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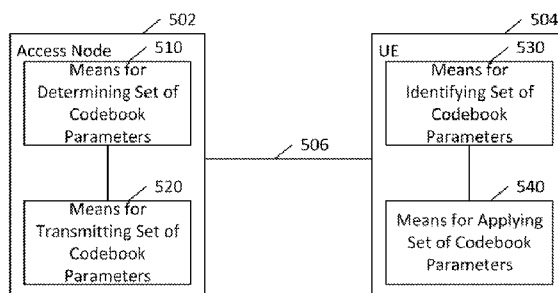


Figure 5

(57) **Abstract:** Various communication systems may benefit from appropriate optimization of transmission and/or reception parameters. For example, massive multiple-input/multiple-output systems may benefit from, for example, two dimensional (2D) codebook optimization that may mitigate frequency and time selectivity. A method can include determining a set of codebook parameters. The method can also include transmitting the set of codebook parameters to a user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

TITLE:

Multidimensional Codebook Optimization

BACKGROUND:**Field:**

[0001] Various communication systems may benefit from appropriate optimization of transmission and/or reception parameters. For example, massive multiple-input/multiple-output systems may benefit from, for example, two dimensional (2D) codebook optimization that may mitigate frequency and time selectivity.

Description of the Related Art:

[0002] Massive multiple-input/multiple-output MIMO is considered for study in fifth generation (5G) communication systems, considering a large number of antenna ports (16 – 64 or more) and 3D antenna arrays. An optimized codebook design for such arrays is useful, for example, for achieving high spectral efficiency. It is also envisioned that codebooks for all ports which are multiples of 2 (e.g. 6 ports, 10 ports) that fall within this range will be utilized. Moreover different 2D antenna configurations are envisioned – for example, a total of 8Tx ports in azimuth only, or a total of 8Tx ports with 2Tx in azimuth and 4 in elevation. Due to this very large number of codebooks, it may be nearly impossible to separately optimize each of the codebooks.

SUMMARY:

[0003] According to certain embodiments, a method can include determining a set of codebook parameters. The method can also include transmitting the set of codebook parameters to a user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0004] In certain embodiments, a method can include identifying a set of codebook parameters at a user equipment. The method can also include

applying the set of codebook parameters by the user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0005] An apparatus, according to certain embodiments, can include at least one processor and at least one memory including computer program code. The at least one memory and the computer program code can be configured to, with the at least one processor, cause the apparatus at least to determine a set of codebook parameters. The at least one memory and the computer program code can also be configured to, with the at least one processor, cause the apparatus at least to transmit the set of codebook parameters to a user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0006] An apparatus, in certain embodiments, can include at least one processor and at least one memory including computer program code. The at least one memory and the computer program code can be configured to, with the at least one processor, cause the apparatus at least to identify a set of codebook parameters at a user equipment. The at least one memory and the computer program code can also be configured to, with the at least one processor, cause the apparatus at least to apply the set of codebook parameters by the user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0007] According to certain embodiments, an apparatus can include means for determining a set of codebook parameters. The apparatus can also include means for transmitting the set of codebook parameters to a user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0008] In certain embodiments, an apparatus can include means for identifying a set of codebook parameters at a user equipment. The apparatus can also include means for applying the set of codebook parameters by the user

equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation.

[0009] A computer program product can, according to certain embodiments, be encoded instructions for performing a process. The process can include any of the preceding methods.

[0010] A non-transitory computer-readable medium can, in certain embodiments, be encoded with instructions that, when executed in hardware, perform a process. The process can include any of the preceding methods.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0011] For proper understanding of the invention, reference should be made to the accompanying drawings, wherein:

[0012] Figure 1 illustrates two options for 2D beam groups.

[0013] Figure 2 illustrates two further options for 2D beam groups.

[0014] Figure 3 illustrates a method according to certain embodiments.

[0015] Figure 4 illustrates a system according to certain embodiments.

[0016] Figure 5 illustrates a further system according to certain embodiments.

DETAILED DESCRIPTION:

[0017] Certain embodiments provide a mechanism, such as a method and/or apparatus, for increasing the spectral efficiency in massive MIMO by optimizing the codebook design applicable for any $2n$ -port configuration. In certain embodiments, a codebook is designed in which the $W1$ matrix uses a set of beams that can be closely spaced in both azimuth and elevation dimensions. An overlap parameter can be defined in azimuth and elevation along with the azimuth and elevation resolution that can uniquely specify a codebook. An overlap parameter can indicate the overlap between different codewords (associated to specific indices) in the azimuth and the elevation

dimension. An overlap parameter that indicates the overlap in azimuth may be provided separately from an overlap parameter that indicates the overlap in elevation. Alternately a common overlap parameter may be provided that indicates the overlap in both elevation and azimuth dimensions. An access node, such as an evolved Node B (eNB) can then determine the best codebook parameters and transmit them to one or more user equipment (UEs). Alternatively, the determination can be made by each UE itself. By defining an overlap parameter, the codebook and payload overhead can remain the same over a plurality of similar options.

[0018] The design of a product codebook for massive MIMO systems has been studied from different aspects, including Kronecker structure of azimuth and elevation, Kronecker polarization structure and so on, but little attention has been paid on extending the design for frequency selective channels. Considering a product codebook structure of W_1W_2 , it can be observed that the W_1 matrix that includes the correlation structure of the channel can be designed in a way such that a single W_1 matrix may be applicable over the wideband and at the same time does not need to be updated frequently.

