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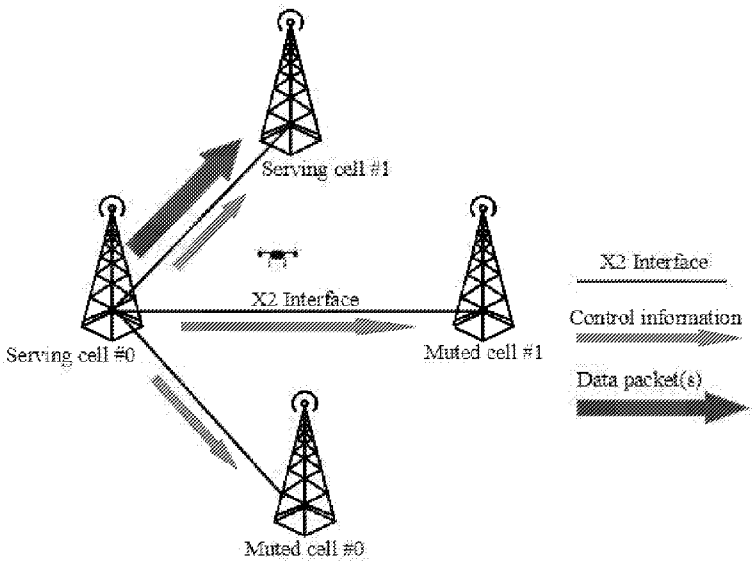


Figure 8

(57) Abstract: A method for mitigating interference in communications between a plurality of wireless communications devices wherein at least a first wireless communications device is moving within a Radio Access Network, the method comprising: identifying the first moving wireless device to be an aerial device based on one or a combination of an Interference Coordination method; a beam forming and steering process and one or more of a collection of criteria indicating a location of the first moving device

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Interference mitigation for aerial vehicles in wireless communications

Technical Field

Embodiments of the present invention generally relate to wireless communication systems and in particular to devices and methods for enabling a wireless communication device, such as a User Equipment (UE) or mobile device to access a Radio Access Technology (RAT) or Radio Access Network (RAN), particularly but

Background

Wireless communication systems, such as the third-generation (3G) of mobile telephone standards and technology are well known. Such 3G standards and technology have been developed by the Third Generation Partnership Project (3GPP). The 3rd generation of wireless communications has generally been developed to support macro-cell mobile phone communications. Communication systems and networks have developed towards a broadband and mobile system.

The 3rd Generation Partnership Project has developed the so-called Long Term Evolution (LTE) system, namely, an Evolved Universal Mobile Telecommunication System Territorial Radio Access Network, (E-UTRAN), for a mobile access network where one or more macro-cells are supported by a base station known as an eNodeB or eNB (evolved NodeB). More recently, LTE is evolving further towards the so-called 5G or NR (new radio) systems where one or more cells are supported by a base station known as a gNB.

One current area of interest is the study of aerial vehicles, often referred to as drones, within an LTE network or equivalent. An objective of the study is to investigate the ability for aerial vehicles for LTE to be served using LTE network deployments with Base Station antennas targeting terrestrial coverage, supporting Release 14 functionality (i.e. including active antennas and FD-MIMO. Thus, the focus includes investigations to determine at which level aerial devices could re-use the existing LTE networks, and, if necessary, what enhancements can be introduced to the LTE standards to allow co-existence with terrestrial or ground devices.

Figure 1 shows a typical network setup for terrestrial and aerial devices. The common coverage area of inter-cells is significantly increased for aerial devices

compared to terrestrial UEs. To achieve this, some potential issues are highlighted and addressed, mainly with respect to the expected interference aerial devices would introduce to the LTE networks. This is because aerial devices, such as drones, are expected to fly above base station (BS) antenna heights, thus having an increased line-of-sight (LOS) probability which then results to decrease experienced path-loss (PL), as shown in Figure 1. As a result, the aerial device visibility to inter-cells is increased and this leads to interference issues in the downlink and the uplink.

In the downlink, interference to a specific UE is caused by Down Link (DL) signals of inter-cells. Thus, ground UEs are not expected to be affected by the presence of drones. However, aerial devices are more accessible by DL signals transmitted from surrounding inter-cells which increases DL interference. These observations are shown in Figure 2, where the case of only ground UEs is compared with the case of 2/3 ground UEs and 1/3 aerial UEs.

In the uplink, interference to a specific UE is caused by Up Link (UL) signals of inter-users. Aerial vehicles have a stronger UL interference contribution to inter-cells which serve ground and aerial UEs. An aerial UE causes UL interference to inter-cells, i.e. neighboring cells using the same carrier frequency as the serving cell of the drone. Therefore, the UL signal of UEs using that cell is interfered with by the drone. Thus, a UE served by an inter-cell related to an aerial UE, would experience increased UL interference compared to the case where the aerial UE were a ground UE. Interference increase is also observed for aerial UEs, although not as severely as for ground UE because aerial devices are more dominant due to the increased Line of Sight (LOS) probability. These observations are shown in the graph in Figure 3.

The DL and UL signal quality degradations depicted in Figure 2 and Figure 3 represent the two problems that the present invention is seeking to addressing and aiming to improve. The comparison of Figure 2 and Figure,3 shows the channel quality difference between the UL and the DL, where the UL is 5 dB better on average. This might lead to situations where, if no interference mitigation technique is used, an aerial device might be able to synchronize to a cell but not complete its attachment as it will be unable to receive DL information (Msg2, etc.). Thus, any intended interference mitigation technique might have to be activated as early as the Random Access Channel (RACH) procedure.

Due to the interference issues an aerial vehicle (AV) introduces to the network, an aerial device may be obligated to inform the system that it is an aerial device. In this case, the eNB can take necessary actions to guarantee that the AV device will not affect the system performance. In some cases, this might be translated to connection limitation or even connection refusal. In addition, the network should be able to detect and refuse connection of any aerial device that has not or falsely reported that it is an aerial.

The two main metrics for evaluating the DL and UL performance of a user *k* are the DL signal-to-interference-plus-noise ratio (SINR) γ_k^{DL} and UL SINR γ_k^{UL}, respectively:

The downlink SINR is given by the equation 1 below:

$$\gamma_k^{DL} = \frac{P_{k,i}^{DL}}{\sigma_N^2 + \sum_{j=1,j\neq i}^{N} P_{k,j}^{DL}}$$

where: $P_{k,i}^{DL}$ is the downlink average received signal power of the serving cell *i* at user *k*, and $P_{k,j}^{DL}$ is the average received signal power of the interfering cell *j* at user *k*, and σ_N^2 is the noise power.

The uplink SINR is given by the equation 2 below:

$$\gamma_k^{UL} = \frac{P_{k,i}^{UL}}{\sigma_N^2 + \sum_{l=1,l\neq k}^{K} P_{l,i}^{UL}}$$

where: $P_{k,i}^{UL}$ is the uplink average received signal power of the serving cell *i* at user *k*, and $P_{l,i}^{UL}$ is the received signal power of the interfering user *l* at cell *i*, and σ_N^2 is the noise power.

It should be noted that this assumes that only one user is being served from a serving cell at a specific Transmission Time Interval (TTI), that occupies the entire bandwidth (full allocation). *N* is the total number of cells in a network and *K* the total number of active users within the network.

Generally, the average received power P_{rx} is given by the equation 3 below:

$$P_{rx}[dBm] = P_{tx} + G_{tx} - PL - SF + G_{rx}$$

where: P_{tx} is the transmit power, G_{tx} and G_{rx} are the antenna gains of the transmitter and receiver respectively, PL is the path-loss between the transmitter and receiver, and finally SF is the shadow fading factor.

Interference management has been an active topic in communications systems and a variety of methods has already been defined. LTE also has several standardized methods for handling different types of interference. Some of them are already being proposed for re-use in the case of aerial devices. The proposed interference mitigation techniques include the following approaches:

- Inter-Cell Interference Coordination (ICIC) and enhanced ICIC (eICIC);
- Uplink power control;
- Beamforming/beam-steering;
- Vertical antenna sectorization;
- Coordinated Multi-point (CoMP); and
- Access and connection control.

It should be noted that any of the methods that have already been standardized were introduced assuming solely terrestrial UEs within the LTE network. The elevation of the aerial devices completely changes the LTE network planning, and these techniques might require varying degrees of adjustments and/or enhancements to be efficiently applied to the aerial vehicles, while maintaining the existing performance of terrestrial UEs.

The various options mentioned above are described in more detail below.

ICIC was originally introduced in LTE, as a method for interference coordination between cells for users at the cell edge. The main concept is that neighboring cells are coordinated to transmit at different power levels for different parts of the frequency spectrum. Thus, at the cell edge, only one cell will be dominant in a given number of resource blocks, see left part of Figure 4 Although this method enables a

desired frequency reuse factor of one, it requires cells to transmit with less power in a large part of their bandwidth which degrades the overall network performance. Additionally, interference is handled only at cells edges. As a result, this concept cannot be applied for example in heterogeneous networks (HetNets) where a pico-cell can be located in the heart of a macro eNB.

To introduce a further interference limitation method, 3GPP introduced new ICIC enhancements named eICIC. The most significant difference was the introduction of Almost Blank Subframes (ABS), where a macro cell is must obey a set of predefined network configurations. These include specific subframes where only broadcast information is transmitted (for example: Cell-specific Reference Signal (CRS), Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS), Physical Broadcast Channel (PBCH)), while control and data information channels are muted (for example, Physical Downlink Shared Channel (PDSCH), Physical Dedicated Control Channel (PDCCH), Physical Hybrid ARQ Indicator Channel (PHICH), Physical Control Format Indicator Channel (PCFICH)), see right part of Figure 4 This allows, e.g. pico-cells to use the almost interference-free subframes to serve users in regions where the macro eNB is still the dominant cell, called Cell Range Extension (CRE) regions. This efficiently offloads a lot of macro eNB traffic towards the pico-cells and allows a quality connection of UEs served by smaller cells.

It is worthy of note that further enhanced ICIC (feICIC) features were added which include sending network assisted information of interfering cells (aggressors) to the UE so that the receiver can perform interference reconstruction and cancellation to further remove interference from the downlink signals. In these two methods ICIC and eICIC, coordination between base station is made using the X2 interface.

Uplink power control is a procedure where the network can control the transmit power of each UE based on some physical layer parameters in order to make sure that the UL receiver power is within a desired range. This can be done per uplink physical channel, as each of them can follow a different formula, depending on the receive requirements of each channel. For example, equation 4 below shows the corresponding power control formula of PUSCH

$$P_{PUSCH}(i) = \min\{P_{CMAX}, 10 \cdot \log(M_{PUSCH}(i)) + P_{0_PUSCH}(j) + a(j) \cdot PL + \Delta_{TF}(i) + f(i)\} \text{ [dBm]}$$

where: $P_{PUSCH}(i)$ is the PUSCH transmit power in subframe *i*, P_{CMAX} and is the maximum transmit power of the UE and depends on the UE power class. $M_{PUSCH}(i)$ are the number of assigned physical resource blocks in that UE in subframe *i*. P_{0_PUSCH} is the nominal PUSCH power, $a(j)$ is a weight factor, PL is the estimated path-loss, $\Delta_{TF}(i)$ is a factor that accounts different modulation and coding the given subframe *i*, and $f(i)$ is the closed-loop power correction applied from the network. Other physical channels have similar power expressions depending on each channel's reliability requirements.

Accordingly, the final transmit power of the UE is a function of several physical layer parameter (power class, path-loss, assigned resources, modulation and coding), but can also be controlled by the network by transmit power control (TPC) commands sent in the uplink grants. The higher the UL transmit power of a UE, the higher the inter-user interference it can cause. By limiting its power, the caused interference is also limited but with a corresponding degradation of that UEs UL performance towards its serving cell.

Beamforming is generally an antenna method for focusing the power of an antenna transmission towards a specific direction, but also receiving a transmission with higher receive power from a specific direction, and having "holes" in the direction of the interferers. Besides the maximum transmit/receive direction (antenna broadside), beamforming has some other properties like beam-width, i.e. how wide is the receive/transmit beam lobe. These properties are usually characterized by the antenna 3D pattern, or alternatively the azimuth and elevation plane patterns, as shown in Figure.5. Figure 5 shows the 3D and 2D antenna patterns of a typical 3-sector cellular base station antenna.

A common use of beamforming is for network planning and cell sectorization. Each sector is designed to cover a specific angle width. In LTE, eNB antennas are designed to have a 120^0 beam-width such that three sectors are able to cover all 360^0 of the azimuth plain. The purpose of the sectorization is to allow sectors of the same eNB to interfere less with each other. By doing this, the network can re-use the same frequency band for all sectors (frequency re-use factor of one). A typical example of the transmission pattern of a 3-sector antenna is depicted in Figure 5

Beam-steering is a technique where the antenna broadside of a beam is steered towards a specific direction instead of pointing to a fixed direction all the time.

The horizontal plane sectorization using directional antennas to achieve a frequency re-use factor of one has been described above. A similar method can be applied in the elevation plane where antenna sectors can cover different elevation angles, as depicted in Figure 6. Figure 6 shows an example of 3-sector horizontal, and 2-sector vertical network sectorization. In this way, each elevation beam can re-use the same frequency resources and multiply the spectral efficiency. A drawback of this technique is that the further sector subdivisions allow inter-users to be very close to each other, resulting in an increase of the DL and UL interference. 3D beamforming has been standardized in LTE in the context of Full Dimensional Multiple Input Multiple Output (MIMO).

CoMP is an eNB cooperative technique to improve the throughput performance of UEs, especially the ones located in the cell edge. UE at the cell edge is usually visible by two or more cells.

In the downlink, CoMP has three “flavors”: Joint Transmission (JT); Coordinated Scheduling and Beamforming (CS/CB); and Dynamic Point Selection (DPS). In JT CoMP the DL signal can be transmitted from two or more cells, instead of one cell, thereby significantly improving the DL SINR. In CS/CB, data to a single UE is transmitted from one eNB. The scheduling decisions as well as any beams are coordinated to control the interference that may be generated. In DPS CoMP the UE selects the best DL signal from the available CoMP cells. Joint Processing (JP) and DPS methods are depicted in Figure 7.

In the uplink, CoMP has two “flavors”: Joint Reception (JR) and Coordinated Scheduling (CS). In JR CoMP, the UE can transmit towards multiple cells and improve the UL SINR by signal combining at the network level. The CS CoMP scheme operates by coordinating the scheduling decisions amongst the eNBs to minimize interference.

