission elements include at least one of orthogonal signals and semi-orthogonal signals
- 15 selected from a codebook of signals.
3. The communication arrangement according to claim 1 or 2, wherein at least one of the respective beacon signals from the active transmission elements includes a tone having a single frequency.
4. The communication arrangement according to claim 2 or 3, further comprising:
- circuitry for transmitting information representative of at least one of a respective frequency, code, and
- 20 time used by the active transmission elements to at least one communication node, CN.
5. The communication arrangement according to any of claims 2 to 4, further comprising:
- circuitry for obtaining reception information from at least one communication node, CN, in response to a reception of the respective beacon signals of the active transmission elements by the at least one CN.
6. The communication arrangement according to claim 5, further comprising:
- 25 circuitry for transmitting position estimation information comprising one or more of a first wave propagation model for a propagation of electromagnetic waves transmitted by the active transmission elements, a position of each of the active transmission elements, and a radiation pattern of each of the active transmission elements to the at least one CN,

wherein the reception information from a respective CN of the at least one CN is indicative of a position of the respective CN relative to the DCS.

7. The communication arrangement according to claim 6, wherein the reception information comprises at least one of an azimuth angle, an elevation angle, and a distance at which the respective CN is positioned with respect to a center of the DCS.

8. The communication arrangement according to any of claims 5 to 7, further comprising channel estimation circuitry for computing a respective channel estimate matrix for each communication channel between the DCS and the respective CN on the basis of the reception information.

9. The communication arrangement according to any of claims 6 to 8, wherein the reception information from the respective CN is indicative of a position of the respective CN relative to the DCS, and wherein the channel estimation circuitry is configured to compute the channel estimate matrix for the communication channel between the DCS and the respective CN on the basis of a second wave propagation model for the propagation of electromagnetic waves from the position of the respective CN to the DCS.

10. The communication arrangement according to any of claims 6 to 9, wherein at least one of the first and second wave propagation models is representative of a propagation of spherical waves between the position of the respective CN and the DCS.

11. The communication arrangement according to claim 10, wherein at least one of the first and second wave propagation models is further based on one or more of:

a number of the plurality of scattering elements of the DCS and a respective position of each scattering element of the plurality of scattering elements;

a number of at least a subset of the active transmission elements of the DCS and a respective position of at least a subset of the active transmission elements of the plurality of active transmission elements; and

a reflection phase shift of each scattering element of the plurality of scattering elements.

12. The communication arrangement according to claim 8, wherein the reception information from the respective CN comprises a sparse channel estimate matrix for the communication channel between the DCS and the respective CN, the sparse channel estimate matrix comprising a subset of elements of the channel estimate matrix for the communication channel between the DCS and the respective CN that corresponds to the active transmission elements of the DCS, and

wherein the channel estimation circuitry is configured to calculate, for the respective CN, the channel estimate matrix for the communication channel between the DCS and the respective CN on the basis of the sparse channel estimate matrix for the communication channel between the DCS and the respective CN using a matrix completion technique.

- 5 13. The communication arrangement according to any of claims 8 to 12, wherein the at least one CN comprises a first CN and a second CN, and wherein the channel estimation circuitry is further configured to compute a channel estimate matrix for an overall communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the DCS and the first CN, the channel estimate matrix for the communication channel between the DCS and the second CN, and the reflection phase shifts of the plurality of scattering elements.

14. The communication arrangement according to any of claims 8 to 13, wherein the circuitry for obtaining the reception information and the channel estimation circuitry are provided at the DCS.

15. The communication arrangement according to claim 13, wherein the circuitry for obtaining the reception information and the channel estimation circuitry are provided at the first CN.

- 15 16. The communication arrangement according to claim 15, wherein the first CN is a base station.

17. The communication arrangement according to any of claims 8 to 12, wherein the plurality of scattering elements further comprises a subset of active receiving elements, each active receiving element being further adapted for receiving electromagnetic radiation, the subset of active receiving elements comprising at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements, wherein the at least one CN comprises a first CN and a second CN, wherein the communication arrangement further comprises circuitry for receiving, at the subset of active receiving elements, a beacon signal from the first CN, and

wherein the channel estimation circuitry is configured to:

- 25 compute a channel estimate matrix for a communication channel between the first CN and the DCS on the basis of the beacon signal from the first CN received at the subset of active receiving elements; and

compute a respective overall channel estimate matrix for the communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the first CN and the DCS, the channel estimate matrix for the communication channel between the DCS and the second CN, and the reflection phase shifts of the plurality of scattering elements.

- 30 18. The communication arrangement according to claim 17, wherein the first CN is a base station.