[0019] For example, a W_1 matrix can be formed using a set of beams that are closely spaced in azimuth as well as in the elevation dimension. Grouping a set of beams in azimuth and in elevation is not unique and therefore multiple codebooks can be formed with exactly the same payload for W_1 and W_2 that differs in how the beam group is defined. Therefore, an overlap parameter can be defined in azimuth and elevation, along with the azimuth and elevation resolution. This overlap parameter, along with the azimuth and elevation resolution, can uniquely specify a codebook.

[0020] The eNB or other access node can determine the best codebook parameters and can send these parameters to the UE or it may be possible for the UE to determine the best codebook parameters and send these

parameters to the eNB – note that in all cases the codebook overhead and payload is the same. It may also be possible to fix these parameter values in the specification though in that case there will not be any UE specific optimizations possible.

[0021] The Rel-10 8Tx LTE codebook has been designed very carefully and provides a variety of features – a) a product structure $W1*W2$ where $W1$ is long-term and $W2$ is short-term b) a Kronecker structure for the polarization dimension where $W1$ is of the form $\begin{bmatrix} x & 0 \\ 0 & x \end{bmatrix}$ and $W2$ includes co-phasing and selection entries c) a DFT based grid-of-beam structure. In order to extend it to the elevation dimension and for optimizing for generic 2D/3D arrays these can be retained, which may allow a minimum change to the specifications and to the UE implementations. Certain embodiments of the present invention provide a mechanism to enable a tradeoff between the azimuth and elevation angular variation across the bandwidth within the same number of feedback bits.

[0022] Figure 1 illustrates two options for 2D beam groups. In option 1 ($W1(n)$, $W1(n+1)$ and $W1(n+2)$) each beam-group can include 4 elevation beams and 1 azimuth beam. In this case, there is no overlap between beam-groups in the azimuth dimension. In option 2 ($W1(k)$, $W1(k+1)$ and $W1(k+2)$) each beam-group can include 4 azimuth beams and 1 elevation beam. In this case, there is no overlap between beam-groups in the elevation dimension.

[0023] According to certain embodiments, the UE can be signaled an azimuth beam granularity Nb_az together with an overlap factor R_az and an elevation beam granularity Nb_el together with an overlap factor R_el along with other parameters for constructing a codebook according to the following steps. These steps may help to ensure that each precoder is of the form $W1*W2$ where $W1$ is of the form $\begin{bmatrix} x & 0 \\ 0 & x \end{bmatrix}$ and $W2$ includes selection and co-phasing entries.

[0024] The beam granularity and overlap factor can provide the ability to customize a codebook to allow a higher variation in a particular domain (azimuth or elevation) across the bandwidth. It may be useful to inform the UE of the overlap factor to uniquely specify a codebook. It is also possible for the UE to determine the best (Nb_az, Raz) and (Nb_el, R_el) from a set of possibilities and inform the eNB of the best codebook.

[0025] The following six steps are illustrative an example implementation. While these steps are provided in a particular order, other orders of the steps may be possible, and these steps and their example mechanisms for implementation should not be taken as limiting, but rather as illustrative.

[0026] In a first step, the azimuth beam space can be sampled using Nb_az beams. This step can target a certain oversampling factor (8x in Rel-10). A simple example could be uniformly sampled DFT beams as used in Rel-10.

[0027] An example of an implementation of the first step may be as follows:

```
Beam_az=zeros(NTx_az,Nb_az);
for m=0:NTx_az-1
    for n=0:Nb_az-1
        Beam_az(1+m,1+n)=exp(1i*2*pi*m*n/Nb_az);
    end
end
```

[0028] In a second step, the elevation beam space can be sampled using Nb_el beams. This step can target a certain oversampling factor. A simple example could be uniformly sampled DFT beams, although other sampling factors are also permitted.

[0029] An example of an implementation of the second step may be as follows:

```
Beam_el=zeros(NTx_el,Nb_el);
for m=0:NTx_el-1
    for n=0:Nb_el-1
```

```

        Beam_el(1+m,1+n)=exp(1i*2*pi*m*n/Nb_el);
    end
end

```

[0030] In a third step, azimuth beam groups can be formed using the samples from the first step, with Nx_az number of beams in each group and Rx_az number of beams overlapped between any two beam-groups. Therefore the total number of azimuth beam groups can be $Nb_az/(Nx_az-Rx_az)$.

[0031] An example of an implementation of the third step may be as follows:

```

    % Generate X_az from Beam_az considering Rx_az
    X_az_size=Nb_az/(Nx_az-Rx_az);
    X_az=zeros(NTx_az,Nx_az,X_az_size);
    for k=0:X_az_size-1
        for kk=0:Nx_az-1
            X_az(:,kk+1,k+1)=1/sqrt(NTx_az)*Beam_az(:,mod((Nx_az-
Rx_az)*k+kk,Nb_az)+1);
        end
    end
end

```

[0032] In a fourth step, elevation beam groups can be formed using the samples from the second step, with Nx_el number of beams in each group and Rx_el number of beams overlapped between any two beam-groups. Therefore the total number of elevation beam groups can be $Nb_el/(Nx_el-Rx_el)$.

[0033] An example of an implementation of the fourth step may be as follows:

```

    % Generate X_el from Beam_el considering Rx-el
    X_el_size=Nb_el/(Nx_el-Rx_el);
    X_el=zeros(NTx_el,Nx_el,X_el_size);
    for k=0:X_el_size-1
        for kk=0:Nx_el-1

```

```

        X_el(:,kk+1,k+1)=1/sqrt(NTx_el)*Beam_el(:,mod((Nx_el-
Rx_el)*k+kk,Nb_el)+1);
    end
end

```

[0034] According to a fifth step, 2D beam groups can be formed from the azimuth and elevation beam groups formed in the third and fourth steps. The total number of 2D beam groups can be $B_{az}/(N_{az}-R_{az}) \times B_{el}/(N_{el}-R_{el})$. Each azimuth beam in an azimuth beam group can be combined with each elevation beam in an elevation beam group using an outer product. Therefore each 2D beam group can include a total of $N_{az} \times N_{el}$ number of beams. Each 2D beam group constitutes a W1 matrix.