CoMP can also be thought of as an interference mitigation technique as inter-cells act as additional serving cells instead of interferers. On the downside, CoMP is a complex technique as it not only requires control, but potentially also data exchange between different nodes.

Clearly, a number of issues relating to aerial devices remains unsolved and the present invention is seeking to solve at least some of the outstanding problems in this domain.

Summary

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

According to a first aspect of the present invention there is provided a method for mitigating interference in communications between a plurality of wireless communications devices wherein at least a first wireless communications device is moving within a Radio Access Network, the method comprising: identifying the first moving wireless device to be an aerial device based on one or a combination of an Interference Coordination method; a beam forming and steering process and one or more of a collection of criteria indicating a location of the first moving device.

Preferably, the network performance method comprises at least one of increasing the power of a predetermined part of a signal in the communication; decreasing the power of interfering signals; decreasing a number of interfering cells in the vicinity of the aerial device.

Preferably, the method further comprises using at least one of joint transmission; muting one or more interfering cells coordinated scheduling; beamforming and dynamic point selection to achieve the interference coordination method.

Preferably, the method further comprising: when an aerial device enters a cell in a network determining a quality metric based on a channel quality of the aerial device; determining a number of serving cell to be used for a first function based on a predicted position of the aerial device; determining a number of muted cells to be used for a second function based on the predicted position of the aerial device; coordinating the control and data requirements of the aerial device based on using one of the determined number of first or second serving cells.

Preferably, the aerial device is capable of beam forming and steering process to enable the antenna to be steered to a predetermined serving cell.

Preferably, the method further comprising activating beam forming such that a metric is improved; acquiring the serving cell; and adjusting to a line of sight of the beam such that interference in the communication is reduced.

Preferably, the aerial device includes a plurality of antennae and the method relies on the aerial device to select the antenna which experiences the lowest level of interference in the communication.

Preferably, the collection of criteria comprises one or more of: an angle of arrival estimation; an angle spread; estimation; a positioning estimation; a estimation of the velocity of the aerial device; a path loss estimation; scheme for reporting intra frequency cells; a MIMO measurement; an aerial vehicle indicator; and explicit signalling.

Preferably, the Radio Access Network is a New Radio/5G network.

Preferably, the aerial device is a drone.

According to a second aspect of the present invention there is provided a base station adapted to perform the method of another aspect of the present invention.

According to a third aspect of the present invention there is provided a UE adapted to perform the method of another aspect of the present invention.

According to a fourth aspect of the present invention there is provided a non-transitory computer readable medium having computer readable instructions stored thereon for execution by a processor to perform the method of another aspect of the present invention.

The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory.

Brief description of the drawings

Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the drawings. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale.

Like reference numerals have been included in the respective drawings to ease understanding.

Figure 1 is a simplified diagram showing a network setup for terrestrial and aerial devices, according to the prior art.

Figure 2 is a graph showing Downlink Signal-to-Noise-Ratio Cumulative Distribution Function (DL SINR CDF) of ground and aerial UEs with and without the presence of aerial devices, according to the prior art.

Figure 3 is a graph showing Uplink Signal-to-Noise-Ratio Cumulative Distribution Function (UL SINR CDF) of ground and aerial UEs with and without the presence of aerial devices, according to the prior art.

Figure 4 is a simplified diagram showing ICIC and eICIC subframes, according to the prior art.

Figure 5 is a simplified diagram showing the 3D and 2D antenna patterns of a typical 3-sector cellular base station antenna, according to the prior art.

Figure 6 is a simplified diagram showing an example of 3-sector horizontal, and 2-sector vertical network sectorization, according to the prior art.

Figure 7 is a graph showing JP and DPS downlink CoMP, according to the prior art.

Figure 8 is a simplified diagram showing an X2 communication of a scenario inter-cell interference coordination with two joint-transmission cells and two muted cells using ABS, according to an embodiment of the present invention.

Figure 9 is a graph DL SINR CDF of aerial UEs with different combination of JP CoMP and eICIC/ABS, according to an embodiment of the present invention.

Figure 10 is a simplified diagram showing a sequence chart of the proposed hybrid IC method, according to an embodiment of the present invention.

Figure 11 is a simplified diagram showing Aerial vehicle interference venerability to inter-cell interference when using omni-directional antennas, according to an embodiment of the present invention.

Figure 12 is a simplified diagram showing aerial vehicle inter-cell interference suppression when using beamforming, according to an embodiment of the present invention

Figure 13 is a graph showing two DL SINR CDF of aerial UEs with agnostic beamforming, according to an embodiment of the present invention.

Figure 14 is a graph showing UL SINR CDF of aerial UEs with agnostic beamforming in the presence of omni-directional ground UEs, according to an embodiment of the present invention.

Figure 15 is a graph showing UL SINR CDF of omni-directional ground UEs in the presence of aerial UEs with agnostic beamforming, according to an embodiment of the present invention.

Figure 16 is a simplified diagram showing aerial vehicle inter-cell interference suppression when using LOS gnostic beamforming, according to an embodiment of the present invention.

Figure 17 is a graph showing DL SINR CDF of aerial UEs with agnostic beamforming, according to an embodiment of the present invention.

Figure 18 is a graph showing UL SINR CDF of aerial UEs with gnostic beamforming in the presence of omni-directional ground UEs, according to an embodiment of the present invention.

Figure 19 is a graph showing UL SINR CDF of omni-directional ground UEs in the presence of aerial UEs with gnostic beamforming, according to an embodiment of the present invention.

Figure 20 is a simplified diagram showing line-of-Sight azimuth and zenith angles between the serving cell and the aerial, according to an embodiment of the present invention.

Detailed description of the preferred embodiments

Those skilled in the art will recognise and appreciate that the specifics of the examples described are merely illustrative of some embodiments and that the teachings set forth herein are applicable in a variety of alternative settings.

The invention relates to methods for mitigating the uplink and downlink interference that aerial vehicles (AV) may introduce and experience inside a network, which comprises for example one or more LTE base stations (eNB), and terrestrial and aerial user equipment (UE). The methods can also be used in future 5G/NR base

stations (gNBs) and in other base stations which function in a similar way and/or experience similar problems and issues.

The invention presents methods to handle the identified interference issues of aerial devices. The methods can be used solely or combined to reduce the interference effects. In broad terms, the following methods are presented.

A hybrid interference mitigation method which inherits properties from Joint Transmission CoMP and eICIC using Almost Blank Subframes (ABS).

A network-assisted beam-steering method for eNB to aid aerial devices capable of beamforming to steer their beam towards the line-of-sight between the serving cell and the aerial device.

A collection of criteria for an LTE network to identify an aerial UE which has not reported that it is an aerial. This may introduce unhandled interference to the network.

The above mentioned hybrid eICIC/CoMP method for AV interference mitigation will now be described. As previously demonstrated in respect of figure 2, there is a significant DL SINR degradation of aerial devices compared to that of ground devices (10 dB at 50% CDF, 20 dB at 90% CDF). A reason for this is the increased visibility of aerial devices to inter-cells. This increases the interference summation in the denominator of equation 1. According to Figure 2 approximately 40% of the time the aerial DL SINR is below the -6 dB operating limit.

This may be address by the two solutions below, either alone or in combinations. The first solution proposes increasing the number of serving cells by using a similar method to DL JP CoMP. This may increase the power of the useful information signal and decrease the power of the interference signal. The second solution proposes decreasing the number of interfering cells by using a similar method to eICIC and the use of ABS. This may decrease the power of the interference signal. The corresponding DL SINRs for JP CoMP, eICIC/ABS and JP CoMP+eICIC/ABS can be respectively equations 5, 6 and 7 below:

$$\gamma_k^{DL,CoMP} = \frac{\sum_{i=1}^{M} P_{k,i}^{DL}}{\sigma_N^2 + \sum_{j=1}^{N-M} P_{k,j}^{DL}}$$

$$\gamma_k^{DL,eICIC} = \frac{P_{k,i}^{UL}}{\sigma_N^2 + \sum_{j=1}^{N-L} P_{k,j}^{DL}}$$

$$\gamma_k^{DL,CoMP+eICIC} = \frac{\sum_{i=1}^{M} P_{k,i}^{DL}}{\sigma_N^2 + \sum_{j=1}^{N-M-L} P_{k,j}^{DL}}$$

where: *M* is the total number of cells used for JP CoMP, and *L* is the total number of cells applying eICIC/ABS.

Typically, the eNB would have available Reference Symbol Received Power (RSRP) and Reference Symbol Received Quality (RSRQ) reports of an aerial UE for a number of intra-frequency interfering cells. Thus, it can decide which cells are the most dominant interferers and which are least dominant. The most dominant interferers are chosen for CoMP and least dominant for ABS in order to maximize the DL SINR gain. Alternatively, due to the increased LOS probability, the eNB can obtain a reliable estimate of an aerial device's position. Then, the eNB can sort the interferers by interfering power based on the aerial device's position and the knowledge of the network layout. Finally, the serving cell reported RSRQ can decide on the number of needed CoMP and ABS cells in order to establish a reliable DL connection. An eNB shall be able to ignore a specific cell to be used in this method if there is the possibility that the aerial device is outside the cover range of that cell.

After deciding on the number of JP CoMP cells *M* and eICIC/ABS cells *L*, the eNB can signal them showing its intention to serve an aerial device. The eNB may then send the needed scheduling control information (scheduled subframes, frequency resources, etc.), similar to those sent to the aerial device, to allow coordination between the *M*+*L* cells. For CoMP cells, the DL packets of the aerial device have to be additionally retrieved from the network. A new hybrid network message can be introduced which can be shared with cells for undertaking either CoMP and/or eICIC. This procedure shall be able to adapt to the movement of the aerial device. As it moves, the aerial device may experience different receive signal powers from different cells. A cell can be added to the list of interferers, removed, or changed from CoMP to eICIC, and the opposite.

A high level description of the procedure for an eNB to apply the proposed hybrid CoMP/eICIC interference mitigation technique for aerial vehicles follows. When an aerial vehicle attaches to an LTE cell (through RACH), based on RSRQ or any other channel quality metric available or derived by the eNB corresponding to an aerial device's channel quality towards the serving cell, a decision is made as to whether a DL interference mitigation technique is required. If yes, the available channel quality of an aerial device towards its intra-frequency cells is sorted relative to others. Based on the aerial device's channel quality towards the serving cell, and the estimated position of the aerial device: the total number of intra-frequency cells *M* and their cell identities to be used for JP CoMP for the aerial; and the total number of intra-frequency cells *L* and their cell identities to be used for eICIC/ABS for the aerial are determined. The required control and data information is coordinated and shared with the network so that during a set of scheduled DL TTIs, the aerial device receives the same PDSCH data from *M* intra-frequency cells, while *L* intra-frequency cells are muted by using ABS.

Figure 8 shows the X2 interface between interference-coordinated eNBs using the hybrid JT-CoMP+eICIC/ABS method. An X2-interface is the interface that allows communication between neighboring cells. In this example, two cells are transmitting PDSCH to the aerial device (serving cells #0 and #1) and two cells transmit ABS (muted cells#0 and #1). The original serving cell of the aerial device needs to communicate a similar control signal to each of the coordinated cells, indicating to each one if it is a JT or an ABS cell. Cells that are indicated as JT additional require the PDSCH data content intended to the aerial to be communicated over the X2 interface.

The control information sent over X2 to all the coordinated cells needs to include all the required scheduling information (TTI, frequency allocation information, etc.) of the aerial device so that the eNBs are aware when and which resources to reserve for the service of the aerial device. The data information sent to JT cells needs to be the exact PDSCH information that the original serving cell intends to transmit to the aerial device.

Figure 9 shows the network performance of aerial devices for different combinations of JP CoMP and eICIC/ABS, which exploit the proposed hybrid interference mitigation method. The figure can provide the SINR gains for the different

techniques and their combination, and different number of cells used for CoMP and/or eICIC.

Figure 10 shows a sequence chart of the proposed hybrid IC method. In this example, the eNB receives an AV indication from an attached UE along with its measurement reports. The measurement reports contain RSRP/RSRQ measurements of intra (same) and inter (different) frequency cells that the UE might re-select or hand-over to. They are a measure of the power and quality of neighboring cells. In this case, intra-frequency RSRP/RSRQ reports can be used as a metrics for defining how much interference is experienced by that UE. Based on RSRP/RSRQ, the eNB decides on the number and identities of the JT and ABS cells. The eNB informs the cells on its intention to perform aerial interference coordination and receives the replies from those cells. Upon reception of a DL packet for the aerial device, the eNB sends the required scheduling/control information to the coordinated cells. For CoMP cells the eNB additionally uses the X2-interface to send the aerial device DL packets.

Directional antennas are an efficient way for interference avoidance between cells using the same frequency band. This means that in the base station antenna gain pattern of equation 3 G_{tx} is actually a function of the azimuth and zenith angles ϕ, θ, respectively. In other words, $G_{tx} = G_{tx}(\phi, \theta)$, where ϕ=0^0, θ=0^0 points to the direction of the antenna broadside. The broadside is the direction of maximum signal transmission and reception of an antenna. It is often used as the reference direction where azimuth and zenith angles are measured.

The antennas of the UE are generally assumed to be omni-directional, i.e. the antenna gain is independent of the direction of the signal, i.e. $G_{rx}^{omni} = 0\ [dB]$. For ground UEs, this is generally required because the serving cell signal can be received from any angle due to the scattering-rich terrestrial environment.

For aerial UEs, the signal from the serving and inter-cells is very likely to arrive from the respective LOSs. The use of omni-directional antennas allows interfering cells to pollute the serving cell's DL signal to the aerial devices, and the aerial devices to pollute the UL signals to other (ground and aerial) UEs of the network, as shown in Figure 11. Thus, the use of directional antennas can be extremely useful to suppress

the interference to a large number of inter-cells. The interference suppression is dependent on the used beam-width and the direction of the broadside.

If the UE is agnostic (not aware) of the direction of the serving cell, it can point in a fixed direction e.g. towards the direction of travel (DoT) for the azimuth angle ϕ and a zenith angle θ which depends e.g. from the inter-site-distance (ISD) of the network, assuming that this is available to the UE. By doing this, the UE suppresses a number of inter-cell interferers as the LOS signals arriving at the UE away from the broadside will be attenuated as depicted in Figure 12. A downside of agnostic beamforming method is that the UE might point its beam away from the serving cell which would reduce the receive power of the serving cell signal and the UL and DL performance of the aerial device. Thus, if the beam is too narrow, it has the effect of degrading the DL signal quality as the reception of the serving cell's signal is negatively impacted.