19. A communication arrangement, comprising:

a digitally controllable scatterer, DCS, comprising a plurality of scattering elements, at least a part of the plurality of scattering elements being adapted such that a reflection phase shift thereof is electronically controllable,

5 wherein the plurality of scattering elements comprises a subset of active receiving elements configured to receive electromagnetic radiation, the subset of active receiving elements comprising at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements;

10 circuitry configured to receive, at the subset of active receiving elements, a respective beacon signal from at least one communication node, CN; and

channel estimation circuitry configured to compute a channel estimate matrix for a respective communication channel between a respective CN of the at least one CN and the DCS by at least one of:

15 determining a position of the respective CN relative to the DCS on the basis of the respective beacon signal from the respective CN, and determining the channel estimate matrix on the basis of a wave propagation model for a propagation of electromagnetic waves from the position of the respective CN to the DCS; and

20 determining, on the basis of the respective beacon signal from the respective CN, a sparse channel estimate matrix comprising a subset of elements of the channel estimate matrix corresponding to the active receiving elements of the DCS, and determining the complete channel estimate matrix from the sparse channel estimate matrix using a matrix completion technique.

20. The communication arrangement according to claim 19, wherein the respective beacon signals from the at least one CN include at least one of orthogonal signals and semi-orthogonal signals selected from a codebook of signals.

21. The communication arrangement according to claim 19 or 20, wherein at least one of the beacon 25 signals from the at least one CN includes a tone having a single frequency.

22. The communication arrangement according to claim 20 or 21, further comprising:

circuitry for transmitting information representative of at least one of a respective frequency, code, and time of the beacon signals to the at least one CN.

23. The communication arrangement according to any of claims 19 to 22, wherein the determined position of the respective CN comprises at least one of an azimuth angle, an elevation angle, and a distance at which the respective CN is positioned with respect to a center of the DCS.
24. The communication arrangement according to any of claims 19 to 23, wherein the wave propagation model is representative of a propagation of spherical waves between the position of the respective CN and the DCS.
25. The communication arrangement according to claim 24, wherein the wave propagation model is further based on one or more of:
- a number of the plurality of scattering elements of the DCS and a respective position of each scattering element of the plurality of scattering elements;
 - a number of the active receiving elements of the DCS and a respective position of each active receiving element of the plurality of active receiving elements; and
 - a reflection phase shift of each scattering element of the plurality of scattering elements.
26. The communication arrangement according to any of claims 19 to 25, wherein the at least one CN comprises a first CN and a second CN, and wherein the channel estimation circuitry is further configured to compute a channel estimate matrix for an overall communication channel from the first CN to the second CN via the DCS on the basis of the channel estimate matrix for the communication channel between the first CN and the DCS, the channel estimate matrix for the communication channel between the second CN and the DCS, and the reflection phase shifts of the plurality of scattering elements.
27. The communication arrangement according to claim 26, wherein the channel estimation circuitry is provided at the DCS.
28. The communication arrangement according to claim 26, wherein the channel estimation circuitry is provided at the first CN.
29. The communication arrangement according to claim 28, wherein the first CN is a base station.
30. A method of operating a digitally controllable scatterer, DCS, wherein the DCS comprises a plurality of scattering elements, at least a part of the plurality of scattering elements being adapted such that a reflection phase shift thereof is electronically controllable, and wherein the plurality of scattering elements comprises a subset of active transmission elements configured to transmit electromagnetic radiation, the subset of active transmission elements comprising at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements, wherein the method comprises:

controlling a transmission of the electromagnetic radiation by the active transmission elements so that each of the active transmission elements transmits a respective beacon signal.

31. A method of operating a digitally controllable scatterer, DCS, wherein the DCS comprises a plurality of scattering elements, at least a part of the plurality of scattering elements being adapted such that a reflection phase shift thereof is electronically controllable, and wherein the plurality of scattering elements comprises a subset of active receiving elements configured to receive electromagnetic radiation, the subset of active receiving elements comprising at least one scattering element of the plurality of scattering elements and less than all scattering elements of the plurality of scattering elements, wherein the method comprises:

10 receiving, at the subset of active receiving elements, a respective beacon signal from at least one communication node, CN;

computing a channel estimate matrix for a respective communication channel between a respective CN of the at least one CN and the DCS by at least one of:

15 determining a position of the respective CN relative to the DCS on the basis of the respective beacon signal from the respective CN, and determining the channel estimate matrix on the basis of a wave propagation model for a propagation of electromagnetic waves from the position of the respective CN to the DCS; and

20 determining, on the basis of the respective beacon signal from the respective CN, a sparse channel estimate matrix comprising a subset of elements of the channel estimate matrix corresponding to the active receiving elements of the DCS, and determining the complete channel estimate matrix from the sparse channel estimate matrix using a matrix completion technique.

32. A computer program comprising instructions which, when carried out on a computer, cause the computer to perform a method according to claim 30 or 31.