[0035] An example of an implementation of the fifth step may be as follows:

```

W1_size=X_az_size*X_el_size;
X=zeros(NTx_az*NTx_el,Nx_az*Nx_el,X_az_size*X_el_size);
W1=zeros(2*NTx_az*NTx_el,2*Nx_az*Nx_el,X_az_size*X_el_size
);

count1=1;
for k=0:X_az_size-1
    for kk=0:X_el_size-1
        count2=1;
        for m=0:Nx_az-1
            for mm=0:Nx_el-1
                y=kron(X_az(:,m+1,k+1).',X_el(:,mm+1,kk+1));
                X(:,count2,count1)=y(:);
                count2=count2+1;
            end
        end
        W1(:,:,count1)=kron(eye(2),X(:,:,count1));
        count1=count1+1;
    end
end

```

end

end

[0036] Finally, in a sixth step, the W2 matrices can include selection and co-phasing entries as in Rel-10.

[0037] The following examples show the impact of different overlap parameters for codebook design. For consideration of a first example, assume 16 TXRU antenna configuration with 4 azimuth locations ($N_{Tx_az}=4$) and 2 elevation locations ($N_{Tx_el}=2$, total 8 locations per polarization), as shown in Figure 1. Assume also that the granularity in the azimuth domain is 32 beams which is 8x oversampling in the beam – domain, $N_{b_az}=32$. Assume further that the granularity in the vertical domain is 16 beams which is 8x oversampling in the beam domain, $N_{b_el}=16$. Under these assumptions, there are at least two different methods for overlapping W1 design possible that leads to exactly the same W1 payload size of 8 bits and W2 payload size of 4 bits.

[0038] As shown in Figure 1, according to option 1 each W1 matrix can include 1 azimuth beam ($N_{x_az}=1$) and 4 elevation beams ($N_{x_el}=4$), the number of overlapping azimuth beams can be 0 ($R_{x_az}=0$) and the number of overlapping elevation beams can be 2 ($R_{x_el}=2$). This is shown in Figure 1 with the matrices $W1(n)$, $W1(n+1)$, $W1(n+2)$.

[0039] According to option 2, each W1 matrix can include 4 azimuth beams ($N_{x_az}=4$) and 1 elevation beam ($N_{x_el}=1$), the number of overlapping azimuth beams can be 2 ($R_{x_az}=2$) and the number of overlapping elevation beams can be 0 ($R_{x_el}=0$). This is shown in Figure 1 with the matrices $W1(k)$, $W1(k+1)$, $W1(k+2)$.

[0040] The total number of bits required for W1 feedback can be 8 and the total number of bits for W2 feedback can be 4 (for both rank-1 and rank-2) for both option 1 and option 2. However, option 1 may allow more variation of the elevation angle across the bandwidth whereas option 2 may allow

more variation of the azimuth angle across the bandwidth. Therefore, a parameter can be used to enable the UE and the eNB to determine and sync their codebooks while distinguishing between these two options.

[0041] Figure 2 illustrates two further options for 2D beam groups. In option 1 of Figure 2 ($W1(n)$, $W1(n+1)$ and $W1(n+2)$) each beam-group can include 4 elevation beams and 2 azimuth beams. In option 2 ($W1(k)$, $W1(k+1)$ and $W1(k+2)$) each beam-group can include 4 azimuth beams and 2 elevation beams.

[0042] For the purposes of a second example, referring to Figure 2, assume 16 TXRU antenna configuration with 4 azimuth locations ($NTx_az=4$) and 2 elevation locations ($NTx_el=2$, total 8 locations per polarization). Assume also that the granularity in the azimuth domain is 32 beams which is 8x oversampling in the beam-domain, $Nb_az=32$. Assume further that the granularity in the vertical domain is 16 beams which is 8x oversampling in the beam domain, $Nb_el=16$. Under these assumptions, there may be at least two different methods for overlapping W1 design possible that leads to exactly the same W1 payload size of 8 bits and W2 payload size of 5 bits.

[0043] In option 1 in Figure 2, each W1 matrix can include 2 azimuth beams ($Nx_az=2$) and 4 elevation beams ($Nx_el=4$), the number of overlapping azimuth beams can be 1 ($Rx_az=1$) and the number of overlapping elevation beams can be 2 ($Rx_el=2$). This is shown in Figure 2 with the matrices $W1(n)$, $W1(n+1)$, $W1(n+2)$.

[0044] According to a second option, option 2 in Figure 2, each W1 matrix can include 4 azimuth beams ($Nx_az=4$) and 2 elevation beams ($Nx_el=2$), the number of overlapping azimuth beams can be 2 ($Rx_az=2$) and the number of overlapping elevation beams can be 1 ($Rx_el=1$). This option is shown in Figure 2 with the matrices $W1(k)$, $W1(k+1)$, $W1(k+2)$.

[0045] The total number of bits required for W1 feedback can be 8 and the total number of bits for W2 feedback can be 5 (for both rank-1 and rank-2)

for both option 1 and option 2. However, option 1 may allow more variation of the elevation angle across the bandwidth, whereas option 2 may allow more variation of the azimuth angle across the bandwidth.

[0046] Figure 3 illustrates a method according to certain embodiments. As shown in Figure 3, a method can include, at 310, determining a set of codebook parameters. Method can also include, at 320, transmitting the set of codebook parameters to a user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation. The set of codebook parameters can further include an azimuth resolution, an elevation resolution, or both an azimuth resolution, and an elevation resolution.

