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PATENT APPLICATION

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

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METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/649,143, filed on May 18, 2012, entitled "Method and System for Soft Frequency Reuse in a Distributed Antenna System," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] Wireless communication systems employing Distributed Antenna Systems (DAS) are available. A DAS typically includes one or more host units, optical fiber cable or other suitable transport infrastructure, and multiple remote antenna units. A radio base station is often employed at the host unit location commonly known as a base station hotel, and the DAS provides a means for distribution of the base station's downlink and uplink signals among multiple remote antenna units. The DAS architecture with routing of signals to and from remote antenna units can be either fixed or reconfigurable.

[0003] A DAS is advantageous from a signal strength and throughput perspective because its remote antenna units are physically close to wireless subscribers. The benefits of a DAS include reducing average downlink transmit power and reducing average uplink transmit power, as well as enhancing quality of service and data throughput.

[0004] Despite the progress made in wireless communications systems, a need exists for improved methods and systems related to wireless communications.

SUMMARY OF THE INVENTION

[0005] The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS) as part of a distributed wireless network. More specifically, the present invention relates to a DAS utilizing Soft Frequency Reuse or Fractional Frequency Reuse techniques. In a particular embodiment, the present invention has been applied to the

reuse of communications frequencies in central portions of adjacent DAS cells, improving system data rates and performance. The methods and systems described herein are applicable to a variety of communications systems including systems utilizing various communications standards.

[0006] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies, and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU in a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU in a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

[0007] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

[0008] According to a specific embodiment of the present invention, a communications system is provided. The communications system includes a host unit and a first communications unit

coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint. The communications system also includes a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

[0009] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU of a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a plurality of additional DRUs of the first cell are operable to communicate using a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint surrounding the first geographic footprint. A first DRU of a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a plurality of additional DRUs of the second cell are operable to communication using a third set of frequencies characterized by a third frequency band different from the first frequency band over a fourth geographic range surrounding the third geographic range.

[0010] The DRUs can comprise remote radio units. The method may also include communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU. One or more of the plurality of BTSs can be coupled to the DAU using a plurality of BTS sector RF connections. The method may further include transporting signals between one or more DRUs and the at least one DAU.

[0011] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units in an array configuration and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized

by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic range surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint surrounding the third geographical footprint.

[0012] In an embodiment, the set of communications units include a plurality of remote units in communication with a host unit. The first geographic footprint can be centered on the first communications unit. The second geographic footprint can be a peripheral footprint centered on the first communications unit. The third geographical footprint can be centered on the second communications unit. The fourth geographical footprint can be a peripheral footprint centered on the second communications unit. The second geographical footprint can abut the fourth geographical footprint. The method can also include transmitting, and receiving, from a third communications unit of the set of communications units, a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint surrounding the fifth geographical footprint.

[0013] According to yet another embodiment, a communications system is provided. The communications system includes a first communications unit operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint and a second communications unit operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and one or more of the second set of frequencies in a region associated with a fourth geographical footprint.

[0014] The first communications unit can include a central DRU and a plurality of peripheral DRUs disposed adjacent the central DRU. The system can also include a DAU communicatively coupled to the central DRU and the plurality of peripheral DRUs. In an embodiment, the system includes a DAU communicatively coupled to the central DRU. Additionally, a second DAU can

be communicatively coupled to the plurality of peripheral DRUs. In an embodiment, the second geographical footprint at least partially surrounds the first geographical footprint. In another embodiment, the fourth geographical footprint at least partially surrounds the third geographical footprint or the second geographical footprint at least partially overlaps the fourth geographical footprint.

[0015] According to a specific embodiment, a frequency sharing system for a distributed antenna system is provided. The frequency sharing system includes a first frequency band characterized by a first frequency range and associated with a first geographic area associated with a first communications unit and a second frequency band characterized by a second frequency range different from the first frequency range and associated with a second geographic area at least partially surrounding the first geographic area. The frequency sharing system also includes a third frequency band overlapping at least a portion of the second frequency band and associated with a third geographic area associated with a second communications unit and a fourth frequency band overlapping at least a portion of the first frequency band and associated with a fourth geographic area at least partially surrounding the third geographic area.