Simulations show that only a few beam-widths of agnostic beamforming offer some DL SINR improvement of around 1 dB on average, see for example figure 13. Wider beam-widths allow more DL interference, while narrower beam-widths are pointing too far away from the serving cell. Thus, agnostic beamforming is relevant, but unlikely to significantly improve the DL performance of aerial devices.

In the UL, the use of agnostic beamforming heavily degrades the performance of aerials as shown in Figure 14. However, the performance of the ground UEs when aerial UEs use agnostic beamforming is significantly improved compared to if aerials used omni-directional antennas, as shown in Figure 15. In fact, the use of very narrow beams would result in aerial devices causing less interference than inter-cell UEs.

Figure 13 to 15 show that there are only a few benefits in using agnostic beamforming. In the DL, the signal of the aerials is improved by very little and for just small range of beam-width. Figure 13 shows 2 DL SINR CDF of aerial UEs with agnostic beamforming (DoT tracking). θ_{3dB} and φ_{3dB} are the zenith and azimuth 3dB beam-width, respectively. Figure 14 shows the UL SINR CDF of aerial UEs with agnostic beamforming (DoT tracking) in the presence of omni-directional ground UEs. θ_{3dB} and φ_{3dB} are the zenith and azimuth 3dB beam-width, respectively. Figure 15 shows the UL SINR CDF of omni-directional ground UEs in the presence of aerial

UEs with agnostic beamforming (DoT tracking). θ_{3dB} and φ_{3dB} are the zenith and azimuth 3dB beam-width, respectively.

In the UL, the performance of ground UEs is benefited by the use of aerial agnostic beamforming, however, the performance of the aerial UEs is heavily degraded and may not achieve the high data rate requirements of the aerial device UL.

In the situation where the aerial device is gnostic (aware) of the direction of the serving cell, by either estimating it itself and/or by receiving it from the eNB, the aerial device can beam-steer the broadside towards the serving cell and maximize its DL receive power. The DL SINR improvement is dependent on the beam-width as shown in Figure 17.

In the UL, the beam-width of the aerial devices has little effect on their UL SINR, as is shown in Figure 18. At the same time, by turning away its beam from inter-cells, the aerial device now causes less UL interference, which is again a function of the used beam-width as shown in Figure 19.

In the situation where an aerial vehicle is not able to self-estimate the direction of the serving cell, this direction can be communicated to the aerial device via the serving cell sending estimates of the LOS Azimuth angle of Arrival (AoA) and the Zenith angle of Arrival (ZoA), which can be relative to a predefined coordination system, see Figure 20, which shows the LOS azimuth and zenith angles between the serving cell and the aerial device. The UE can then point towards that direction to improve the DL and UL SINR and reduce interference. After the initial communication of the AoA/ZoA angles, either the beam-steering towards the serving cell can be carried out by the UE based on its velocity and direction of travel (DoT), or the AoA/ZoA can be signalled periodically from the eNB.

Any interference mitigation technique may have to be activated as early as the RACH procedure. However, AoA/ZoA may be difficult to be communicated through the initial attachment steps (Msg2, Msg4). If so, the UE can perform synchronization via, for example, PSS/SSS processing and attachment via RACH as follows. Firstly, agnostic beamforming is activated to obtain an initial improvement on a metric such as the SINR. Secondly, the beam is steered or rotated until a serving cell is acquired. Next, the altitude is reduced until interference of any intra-cells is less severe. This could occur in the initial stage of the aerial devices' flight.

When attached, the eNB can assist the UE to find the LOS direction and further improve the UL and DL communication with the serving cell, and reduce the UL interference it causes to other UEs.

The aerial vehicle shall communicate its beamforming capabilities, for example, its beam-width, beam-steering and beam-tracking capabilities. For beam-width, the AV can communicate the 3dB beam-width and maximum attenuation in both the vertical and horizontal planes.

- The following list describes a high-level procedure and message exchange between the aerial vehicle and the eNB to enable the proposed functionalities to take place. The UE activates beamforming and performs cell acquisition. The UE might have to steer its beam until it is able to successfully receive DL signals from the serving cell. Upon connection, such as via RACH completion, and during Radio Resource Control (RRC) connection, the UE informs the eNB about its beamforming capabilities through the RRC UE capability information message. This may comprise the following beamforming properties such as AV-BeamformingEnabled is the aerial vehicle beamforming indicator;
- AV-H-Beamwidth is the 3 dB beam-width in the horizontal direction;
- AV-V-Beamwidth is the 3 dB beam-width in the vertical direction;
- AV-max-H-BeamAttenuation is the maximum antenna attenuation in the horizontal direction;
- AV-max-V-BeamAttenuation is the maximum antenna attenuation in the vertical direction;
- AV-BeamSteeringEnabled is the aerial vehicle beam-steering capability indicator; and
- AV-BeamTrackingEnabled is the aerial vehicle beam-tracking indicator.

Once beamforming capabilities have been received, in case of enabled beamforming and beam-steering capabilities, and if supported, the eNB can estimate and communicate the AoA/ZoA angles to the UE through signaling. Where the UE has signaled beamforming and beam-steering capabilities, but not beam-tracking capabilities, the eNB can periodically estimate and communicate the AoA/ZoA angles

to the UE through signaling so that the UE corrects its beam direction. The eNB can use the UEs beam-forming reported capabilities to estimate the level of UL interference the aerial is causing and determine if adaptation to its UL power transmission is needed and at which level.

A simpler embodiment of beam-steering at the AV side may be to consider that the aerial vehicle embeds by default several sectorized antenna. To illustrate, it is assume that a drone quadcopter (with four legs) will have one antenna per leg, which may further reduce the probability of having the antenna hidden during a flight event (yaw or roll or pitch with high angle). The AV could then select the antenna that provides the best SINR and conduct regular measurement on the other to anticipate handover when and if needed.

This approach can be achieved by at least one of the following. Relying on AV (UE) decision only, with no network implication and extending the existing LTE feature of antenna selection to support more antennas and aerial case

The network may need to be able to detect any aerial devices that have not properly reported that they are aerial devices, in order to protect the network's performance degradation of any unhandled interference introduced by non-reported aerial devices. This may require eNBs to be able to efficiently detect if a UE is an aerial vehicle and act accordingly. The eNB could use one or more methods for the aerial vehicle detection.

The eNB could estimate the ZoA and based on the outcome can set a ZoA limit after which the UE device is considered to be an aerial device. This can be dependent on, for example, the eNB antenna height, the local environment, the max/average building height, and other similar parameters. However, the ZoA criteria to refuse connection may be standardized so that all eNBs follow the same criteria for rejecting aerial devices.

Angle spread (AS) estimation is not an efficient standalone method for aerial vehicle detection because ground UEs can also experience low AS when e.g. in LOS. However, AS estimation can be an ideal complementary method to other aerial device detection methods because aerial devices have higher LOS probability which results to very narrow angle spreads. If other detection methods have indicated a UE is an aerial device, AS estimation can act as a sanity check, e.g. if the estimated AS

is low then the eNB can be sure the UE is an aerial device. If the AS is high then the eNB can re-estimate the ZoA and AS before making a decision for connection refusal. The angle spread range in which a UE cannot be considered an aerial device may be standardized.

While ZoA estimation shows the zenith direction of a device, 3D positioning can directly provide the position estimate of a device, including its z-axis coordinate. Based on this information, the eNB can add another criterion for deciding if a UE is an aerial device or not. Observed Time Difference of Arrival (OTDOA) is a two-dimensional method for estimating the position of a UE in the terrestrial x-y plane. It is based on the intersection of hyperbolas formed by $t_{i,0} = t_i - t_0$, where $t_{i,0}$ is the derived time difference between a cell *i* and a reference cell 0. At least three timing measurements from geographically dispersed eNBs with good geometry may be needed to solve for two coordinates (x, y) of the UE. This method is designed with the assumption that UEs are moving within the terrestrial plane. For aerial devices this assumption may not always be true. Thus, for OTDOA to be used as a 3D positioning method there is a need for at least one additional cell timing measurement to solve for three coordinates (x, y, z). This is because $t_{i,0} = t_i - t_0$ forms 3D surfaces instead of 2D hyperbolas. Thus, the eNB may be required to handle this geometry problem in 3 dimensions. There are some similarities to the four sphere intersection positioning method used in Global Positioning Systems (GPS).

Velocity estimation can provide additional information in order for an eNB to differentiate an aerial device from an outdoor stationary UE in elevated areas (e.g. antenna technician), since aerial devices are expected to be moving in a higher velocity. Velocity estimation can be derived by a time derivative of available parameters such as AoA, ZoA (through AoZ/ZoA estimation) or x, y, z (through positioning). Doppler shift estimation could be another method for velocity estimation, (e.g. based on rotation of the reference signals.

Path-loss estimation can provide additional information in order for an eNB to differentiate an aerial device from an indoor UE which is located within a high building. Indoor UEs are expected to have a higher path-loss value due to penetration losses.

The eNB can additionally process the RSRP/RSRQ reports for the intra-frequency cells that a UE makes and then use this to decide if the reported values are too high

for a ground UE. This information may be combined with other criteria to decide if a UE is actually an aerial device.

The network may also exploit the 3D MIMO feature 3GPP has introduced and from this determine which elevation angle provides the best communication path with the UE and use this information for the decision to mark a UE as an aerial device or not.

eNBs that have detected the presence of an aerial vehicle which has not indicated as being an aerial vehicle shall be able to communicate this information over the X2-interface to neighboring cells. These cells might be potential serving cells of the aerial device when a hand-over occurs. Thus, this information may be shared between potential serving cells of the aerial device so that any necessary interference mitigation actions take place.

Another possibility for the network to detect aerial devices would be to use explicit signaling. Every AV should declare themselves as being an aerial device. This can be done by in a number of different ways. For example, by extending an existing UE capability to indicate an aerial vehicle or by introducing a new UE capability, such as the following:

isAerialVehicle
Indicates whether the UE is an aerial vehicle flying above the terrestrial environment.

However, indicating that something is an aerial device may not always be interpreted as causing or experiencing excess interference. The network can set and broadcast (e.g. in the System Information Block (SIB)) an altitude threshold above which a UE shall be considered an aerial. The altitude threshold can be dependent on at least the following criteria: eNB antenna height; network environment (macro-cell, micro-cell, etc.); and other environment properties (average building height, street width, etc.)

By knowing its altitude, when the UE exceeds this threshold, it can inform the eNB via signaling that it is now flying above that threshold. It can also indicate the opposite, i.e. when it is no longer flying above that threshold.

Alternatively, two indications can be introduced. A first which informs of its capability of flying above the terrestrial environment and another which informs that the aerial is actually flying above the altitude threshold.

isAerialVehicle Indicates whether the UE is an aerial vehicle capable of flying above the terrestrial environment.
aerialVehicleAboveAltitudeThreshold Indicates whether the aerial vehicle is flying above the altitude threshold set by the network. This threshold indicates that excess interference might be caused and experienced by the UE.

The various examples are just that and are not intended to be limitative in any way. There are many different examples, schemes and methods that are included within the present invention as will be clear to those skilled in the art. The present invention can apply to any scenario where aerial devices may be found and are intended to use a wireless communications system.

Although not shown in detail any of the devices or apparatus that form part of the network may include at least a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method of any aspect of the present invention. Further options and choices are described below.

The signal processing functionality of the embodiments of the invention especially the gNB and the UE may be achieved using computing systems or architectures known to those who are skilled in the relevant art. Computing systems such as, a desktop, laptop or notebook computer, hand-held computing device (PDA, cell phone, palmtop, etc.), mainframe, server, client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or environment can be used. The computing system can include one or more processors which can be implemented using a general or special-purpose processing engine such as, for example, a microprocessor, microcontroller or other control module.

The computing system can also include a main memory, such as random access memory (RAM) or other dynamic memory, for storing information and instructions to be executed by a processor. Such a main memory also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor. The computing system may likewise include a read only memory (ROM) or other static storage device for storing static information and instructions for a processor.

The computing system may also include an information storage system which may include, for example, a media drive and a removable storage interface. The media drive may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an optical disk drive, a compact disc (CD) or digital video drive (DVD) read or write drive (R or RW), or other removable or fixed media drive. Storage media may include, for example, a hard disk, floppy disk, magnetic tape, optical disk, CD or DVD, or other fixed or removable medium that is read by and written to by media drive. The storage media may include a computer-readable storage medium having particular computer software or data stored therein.

In alternative embodiments, an information storage system may include other similar components for allowing computer programs or other instructions or data to be loaded into the computing system. Such components may include, for example, a removable storage unit and an interface , such as a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory module) and memory slot, and other removable storage units and interfaces that allow software and data to be transferred from the removable storage unit to computing system.

The computing system can also include a communications interface. Such a communications interface can be used to allow software and data to be transferred between a computing system and external devices. Examples of communications interfaces can include a modem, a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a universal serial bus (USB) port), a PCMCIA slot and card, etc. Software and data transferred via a communications interface are in the form of signals which can be electronic,

electromagnetic, and optical or other signals capable of being received by a communications interface medium.

In this document, the terms 'computer program product', 'computer-readable medium' and the like may be used generally to refer to tangible media such as, for example, a memory, storage device, or storage unit. These and other forms of computer-readable media may store one or more instructions for use by the processor comprising the computer system to cause the processor to perform specified operations. Such instructions, generally referred to as 'computer program code' (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system to perform functions of embodiments of the present invention. Note that the code may directly cause a processor to perform specified operations, be compiled to do so, and/or be combined with other software, hardware, and/or firmware elements (e.g., libraries for performing standard functions) to do so.

The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory

In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system using, for example, removable storage drive. A control module (in this example, software instructions or executable computer program code), when executed by the processor in the computer system, causes a processor to perform the functions of the invention as described herein.

Furthermore, the inventive concept can be applied to any circuit for performing signal processing functionality within a network element. It is further envisaged that, for example, a semiconductor manufacturer may employ the inventive concept in a design of a stand-alone device, such as a microcontroller of a digital signal processor (DSP), or application-specific integrated circuit (ASIC) and/or any other sub-system element.

It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to a single processing logic. However, the inventive concept may equally be implemented by way of a plurality of different functional units and processors to provide the signal processing functionality. Thus, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organisation.