[0047] The at least one overlap parameter defined in azimuth and elevation, can include one overlap parameter defined in both azimuth and elevation, or two overlap parameters, one defined in azimuth and one defined in elevation. Other possible parameter definitions and numbers of overlap parameters are also permitted.

[0048] Determining the set of codebook parameters can include selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters having a same number of feedback bits. The plurality of candidate sets can be otherwise defined, for example as having a same payload, or some other common characteristic.

[0049] The method features 310 and 320 can be performed by an access node, such as a base station, eNB, or other access point. These method features can be performed as a standalone method, or can be performed in conjunction with the following features 330 and 340, which alternatively can serve as a standalone method. Features 330 and 340 may be performed by, for example, a device such as a user equipment.

[0050] Thus, the method may include, at 330, identifying a set of codebook parameters at a user equipment. The identifying can include receiving the

set of codebook parameters from an access node, such as the set transmitted at 320. Alternatively, or in addition, the identifying can include selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters having a same number of feedback bits. In other words, as mentioned above, the UE can perform a step similar to or the same as that described at 310 above and the determining the set of codebook parameters can be performed by the user equipment. As mentioned above, the plurality of candidate sets can be otherwise defined, for example as having a same payload, or some other common characteristic rather than being limited to having a same number of feedback bits.

[0051] The method can also include, at 340, applying the set of codebook parameters by the user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation, as mentioned above. Moreover, as mentioned above, the set of codebook parameters can further include an azimuth resolution and/or an elevation resolution.

[0052] Figure 4 illustrates a system according to certain embodiments of the invention. It should be understood that each block of the flowchart of Figure 3 may be implemented by various means or their combinations, such as hardware, software, firmware, one or more processors and/or circuitry. In one embodiment, a system may include several devices, such as, for example, network element 410 and user equipment (UE) or user device 420. The system may include more than one UE 420 and more than one network element 410, although only one of each is shown for the purposes of illustration. A network element can be an access point, a base station, an eNode B (eNB), or any other network element.

[0053] Each of these devices may include at least one processor or control unit or module, respectively indicated as 414 and 424. At least one memory may be provided in each device, and indicated as 415 and 425, respectively.

The memory may include computer program instructions or computer code contained therein, for example for carrying out the embodiments described above. One or more transceiver 416 and 426 may be provided, and each device may also include an antenna, respectively illustrated as 417 and 427. Although only one antenna each is shown, many antennas and multiple antenna elements may be provided to each of the devices. Other configurations of these devices, for example, may be provided. For example, network element 410 and UE 420 may be additionally configured for wired communication, in addition to wireless communication, and in such a case antennas 417 and 427 may illustrate any form of communication hardware, without being limited to merely an antenna.

[0054] Transceivers 416 and 426 may each, independently, be a transmitter, a receiver, or both a transmitter and a receiver, or a unit or device that may be configured both for transmission and reception. The transmitter and/or receiver (as far as radio parts are concerned) may also be implemented as a remote radio head which is not located in the device itself, but in a mast, for example. It should also be appreciated that according to the “liquid” or flexible radio concept, the operations and functionalities may be performed in different entities, such as nodes, hosts or servers, in a flexible manner. In other words, division of labor may vary case by case. One possible use is to make a network element deliver local content. One or more functionalities may also be implemented as a virtual application that is provided as software that can run on a server.

[0055] A user device or user equipment 420 may be a mobile station (MS) such as a mobile phone or smart phone or multimedia device, a computer, such as a tablet, provided with wireless communication capabilities, personal data or digital assistant (PDA) provided with wireless communication capabilities, portable media player, digital camera, pocket video camera, navigation unit provided with wireless communication

capabilities or any combinations thereof. The user device or user equipment 420 may be a sensor or smart meter, or other device that may usually be configured for a single location.

[0056] In an exemplifying embodiment, an apparatus, such as a node or user device, may include means for carrying out embodiments described above in relation to Figure 3.

[0057] Processors 414 and 424 may be embodied by any computational or data processing device, such as a central processing unit (CPU), digital signal processor (DSP), application specific integrated circuit (ASIC), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), digitally enhanced circuits, or comparable device or a combination thereof. The processors may be implemented as a single controller, or a plurality of controllers or processors. Additionally, the processors may be implemented as a pool of processors in a local configuration, in a cloud configuration, or in a combination thereof.

[0058] For firmware or software, the implementation may include modules or unit of at least one chip set (e.g., procedures, functions, and so on). Memories 415 and 425 may independently be any suitable storage device, such as a non-transitory computer-readable medium. A hard disk drive (HDD), random access memory (RAM), flash memory, or other suitable memory may be used. The memories may be combined on a single integrated circuit as the processor, or may be separate therefrom. Furthermore, the computer program instructions may be stored in the memory and which may be processed by the processors can be any suitable form of computer program code, for example, a compiled or interpreted computer program written in any suitable programming language. The memory or data storage entity is typically internal but may also be external or a combination thereof, such as in the case when additional memory capacity is obtained from a service provider. The memory may be fixed or

removable.

[0059] The memory and the computer program instructions may be configured, with the processor for the particular device, to cause a hardware apparatus such as network element 410 and/or UE 420, to perform any of the processes described above (see, for example, Figure 3). Therefore, in certain embodiments, a non-transitory computer-readable medium may be encoded with computer instructions or one or more computer program (such as added or updated software routine, applet or macro) that, when executed in hardware, may perform a process such as one of the processes described herein. Computer programs may be coded by a programming language, which may be a high-level programming language, such as objective-C, C, C++, C#, Java, etc., or a low-level programming language, such as a machine language, or assembler. Alternatively, certain embodiments of the invention may be performed entirely in hardware.