Aspects of the invention may be implemented in any suitable form including hardware, software, firmware or any combination of these. The invention may optionally be implemented, at least partly, as computer software running on one or more data processors and/or digital signal processors or configurable module components such as FPGA devices. Thus, the elements and components of an embodiment of the invention may be physically, functionally and logically implemented in any suitable way. Indeed, the functionality may be implemented in a single unit, in a plurality of units or as part of other functional units.

Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' does not exclude the presence of other elements or steps.

Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather indicates that the feature is equally applicable to other claim categories, as appropriate.

Furthermore, the order of features in the claims does not imply any specific order in which the features must be performed and in particular the order of individual steps in

a method claim does not imply that the steps must be performed in this order. Rather, the steps may be performed in any suitable order. In addition, singular references do not exclude a plurality. Thus, references to 'a', 'an', 'first', 'second', etc. do not preclude a plurality.

Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' or "including" does not exclude the presence of other elements.

Claims

1. A method for mitigating interference in communications between a plurality of wireless communications devices wherein at least a first wireless communications device is moving within a Radio Access Network, the method comprising:

identifying the first moving wireless device to be an aerial device based on one or a combination of an Interference Coordination method; a beam forming and steering process and one or more of a collection of criteria indicating a location of the first moving device.

2. The method of claim 1, wherein the network performance method comprises at least one of increasing the power of a predetermined part of a signal in the communication; decreasing the power of interfering signals; decreasing a number of interfering cells in the vicinity of the aerial device.

3. The method of claim 2, further comprising using at least one of joint transmission; muting one or more interfering cells coordinated scheduling; beamforming and dynamic point selection to achieve the interference coordination method.

4. The method of any one of the preceding claim, further comprising:

when an aerial device enters a cell in a network determining a quality metric based on a channel quality of the aerial device;

determining a number of serving cell to be used for a first function based on a predicted position of the aerial device;

determining a number of muted cells to be used for a second function based on the predicted position of the aerial device;

coordinating the control and data requirements of the aerial device based on using one of the determined number of first or second serving cells.

5. The method of any one of the preceding claim, wherein the aerial device is capable of beam forming and steering process to enable the antenna to be steered to a predetermined serving cell.

6. The method of claim 5, further comprising activating beam forming such that a metric is improved; acquiring the serving cell; and adjusting to a line of sight of the beam such that interference in the communication is reduced.

7. The method of any preceding claims, wherein the aerial device includes a plurality of antennae and the method relies on the aerial device to select the antenna which experiences the lowest level of interference in the communication.

8. The method of any one of the preceding claim, wherein the collection of criteria comprises one or more of: an angle of arrival estimation; an angle spread; estimation; a positioning estimation; a estimation of the velocity of the aerial device; a path loss estimation; scheme for reporting intra frequency cells; a MIMO measurement; an aerial vehicle indicator; and explicit signalling.

9. The method of any preceding claims, wherein the first moving wireless device is a drone

10. The method of any one of the preceding claim wherein the Radio Access Network is a New Radio/5G network.

11. A user equipment, UE, apparatus comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 1-9.

12. A user equipment, according to claims 10, wherein the user equipment is an aerial device such as a drone.

13. A base station, BS, apparatus comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 1-9

14. A non-transitory computer readable medium having computer readable instructions stored thereon for execution by a processor to perform the method according to any of claims 1-9.

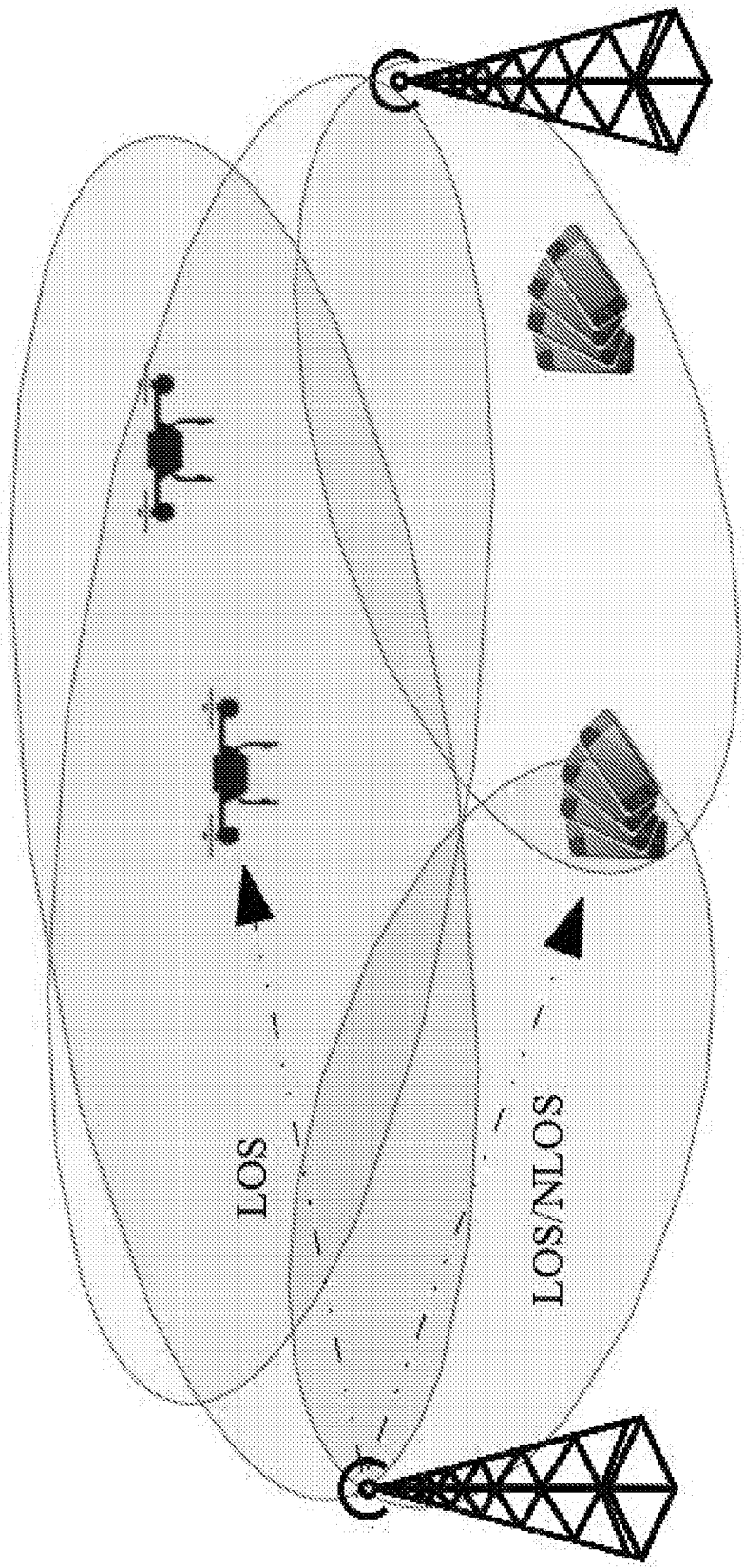


Figure 1

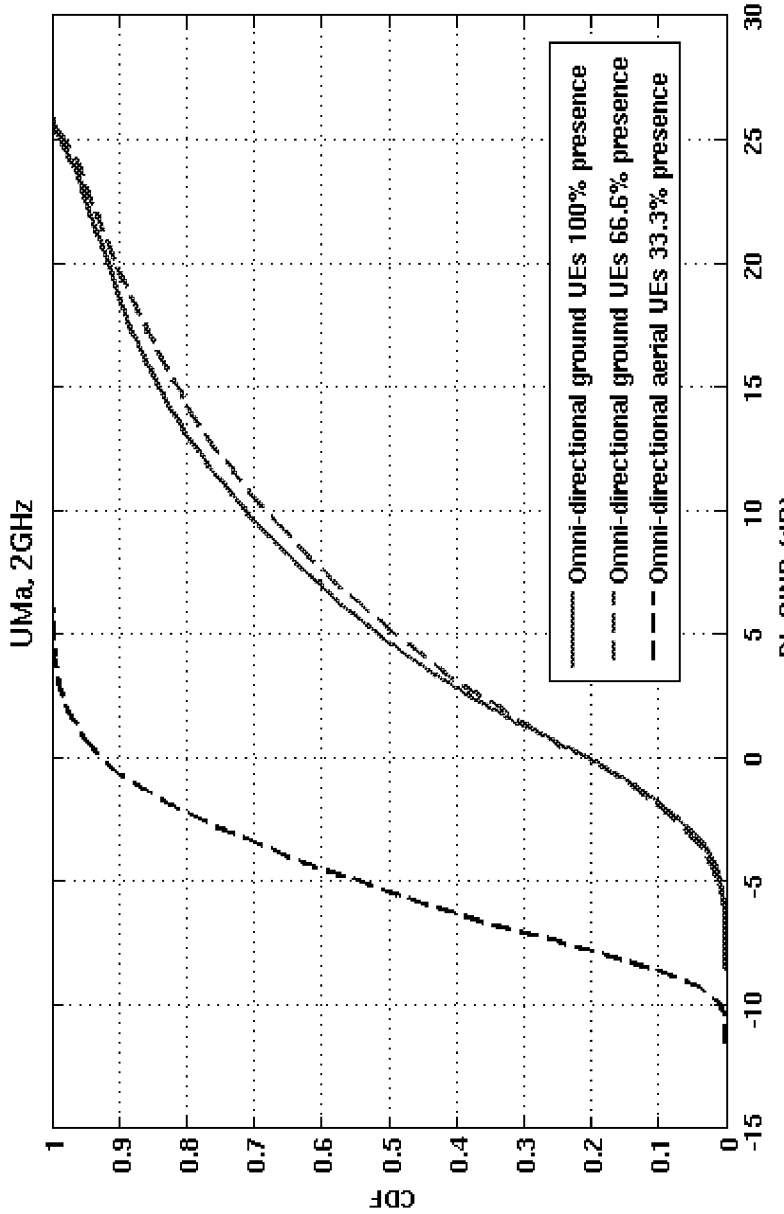

UMa, 2GHz
CDF
DL SINR (dB)
Omni-directional ground UEs 100% presence
Omni-directional ground UEs 66.6% presence
Omni-directional aerial UEs 33.3% presence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-15
-10
-5
0
5
10
15
20
25
30

Figure 2

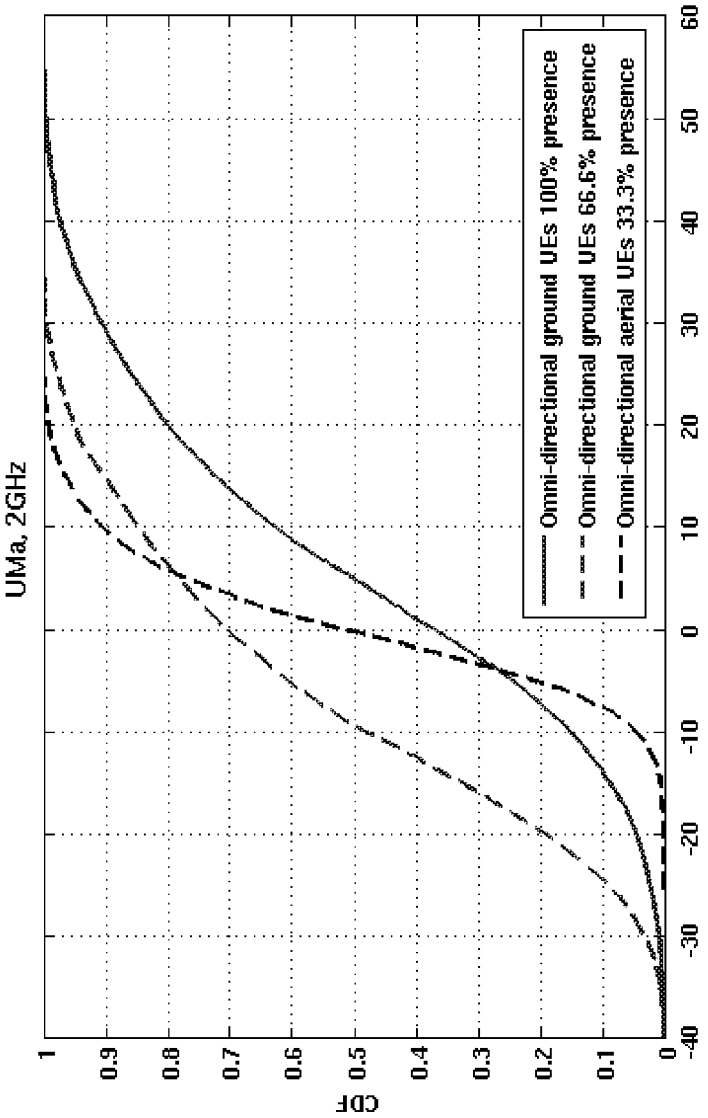

UMa, 2GHz
CDF
UL SINR (dB)
Omni-directional ground UEs 100% presence
Omni-directional ground UEs 66.6% presence
Omni-directional aerial UEs 33.3% presence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-40
-30
-20
-10
0
10
20
30
40
50
60

Figure 3

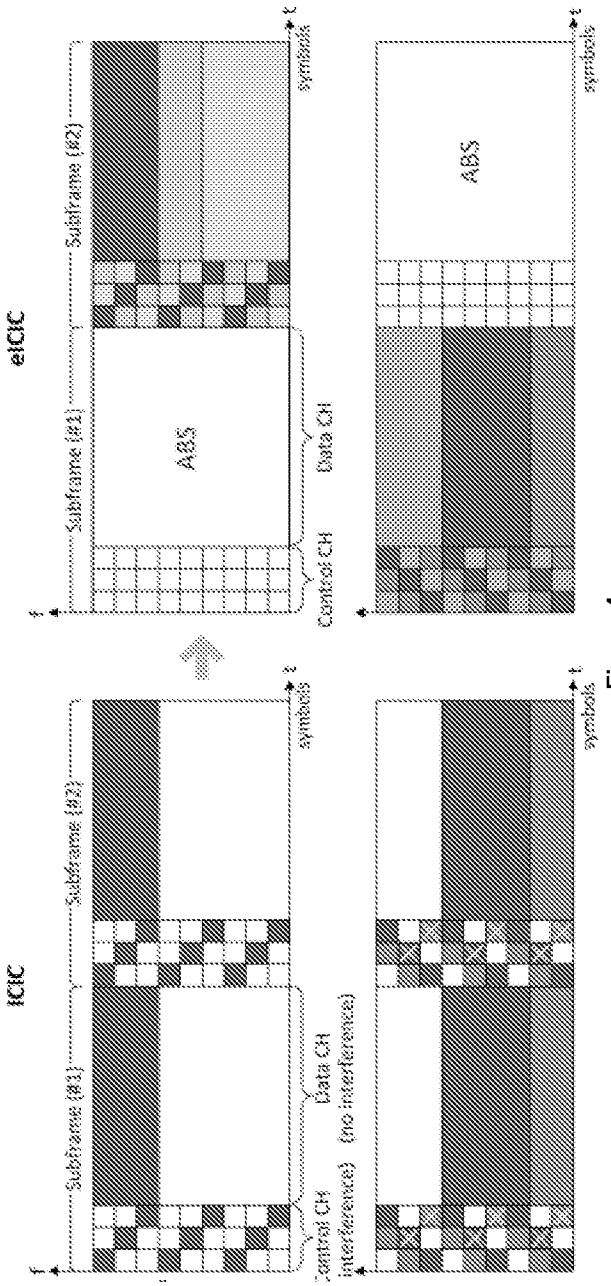

eICIC
Subframe (#1)
Subframe (#2)
ABS
Control CH
Data CH
symbols
t
f
ICIC
Control CH
(interference)
Data CH
(no interference)

Figure 4

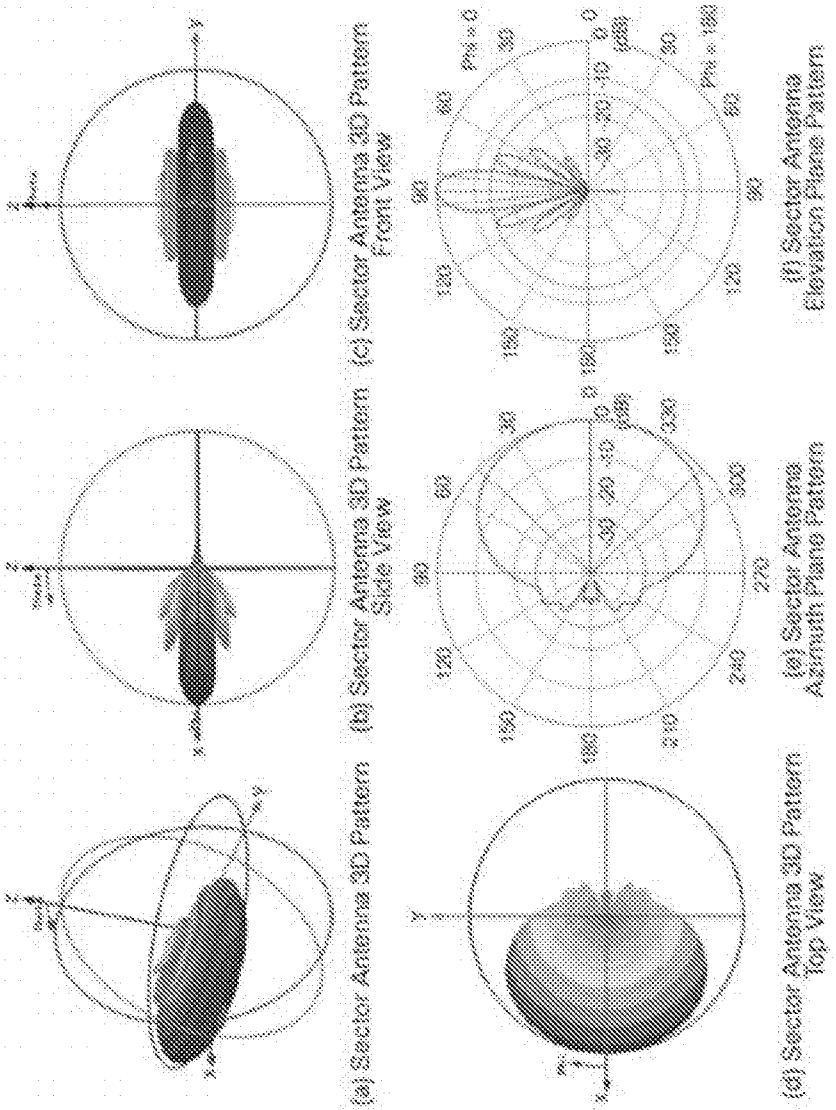

(a) Sector Antenna 3D Pattern
(b) Sector Antenna 3D Pattern Side View
(c) Sector Antenna 2D Pattern Front View
(d) Sector Antenna 3D Pattern Top View
(e) Sector Antenna Azimuth Plane Pattern
(f) Sector Antenna Elevation Plane Pattern

Figure 5

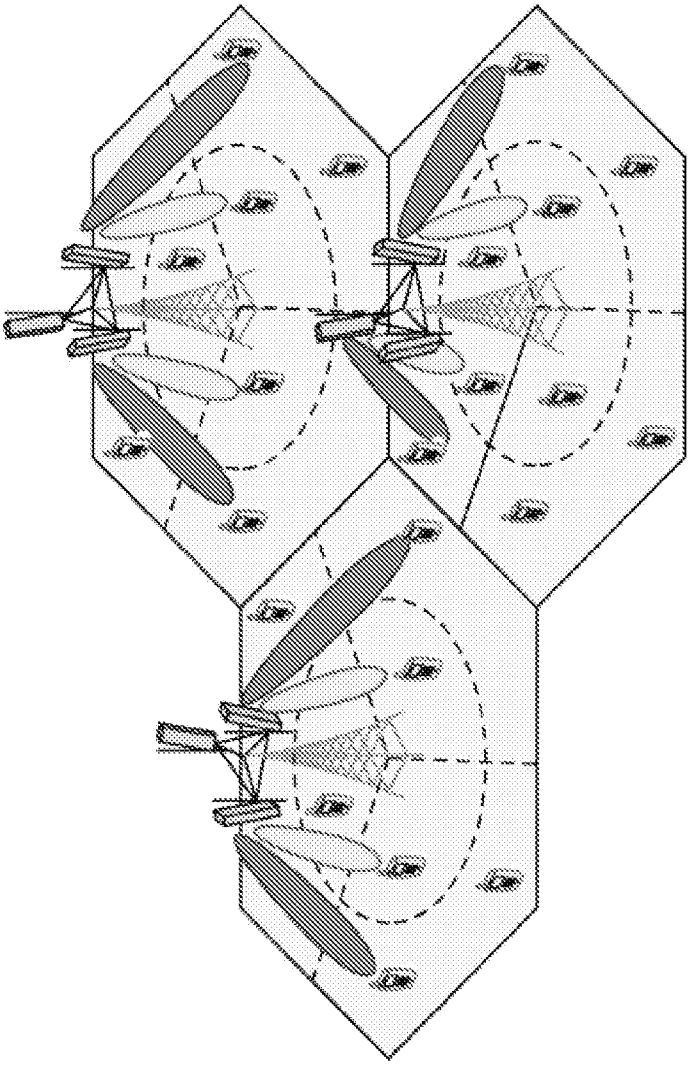


Figure 6

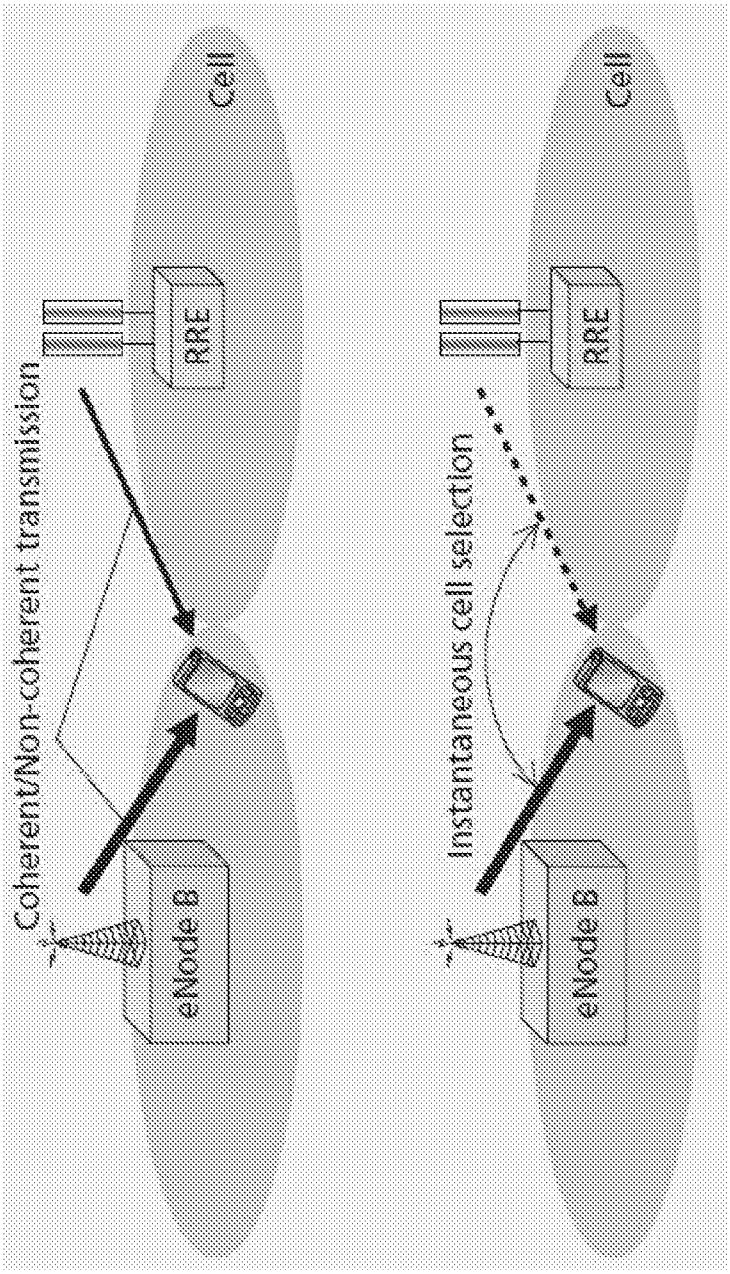

Coherent/Non-coherent transmission
Cell
RRE
eNode B
Instantaneous cell selection
Cell
RRE
eNode B

Figure 7

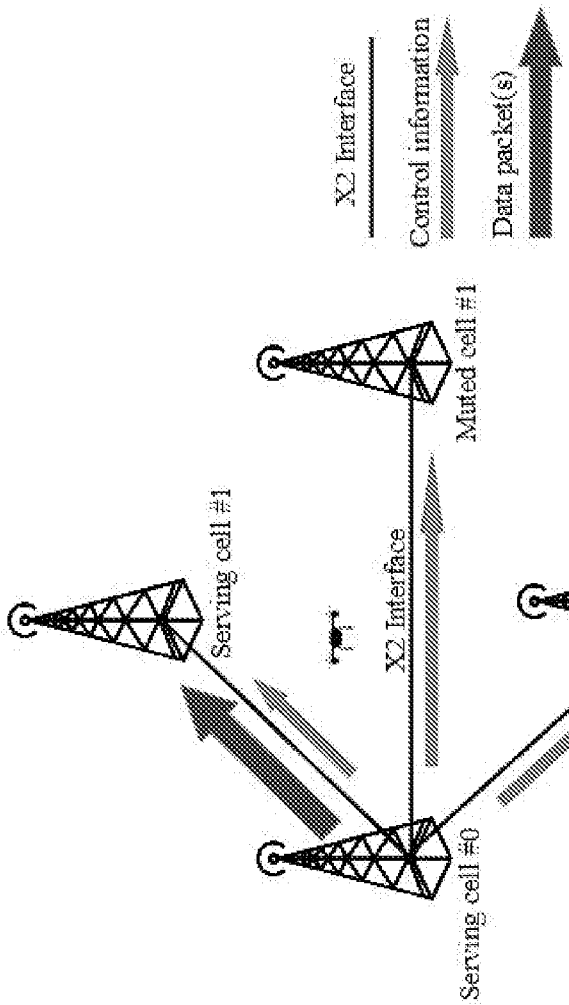

X2 Interface
Control information
Data packet(s)
Muted cell #1
Serving cell #1
X2 Interface
Muted cell #0
Serving cell #0

Figure 8

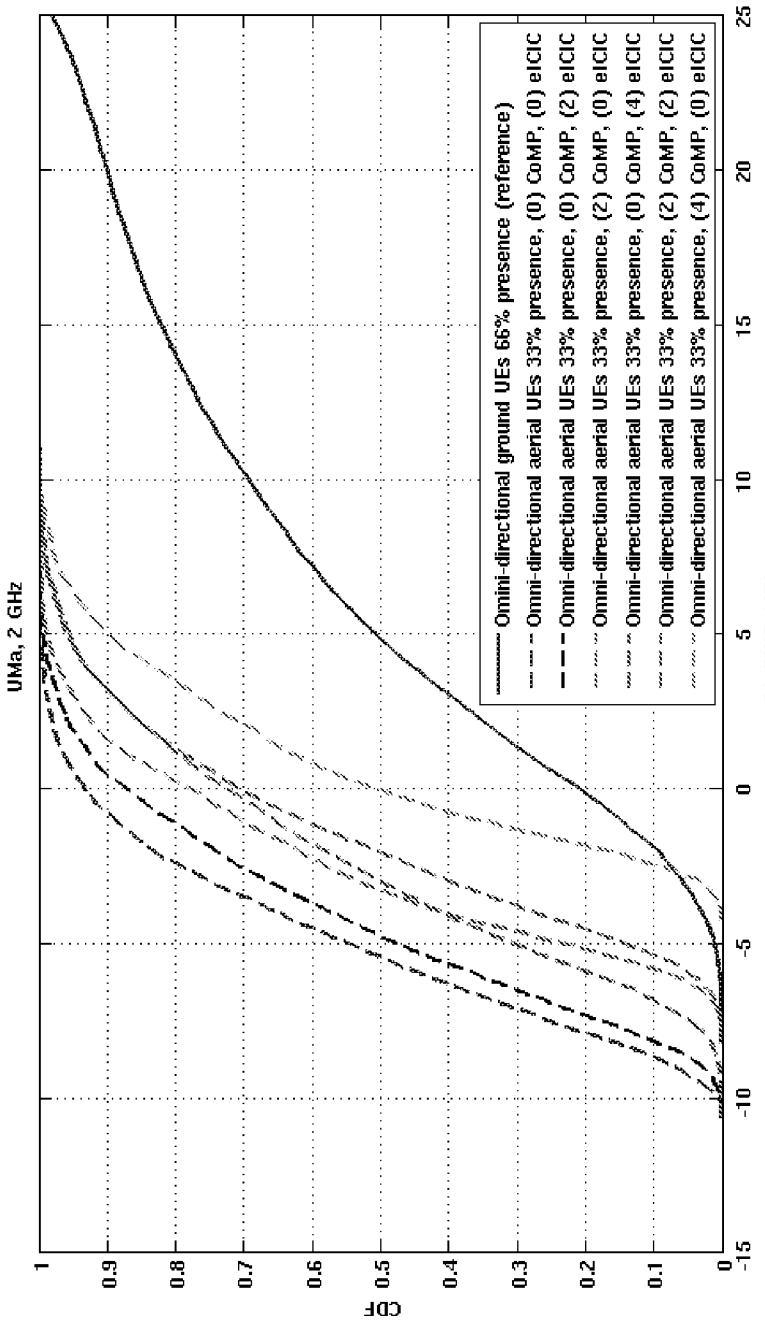

UMa, 2 GHz
CDF
DL SINR (dB)
Omini-directional ground UEs 66% presence (reference)
Omni-directional aerial UEs 33% presence, (0) CoMP, (0) eICIC
Omni-directional aerial UEs 33% presence, (0) CoMP, (2) eICIC
Omni-directional aerial UEs 33% presence, (2) CoMP, (0) eICIC
Omni-directional aerial UEs 33% presence, (0) CoMP, (4) eICIC
Omni-directional aerial UEs 33% presence, (2) CoMP, (2) eICIC
Omni-directional aerial UEs 33% presence, (4) CoMP, (0) eICIC