[0060] Furthermore, although Figure 4 illustrates a system including a network element 410 and a UE 420, embodiments of the invention may be applicable to other configurations, and configurations involving additional elements, as illustrated and discussed herein. For example, multiple user equipment devices and multiple network elements may be present, or other nodes providing similar functionality, such as nodes that combine the functionality of a user equipment and an access point, such as a relay node.

[0061] Future networks may utilize network functions virtualization (NFV) which is a network architecture concept that proposes virtualizing network node functions into “building blocks” or entities that may be operationally connected or linked together to provide services. A virtualized network function (VNF) may comprise one or more virtual machines running computer program codes using standard or general type servers instead of customized hardware. Cloud computing or data storage may also be utilized. In radio communications this may mean node operations can be carried out,

at least partly, in a server, host or node operationally coupled to a remote radio head. It is also possible that node operations will be distributed among a plurality of servers, nodes or hosts. It should also be understood that the distribution of labor between core network operations and base station operations may differ from that of the LTE or even be non-existent. Some other technology advancements probably to be used are Software-Defined Networking (SDN), Big Data, and all-IP, which may change the way networks are being constructed and managed.

[0062] Figure 5 illustrates another system according to certain embodiments. The system of Figure 5 may be implemented in a variety of ways, including, for example, using the devices as illustrated in Figure 4.

[0063] As shown in Figure 5, an apparatus such as access node 502 can include means for determining 510 a set of codebook parameters. The access node 502 can also include means for transmitting 520 the set of codebook parameters to a user equipment, such as UE 504. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation. As described above, the set of codebook parameters can further include an azimuth resolution and/or an elevation resolution.

[0064] The means for determining 510 the set of codebook parameters can be configured to select the set of codebook parameters from a plurality of candidate sets of codebook parameters having a same number of feedback bits.

[0065] Also, as shown in Figure 5, an apparatus such as UE 504 can include means for identifying 530 a set of codebook parameters at a user equipment. The apparatus can also include means for applying 540 the set of codebook parameters by the user equipment. The set of codebook parameters can include at least one overlap parameter defined in azimuth and elevation. The set of codebook parameters can further include an azimuth resolution and/or an elevation resolution.

[0066] The means for identifying 530 can be configured to determine the set of

codebook parameters at the user equipment. Alternatively, the means for identifying 530 can be configured to receive the set of codebook parameters from an access node. The means for identifying 530 can be configured to select the set of codebook parameters from a plurality of candidate sets of codebook parameters having a same number of feedback bits.

[0067] The access node 502 and UE 504 can be configured to communicate with one another over wireless communication link 506. Although only one link is shown, there can be multiple simultaneous connections between access node 502 and UE 504.

[0068] Certain embodiments may have various benefits and/or advantages. For example, it may not be possible to separately optimize and specify each and every codebook for $2n$ ports. A method for a rule-based codebook generation according to certain embodiments, however, may be applicable for any $2n$ port configuration.

[0069] One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

WE CLAIM:

1. A method, comprising:
determining a set of codebook parameters; and
transmitting the set of codebook parameters to a user equipment,
wherein the set of codebook parameters comprises at least one overlap
parameter defined in azimuth and elevation.
2. The method of claim 1, wherein the set of codebook parameters
further comprises an azimuth resolution.
3. The method of claim 1 or claim 2, wherein the set of codebook
parameters further comprises an elevation resolution.
4. The method of any of claims 1-3, wherein determining the set of
codebook parameters comprises selecting the set of codebook parameters from
a plurality of candidate sets of codebook parameters.
5. The method of claim 4, wherein the plurality of candidate sets of
codebook parameters comprise candidate sets having a same number of
feedback bits.
6. A method, comprising:
identifying a set of codebook parameters at a user equipment; and
applying the set of codebook parameters by the user equipment,
wherein the set of codebook parameters comprises at least one overlap
parameter defined in azimuth and elevation.
7. The method of claim 6, wherein the set of codebook parameters
further comprises an azimuth resolution.

8. The method of claim 6 or claim 7, wherein the set of codebook parameters further comprises an elevation resolution.

9. The method of any of claims 6-87, wherein the identifying comprises determining the set of codebook parameters by the user equipment.

10. The method of any of claims 6-8, wherein the identifying comprises receiving the set of codebook parameters from an access node.

11. The method of any of claims 6-8, wherein the identifying comprises selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters.

12. The method of claim 11, wherein the plurality of candidate sets of codebook parameters comprise candidate sets having a same number of feedback bits.

13. An apparatus, comprising:
at least one processor; and
at least one memory including computer program code,
wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to
determine a set of codebook parameters; and
transmit the set of codebook parameters to a user equipment,
wherein the set of codebook parameters comprises at least one overlap parameter defined in azimuth and elevation.

14. The apparatus of claim 13, wherein the set of codebook parameters further comprises an azimuth resolution.

15. The apparatus of claim 13 or claim 14, wherein the set of codebook parameters further comprises an elevation resolution.

16. The apparatus of any of claims 13-15, wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to determine the set of codebook parameters by selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters.

17. The method of claim 16, wherein the plurality of candidate sets of codebook parameters comprise candidate sets having a same number of feedback bits.

18. An apparatus, comprising:
at least one processor; and
at least one memory including computer program code,
wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to
identify a set of codebook parameters at a user equipment; and
apply the set of codebook parameters by the user equipment,
wherein the set of codebook parameters comprises at least one overlap parameter defined in azimuth and elevation.

19. The apparatus of claim 18, wherein the set of codebook parameters further comprises an azimuth resolution.

20. The apparatus of claim 18 or claim 19, wherein the set of codebook parameters further comprises an elevation resolution.