Figure 9

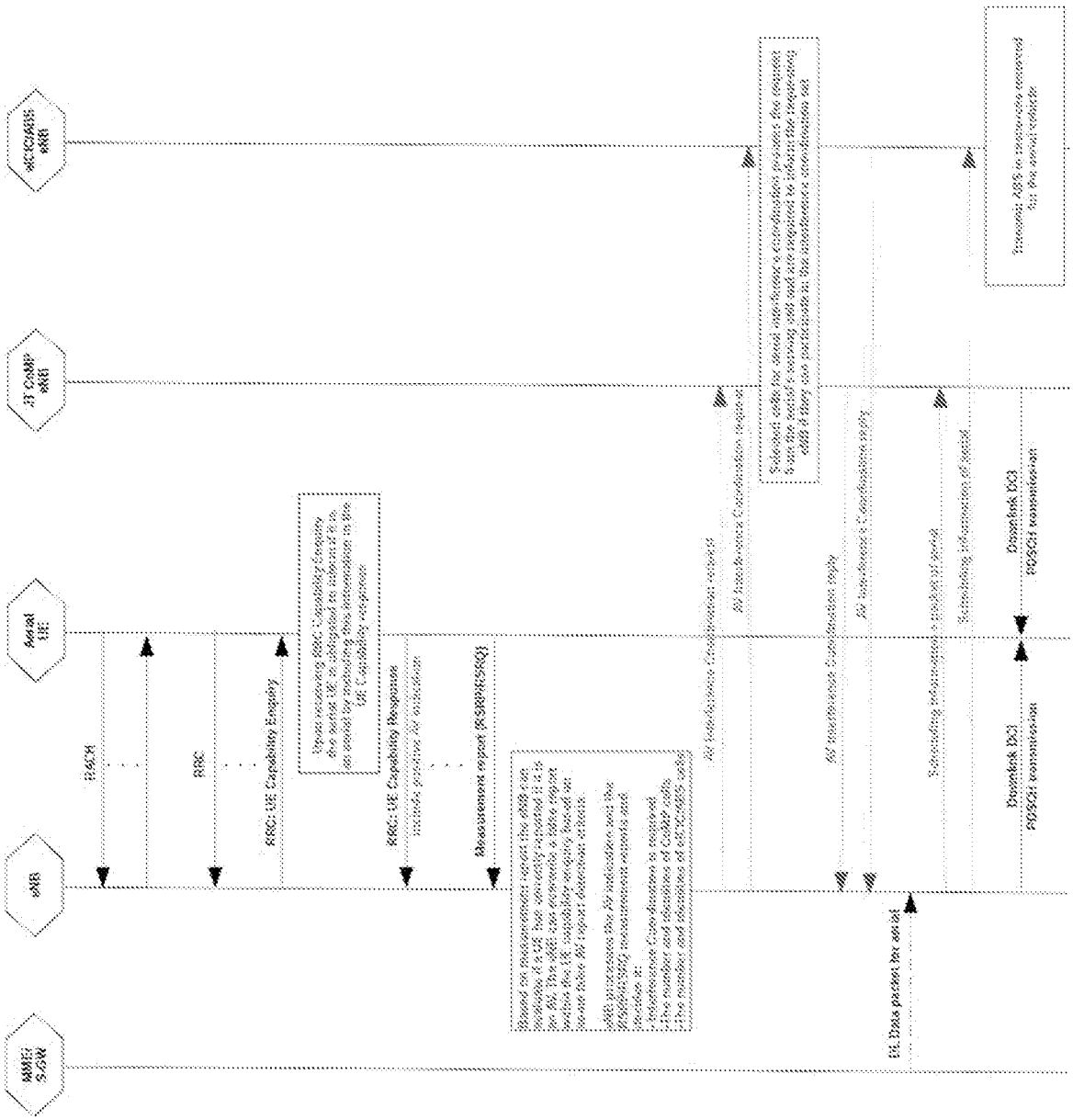

MME/ S-GW
eNB
Aerial UE
JT CoMP eNB
Access eNB
RRC
RRC: UE Capability Enquiry
RRC: UE Capability Response
Measurement report (RSRP/RSRQ)
Downlink DCI
PDSCH transmission
Downlink DCI
PDSCH transmission

Figure 10

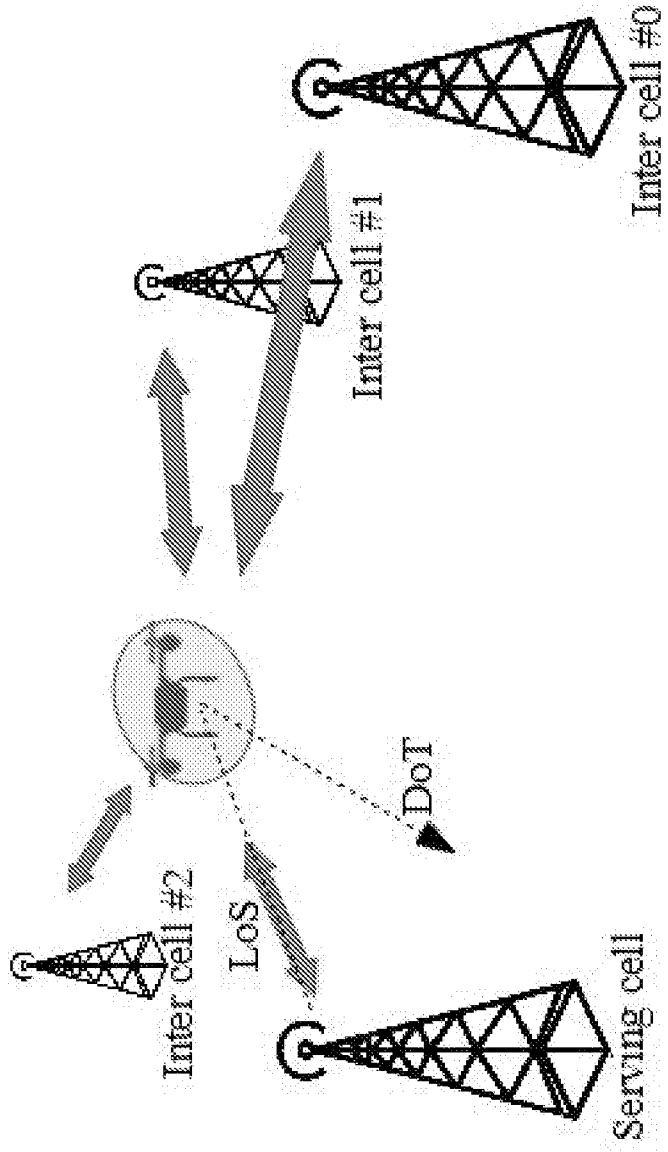


Figure 11

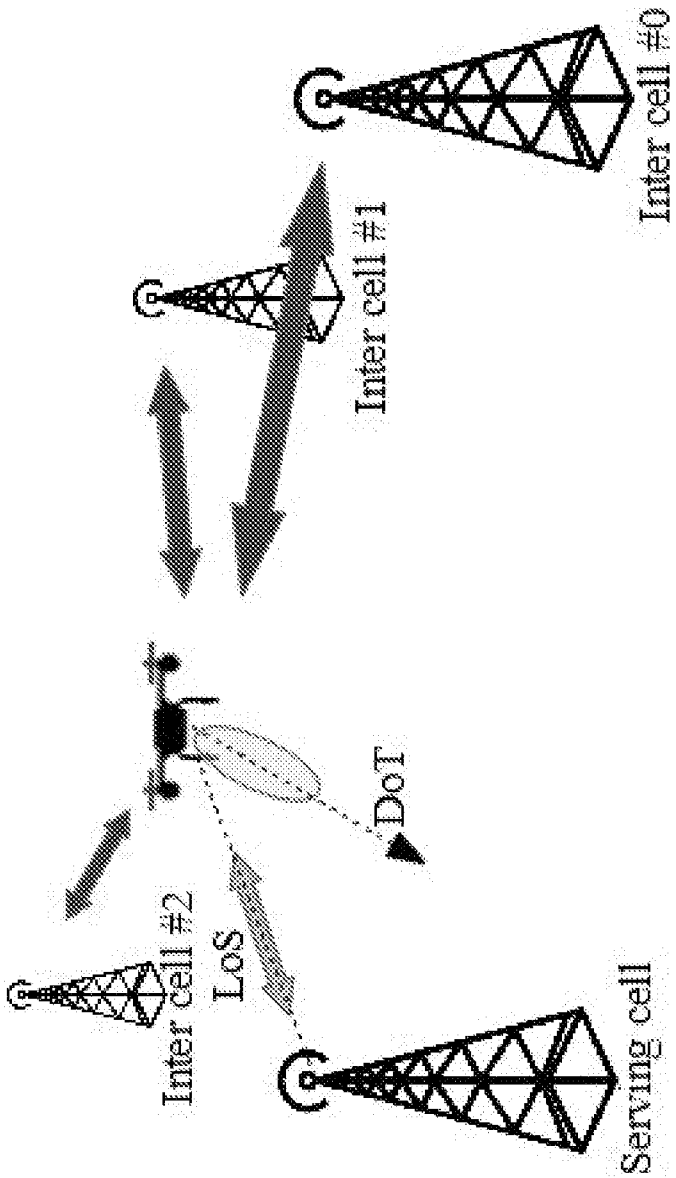


Figure 12

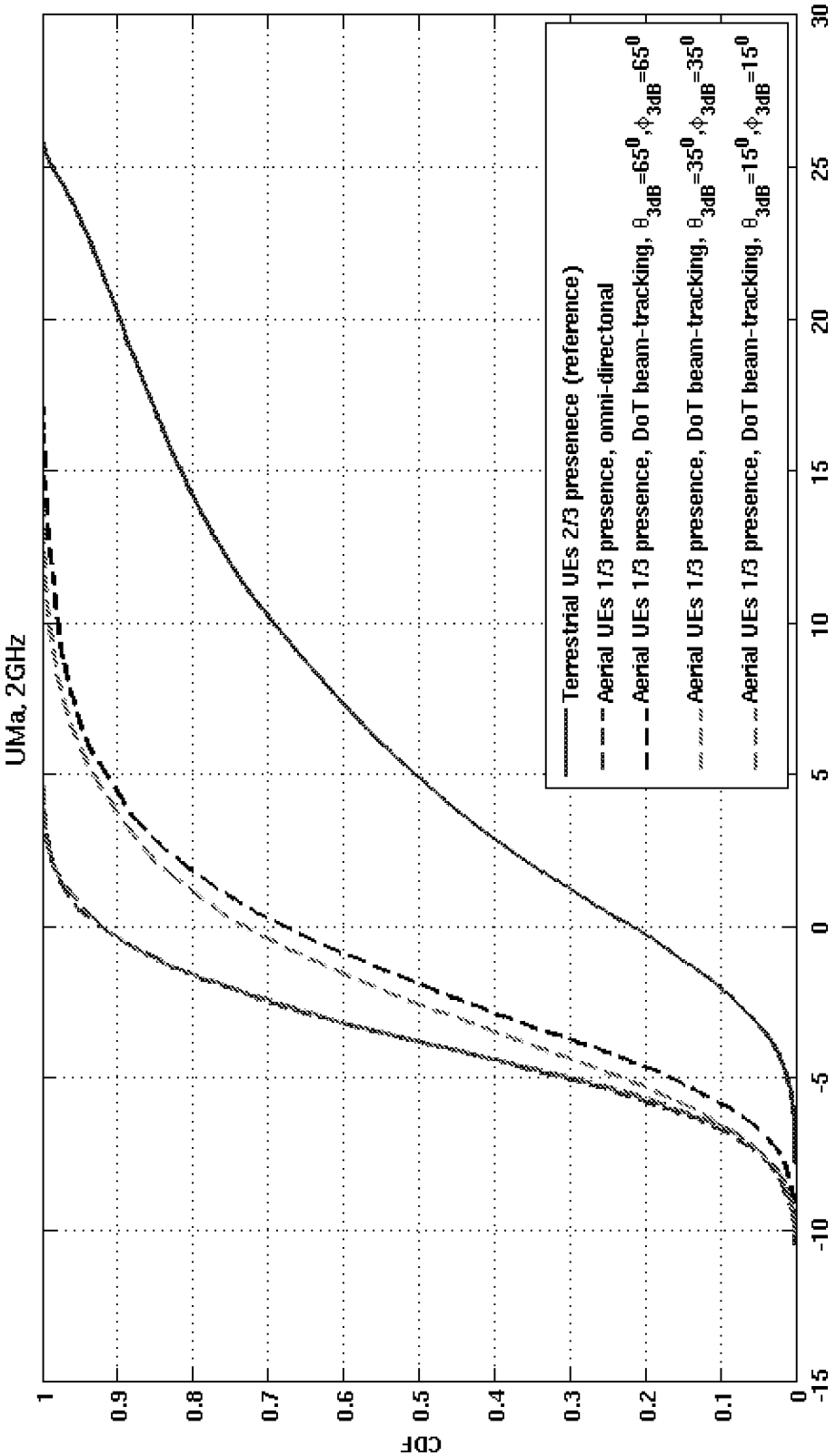

UMa, 2GHz
CDF
DL SINR (dB)
Terrestrial UEs 2/3 presenece (reference)
Aerial UEs 1/3 presence, omni-directional
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=65⁰,ϕ3dB=65⁰
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=35⁰,ϕ3dB=35⁰
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=15⁰,ϕ3dB=15⁰

Figure 13

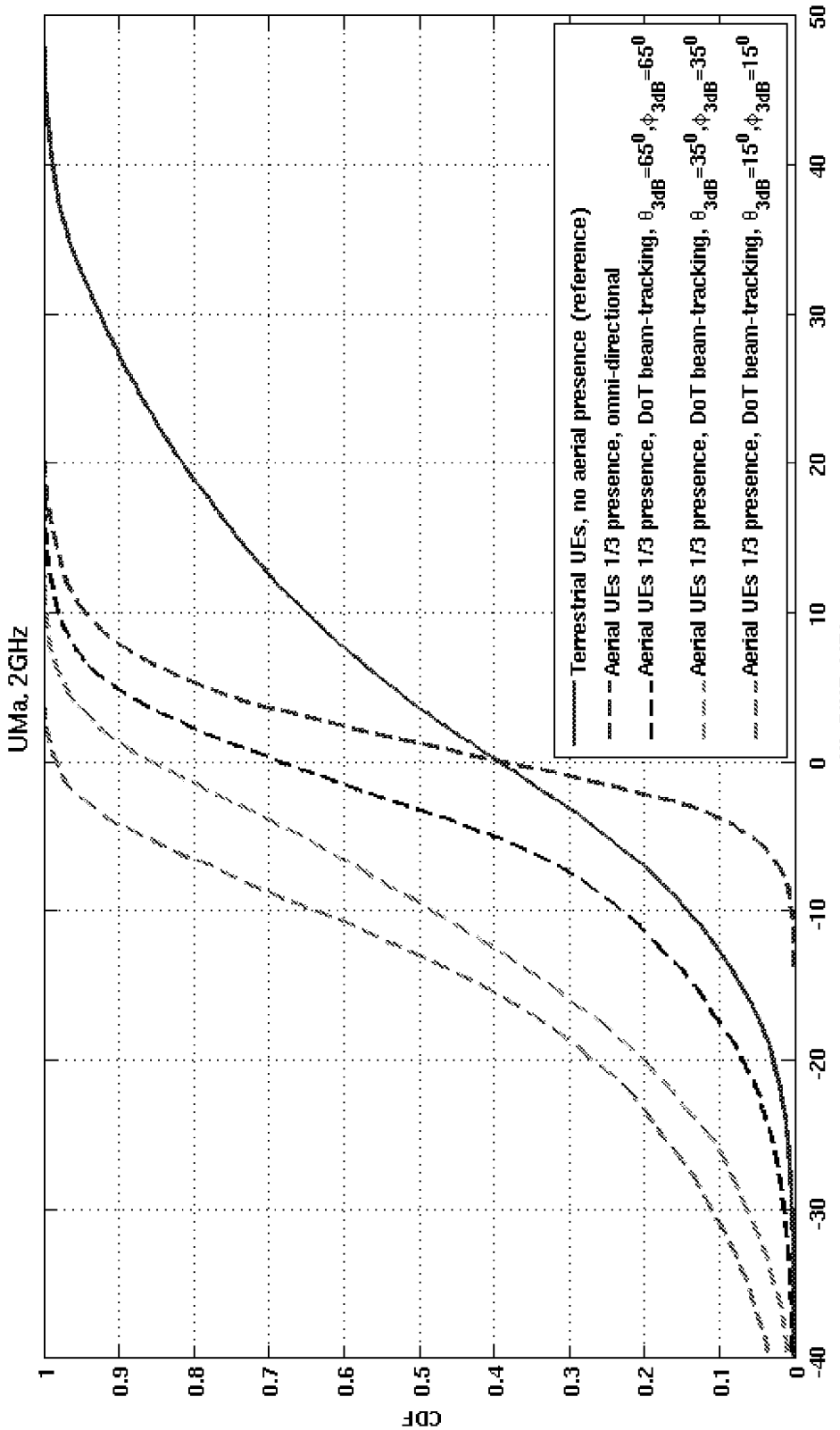

UMa, 2GHz
CDF
UL SINR (dB)
Terrestrial UEs, no aerial presence (reference)
Aerial UEs 1/3 presence, omni-directional
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=65°,ϕ3dB=65°
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=35°,ϕ3dB=35°
Aerial UEs 1/3 presence, DoT beam-tracking, θ3dB=15°,ϕ3dB=15°

Figure 14

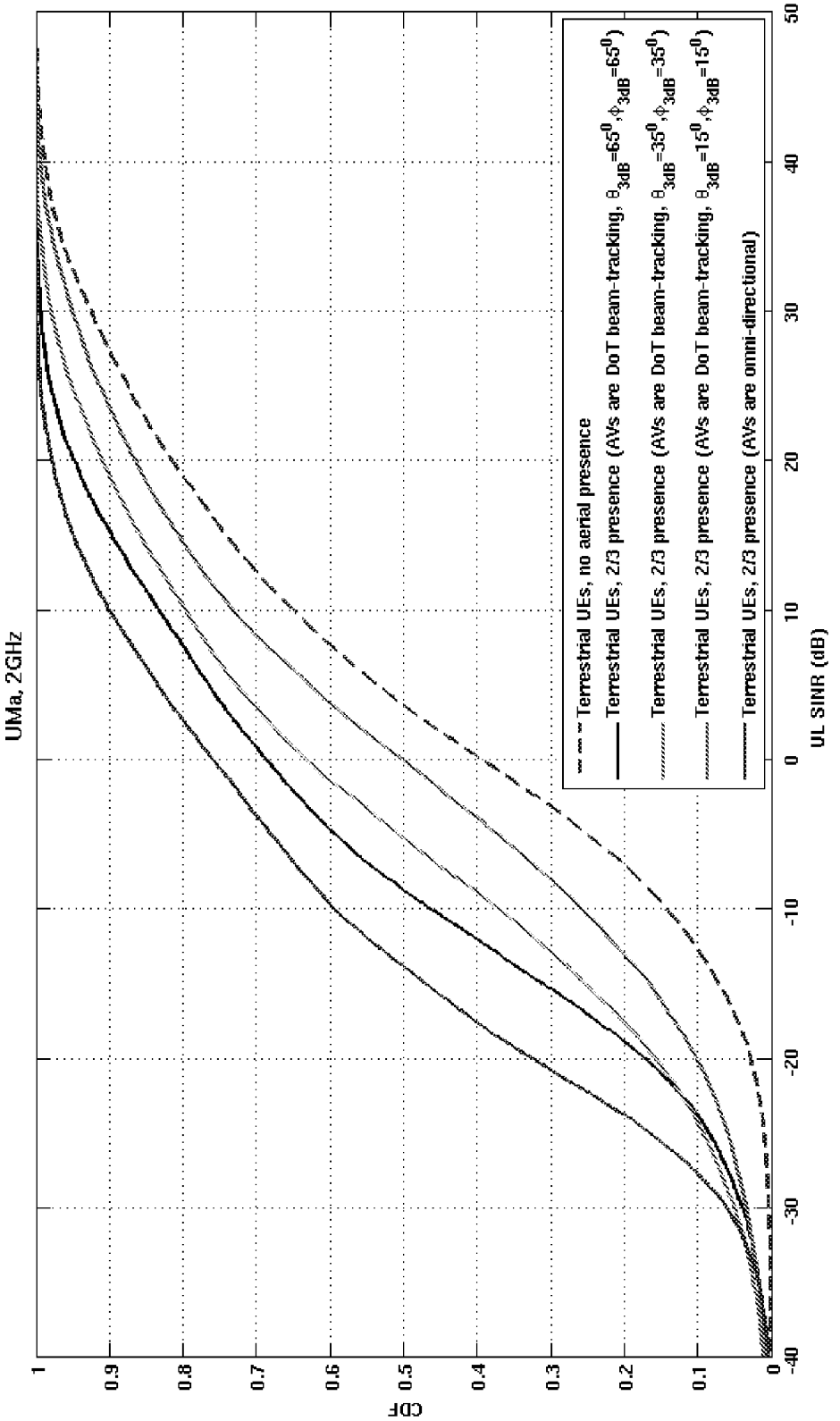

UMa, 2GHz
CDF
UL SINR (dB)
Terrestrial UEs, no aerial presence
Terrestrial UEs, 2/3 presence (AVs are DoT beam-tracking, θ3dB=65°,Φ3dB=65°)
Terrestrial UEs, 2/3 presence (AVs are DoT beam-tracking, θ3dB=35°,Φ3dB=35°)
Terrestrial UEs, 2/3 presence (AVs are DoT beam-tracking, θ3dB=15°,Φ3dB=15°)
Terrestrial UEs, 2/3 presence (AVs are omni-directional)

Figure 15

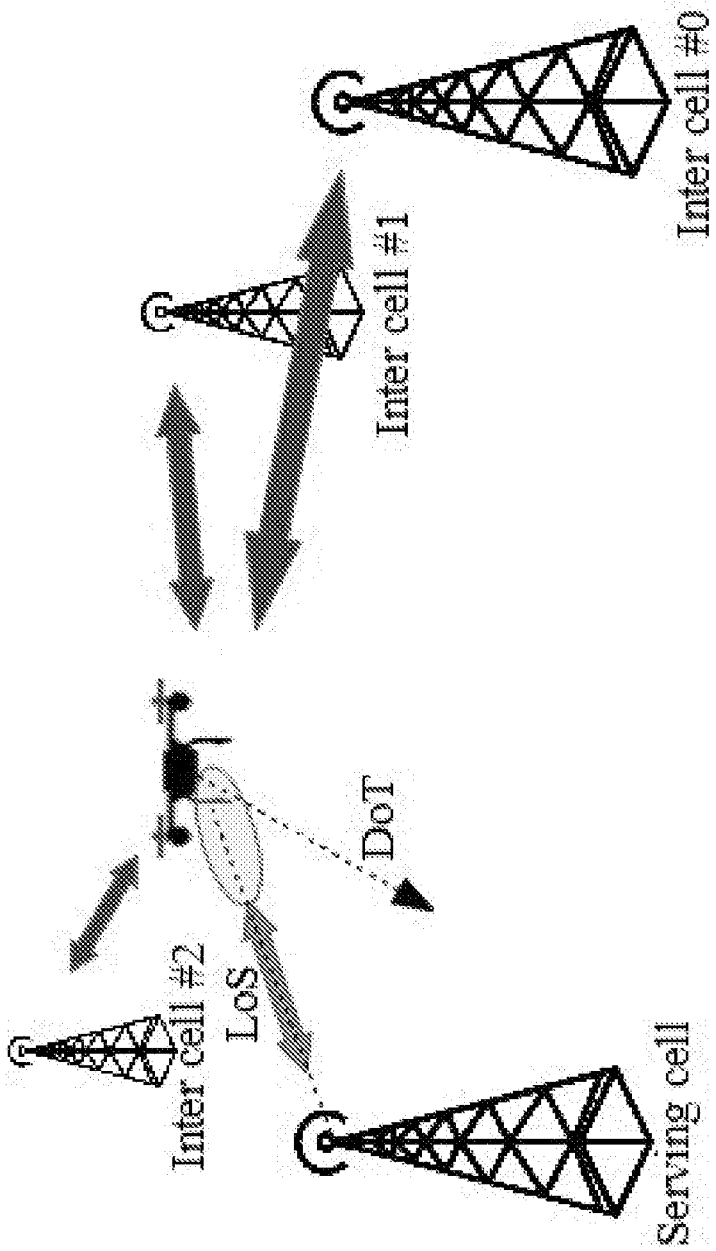


Figure 16

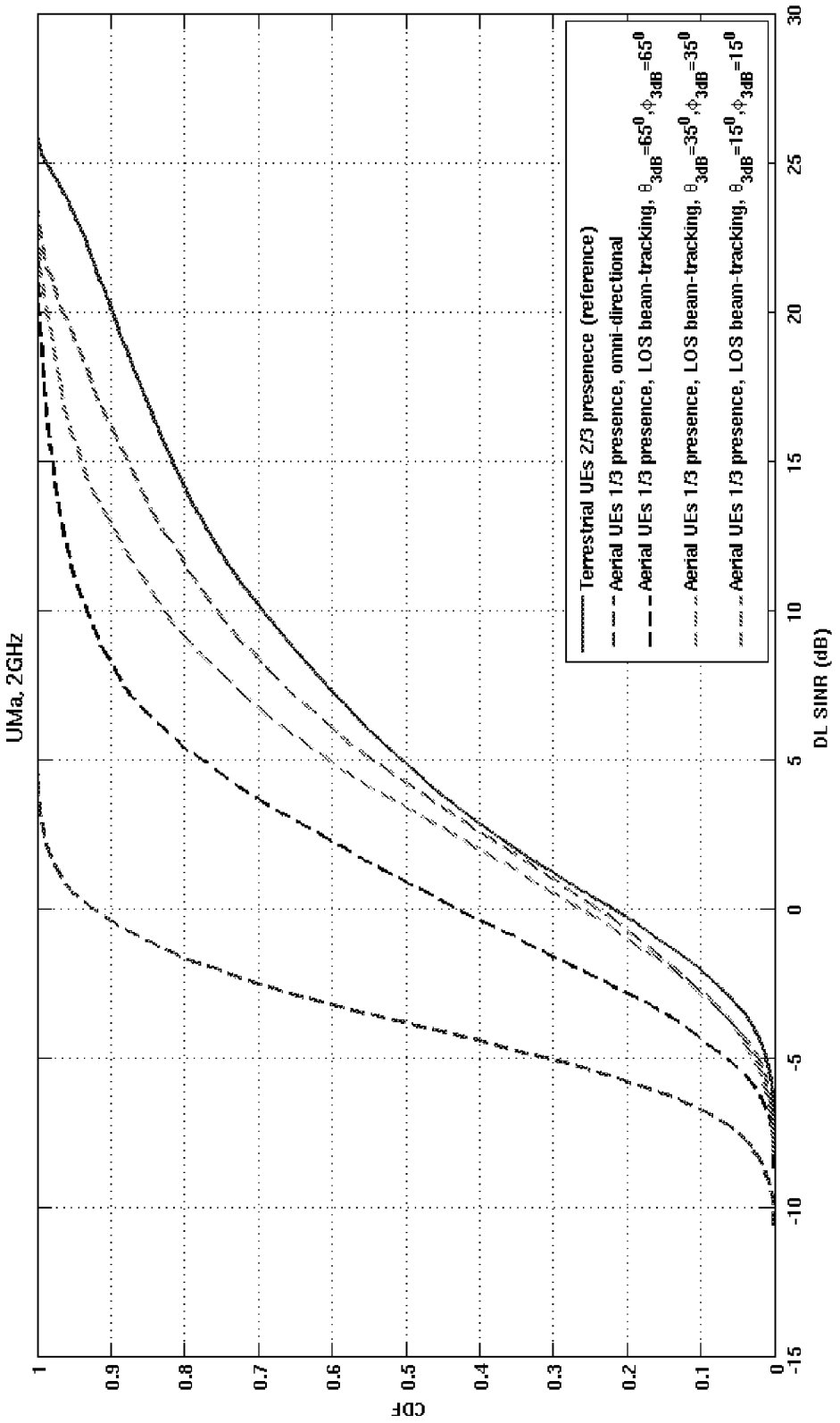

UMa, 2GHz
CDF
DL SINR (dB)
Terrestrial UEs 2/3 presenece (reference)
Aerial UEs 1/3 presence, omni-directional
Aerial UEs 1/3 presence, LOS beam-tracking, θ3dB=65°,ϕ3dB=65°
Aerial UEs 1/3 presence, LOS beam-tracking, θ3dB=35°,ϕ3dB=35°
Aerial UEs 1/3 presence, LOS beam-tracking, θ3dB=15°,ϕ3dB=15°