21. The apparatus of any of claims 18-20, wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to determine the set of codebook parameters at the user equipment.

22. The apparatus of any of claims 18-20, wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to receive the set of codebook parameters from an access node.

23. The apparatus of any of claims 18-20, wherein the at least one memory and the computer program code are configured to, with the at least one processor, cause the apparatus at least to select the set of codebook parameters from a plurality of candidate sets of codebook parameters.

24. The apparatus of claim 23, wherein the plurality of candidate sets of codebook parameters comprise candidate sets having a same number of feedback bits.

25. An apparatus, comprising:
means for determining a set of codebook parameters; and
means for transmitting the set of codebook parameters to a user equipment,
wherein the set of codebook parameters comprises at least one overlap parameter defined in azimuth and elevation.

26. The apparatus of claim 25, wherein the set of codebook parameters further comprises an azimuth resolution.

27. The apparatus of claim 25 or claim 22, wherein the set of codebook parameters further comprises an elevation resolution.

28. The apparatus of any of claims 25-23, wherein determining the set of codebook parameters comprises selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters.

29. The apparatus of claim 28, wherein the plurality of candidate sets of codebook parameters comprise candidate sets having a same number of feedback bits.

30. An apparatus, comprising:
means for identifying a set of codebook parameters at a user equipment;
and
means for applying the set of codebook parameters by the user equipment,
wherein the set of codebook parameters comprises at least one overlap parameter defined in azimuth and elevation.

31. The apparatus of claim 30, wherein the set of codebook parameters further comprises an azimuth resolution.

32. The apparatus of claim 30 or claim 31, wherein the set of codebook parameters further comprises an elevation resolution.

33. The apparatus of any of claims 30-32, wherein the identifying comprises determining the set of codebook parameters at the user equipment.

34. The apparatus of any of claims 30-32, wherein the identifying comprises receiving the set of codebook parameters from an access node.

35. The apparatus of any of claims 30-32, wherein the identifying comprises selecting the set of codebook parameters from a plurality of candidate sets of codebook parameters.

36. The apparatus of claim 35, wherein the plurality of candidate sets of codebook parameters comprise candidate sets having a same number of feedback bits.

37. A computer program product encoding instructions for performing a process, the process comprising the method according to any of claims 1-12.

38. A non-transitory computer-readable medium encoded with instructions that, when executed in hardware, perform a process, the process comprising the method according to any of claims 1-12.