Figure 17

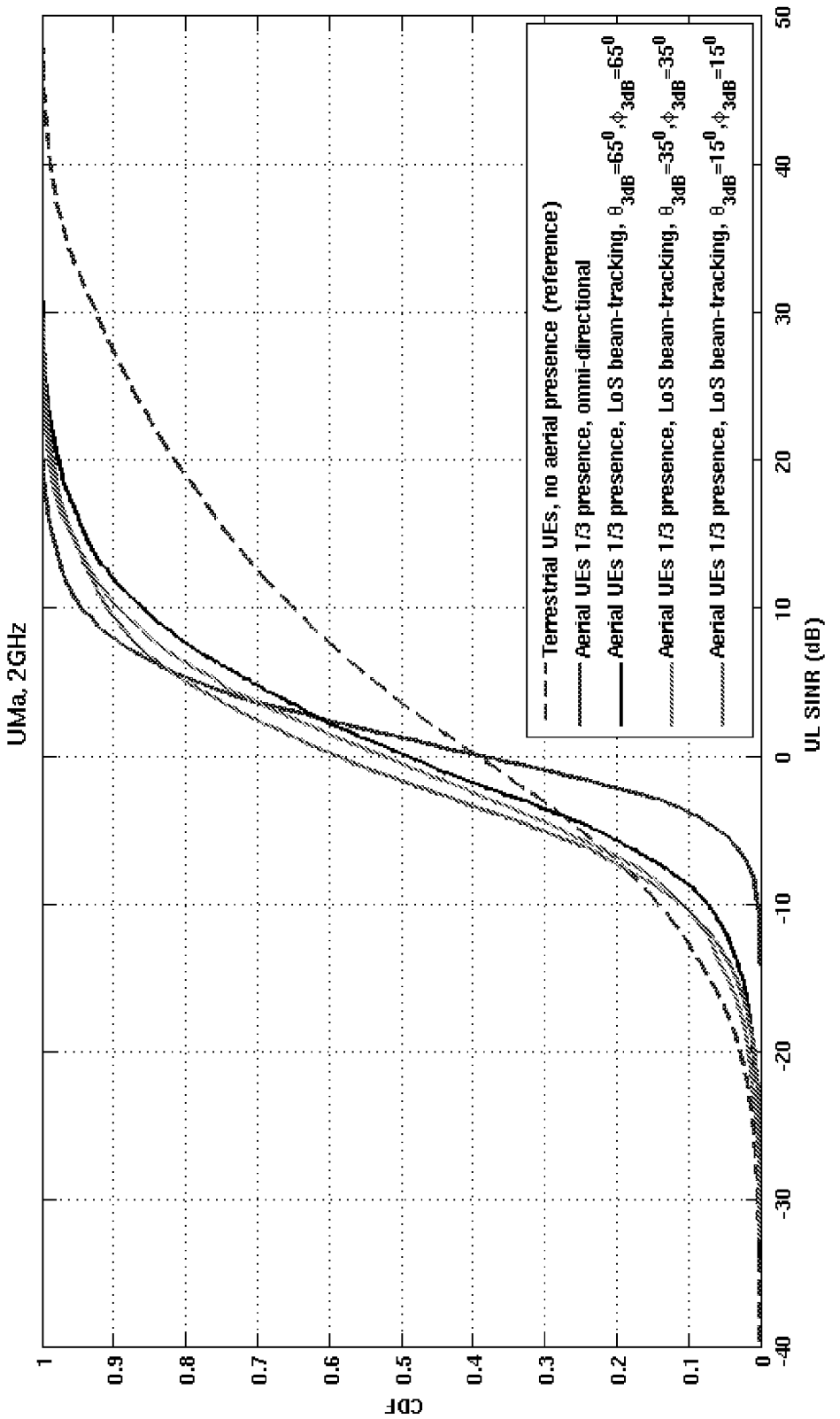

UMa, 2GHz
CDF
UL SINR (dB)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-40
-30
-20
-10
0
10
20
30
40
50
Terrestrial UEs, no aerial presence (reference)
Aerial UEs 1/3 presence, omni-directional
Aerial UEs 1/3 presence, LoS beam-tracking, $\theta_{3dB}=65^0$,$\phi_{3dB}=65^0$
Aerial UEs 1/3 presence, LoS beam-tracking, $\theta_{3dB}=35^0$,$\phi_{3dB}=35^0$
Aerial UEs 1/3 presence, LoS beam-tracking, $\theta_{3dB}=15^0$,$\phi_{3dB}=15^0$

Figure 18

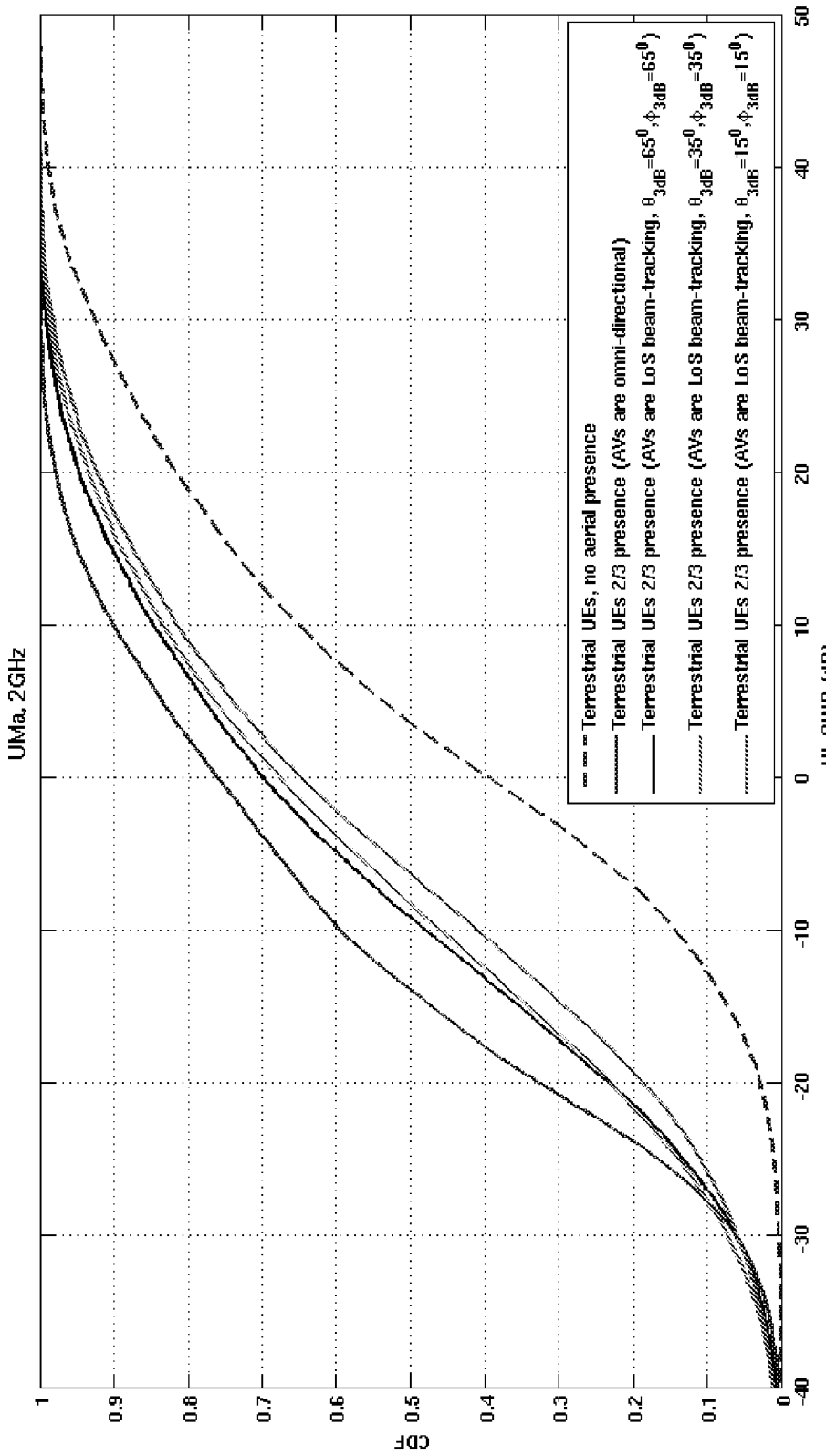

UMa, 2GHz
CDF
UL SINR (dB)
Terrestrial UEs, no aerial presence
Terrestrial UEs 2/3 presence (AVs are omni-directional)
Terrestrial UEs 2/3 presence (AVs are LoS beam-tracking, θ3dB=65°;ϕ3dB=65°)
Terrestrial UEs 2/3 presence (AVs are LoS beam-tracking, θ3dB=35°;ϕ3dB=35°)
Terrestrial UEs 2/3 presence (AVs are LoS beam-tracking, θ3dB=15°;ϕ3dB=15°)

Figure 19

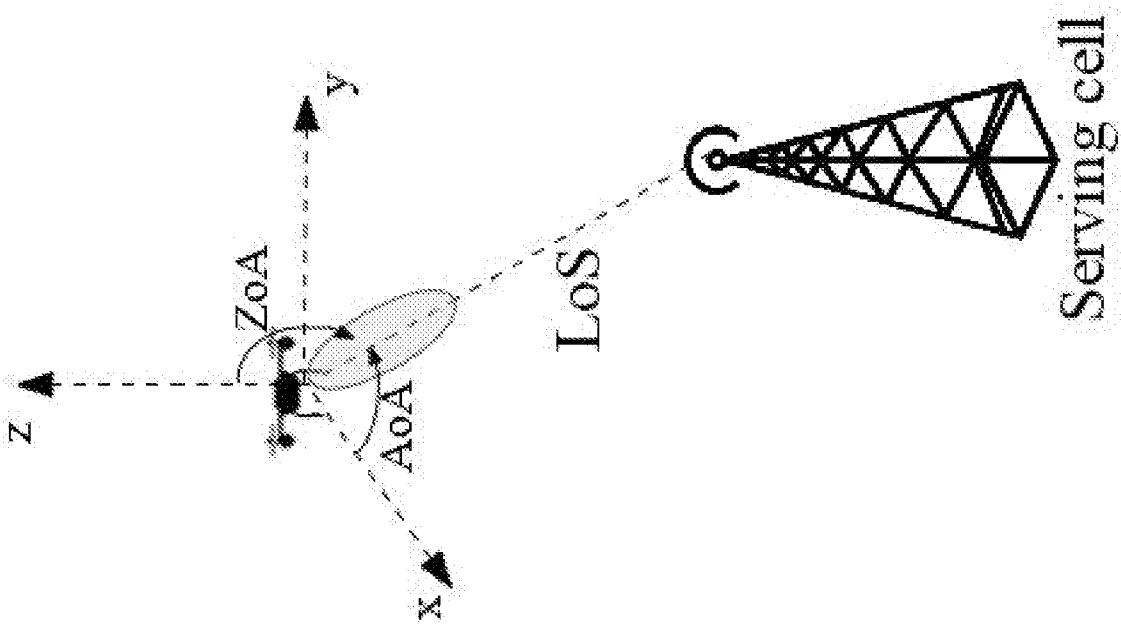


Figure 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2017/116337

A. CLASSIFICATION OF SUBJECT MATTER

H04W 4/00(2018.01)i; H04B 7/08(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04B; H04L; H04Q

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

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

CNKI,CNPAT,WPI,EPODOC:interference, drone, aircraft, beam, form+, coordinat+, location

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015038591 A1 (SMARTSKY NETWORKS LLC) 19 March 2015 (2015-03-19) description, page 4 line 3 to page 16 line 22, figures 1-9	1-14
A	CN 107017938 A (SHENZHEN UNIVERSITY ET AL.) 04 August 2017 (2017-08-04) the whole document	1-14
A	CN 106712827 A (SHANGHAI SATELLITE ENGINEERING INSTITUTE) 24 May 2017 (2017-05-24) the whole document	1-14
A	CN 106603138 A (UNIVERSITY OF NANJING AERONAUTICS & ASTRONAUTICS) 26 April 2017 (2017-04-26) the whole document	1-14

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

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

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"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	Date of mailing of the international search report
16 April 2018	**04 May 2018**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**HUANG,Fei**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961743**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2017/116337

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2015038591 A1	19 March 2015	CN 105594233 A	18 May 2016
		JP 2016539588 A	15 December 2016
		EP 3044977 A1	20 July 2016
		US 2016227460 A1	04 August 2016
		AU 2014318944 A1	31 March 2016
		IN 201637008600 A	17 June 2016
CN 107017938 A	04 August 2017	None	
CN 106712827 A	24 May 2017	None	
CN 106603138 A	26 April 2017	None	