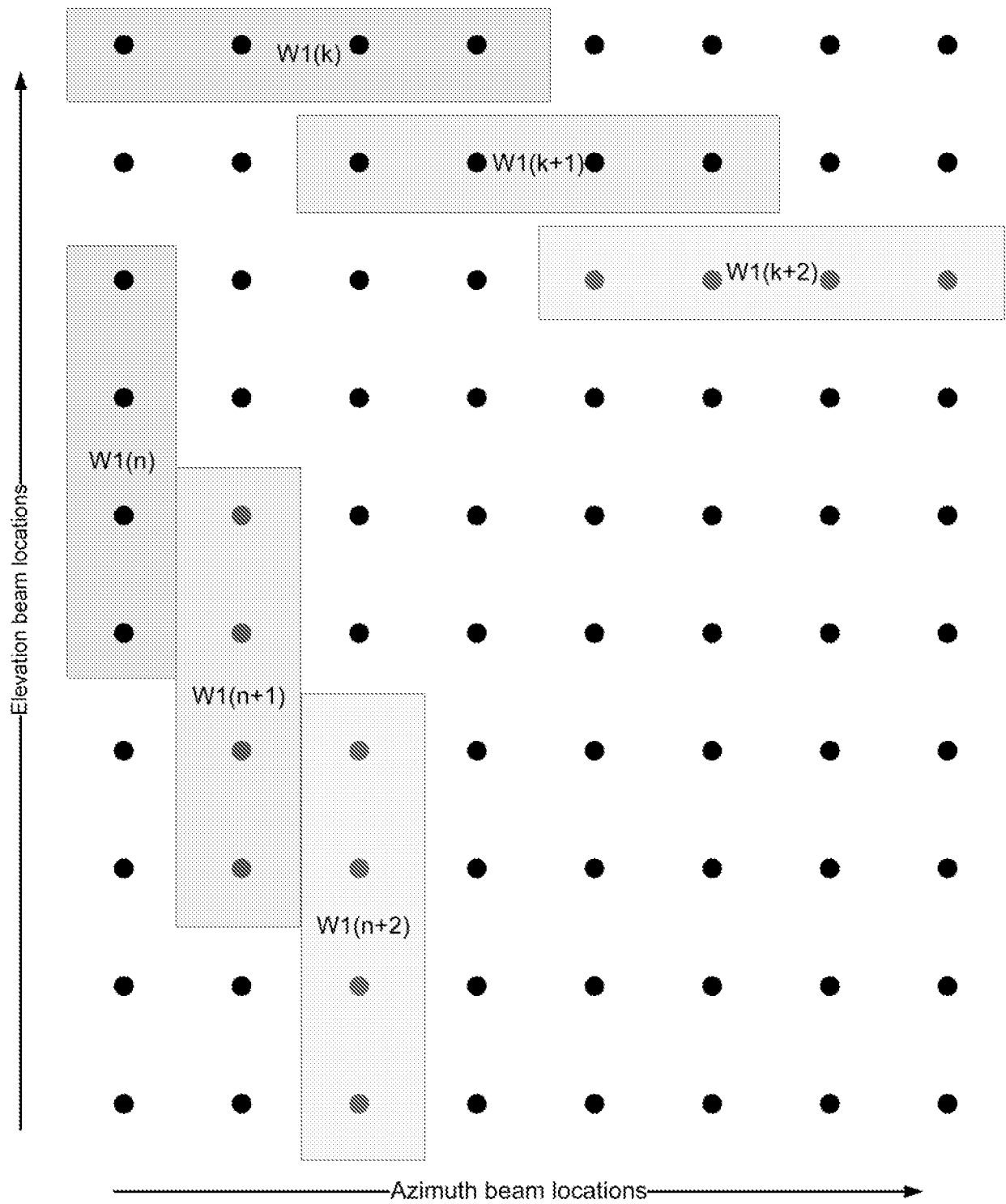


Figure 1

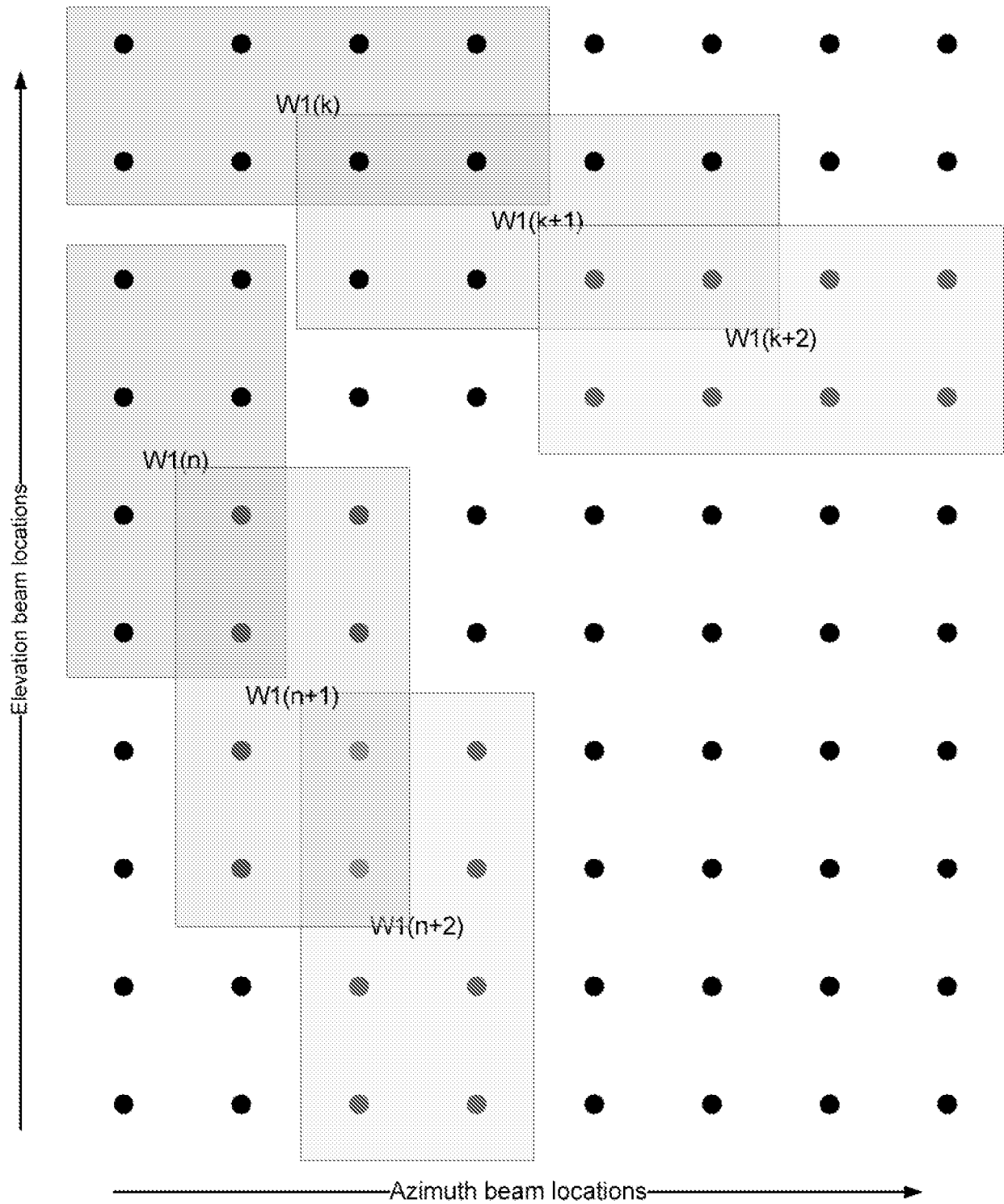


Figure 2

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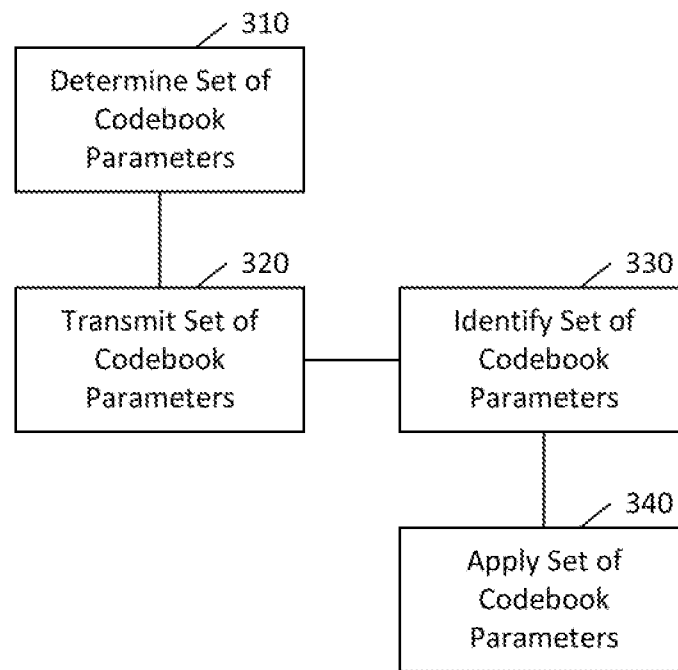


Figure 3

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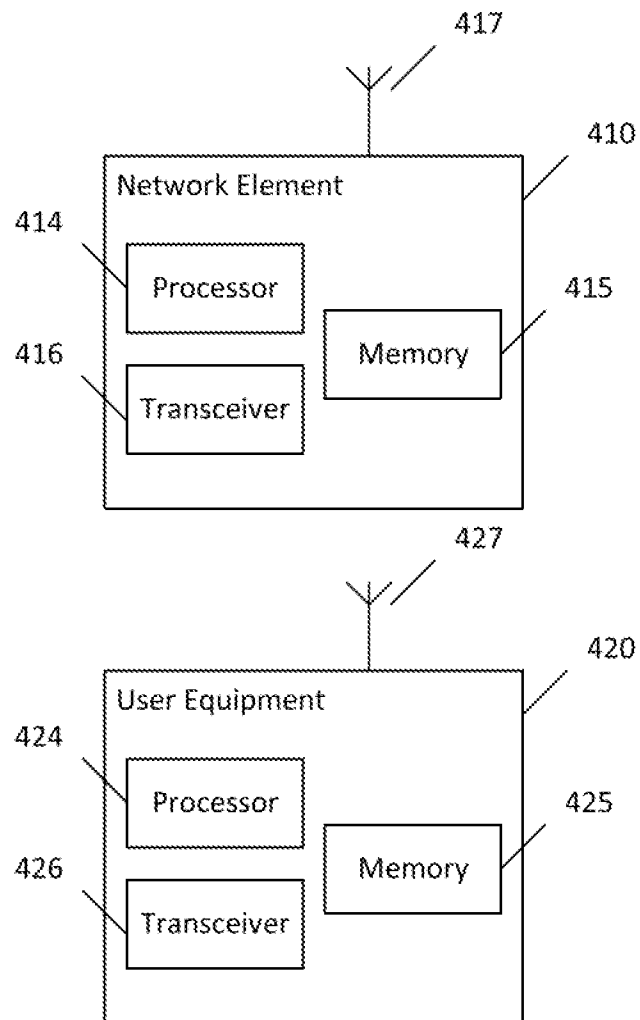


Figure 4

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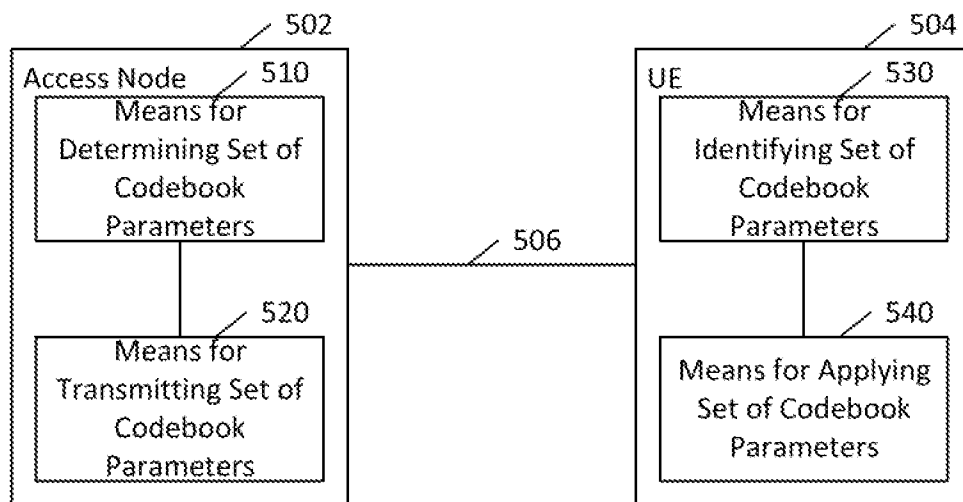


Figure 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/25444

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H04B 7/216 (2015.01)

CPC - H04B1/707, H04B2201/70701, H04B7/2628, H04J13/00, H04J13/16

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): H04B 7/216 (2015.01); CPC: H04B1/707, H04B2201/70701, H04B7/2628, H04J13/00, H04J13/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 370/335, 370/342, 370/310Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, ProQuest Dialog, Google Web, Google Patents (Search terms: codebook, transmit, send, apply, receive, overlap parameter, azimuth, elevation, altitude, inclination, overlay, measure, degree, factor, value, number of overlapping beams, etc.)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 2014/0301492 A1 (Xin et al.) 09 October 2014 (09.10.2014), para. [0039], [0042], [0044], [0046]-[0048], [0053], [0057], [0065], [0071], [0079]-[0081], [0136]-[0137], and [0190], and Figs. 1, 2A-2B, 3, and 11.	1-3, 6-8, 18-20, 25-26, 30-32 ----- 13-15
Y	WO 2015/005609 A1 (Kim et al.) 15 January 2015 (15.01.2015), para. [0116], [0227], and [0286]-[0287], and Fig. 7.	13-15

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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

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

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

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

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

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

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

“&” document member of the same patent family

Date of the actual completion of the international search

26 June 2015 (26.06.2015)

Date of mailing of the international search report

24 JUL 2015

Name and mailing address of the ISA/US

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P.O. Box 1450, Alexandria, Virginia 22313-1450

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PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/25444

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-5, 9-12, 16-17, 21-24, 27-29, 33-38
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.