[0016] The first geographic area can be characterized by a first border and the second geographic area can be characterized by a second border, wherein a predetermined distance separates the first border and the second border. The first frequency band and the second frequency band can be contiguous frequency bands. In an embodiment, the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent the first frequency band.

[0017] According to another specific embodiment, a communications system is provided and includes a first communications unit operable to transmit and receive communications using a first set of frequencies over a first predetermined area and a second communications unit operable to transmit and receive communications using a second set of frequencies over a second predetermined area. The first communications unit is operable to transmit and receive communications using a third set of frequencies over a third predetermined area and the second communications unit is operable to transmit and receive communications using at least a portion of the third set of frequencies over a fourth predetermined area.

[0018] The first communications unit can include a plurality of DRUs, at least one of the plurality of DRUs being coupled to a DAU. The third predetermined area can be at least

partially surrounded by the first predetermined area and the fourth predetermined area can be at least partially surrounded by the second predetermined area. In an embodiment, the first set of frequencies, the second set of frequencies, and the third set of frequencies are distinct frequencies. The first communications unit and the second communications unit can be disposed in an array configuration. The first predetermined area overlaps at least a portion of the second predetermined area in some implementations and the third predetermined area includes a location of the first communications unit and the fourth predetermined area includes a location of the second communications unit. The first communications unit can include a first plurality of digital remote units and the second communications unit comprises a second plurality of digital remote units. The first set of frequencies can be associated with a first number of the first plurality of digital remote units and the third set of frequencies can be associated with another of the first plurality of digital remote units. The second set of frequencies can be associated with a first number of the second plurality of digital remote units and the third set of frequencies can be associated with another of the second plurality of digital remote units.

[0019] Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIGS. 1A - 1C illustrate different frequency reuse techniques according to embodiments of the present invention;

[0021] FIG. 2 illustrates the structure of a Distributed Antenna System (DAS) according to an embodiment of the present invention;

[0022] FIG. 3 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to an embodiment of the present invention;

[0023] FIG. 4 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to another embodiment of the present invention;

[0024] FIG. 5 illustrates a capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area according to an embodiment of the present invention;

[0025] FIG. 6 is a plot illustrating analytical ergodic capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention; and

[0026] FIG. 7 is a plot illustrating simulation capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention.

[0027] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention; and

[0028] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0029] Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency.

[0030] Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the transmission scheme for the next generation wireless communication systems. However, the downlink performance of cellular networks is known to be strongly limited by inter-cell interference in OFDMA based systems. In order to mitigate this interference, a number of techniques have recently been proposed, e.g. the Soft Frequency Reuse (SFR) scheme and Distributed Antenna System (DAS). According to embodiments of the present invention, these two techniques are combined in a unique cell architecture, which can be referred to as DAS-SFR. In an implementation of this architecture, which is described herein, the antennas are distributed in a hexagonal cell such that the central antenna is responsible for serving a special area using multiple frequency bands (e.g., all of the frequency bands) while the remaining antennas utilize only a subset of the frequency bands based on a frequency reuse factor. The inventors have analytically quantified the performance of the downlink multi-cell DAS-SFR in terms of the individual user's throughput under three different resource allocation scenarios. The results show that DAS-SFR reduces inter-cell interference in a multi-cell environment for users near the cell boundaries as compared to a Hard Frequency Reuse (HFR) scheme with a frequency reuse factor

of 1. The results also show that DAS-SFR significantly increases the system capacity as compared to the HFR scheme with a frequency reuse factor of 3.

[0031] In DAS-SFR, by controlling the amount of resources allocated to users located in different areas, embodiments of the present invention increase the frequency efficiency and also improve the data rate for cell edge users. If the throughput requirement for the interior users is small, more resources can be assigned to the exterior users.

[0032] In the next generation wireless communication systems that use the 3GPP LTE (Long Term Evolution) standard, there is tremendous pressure to support a high data rate transmission. These systems are based on Orthogonal Frequency Division Multiple Access (OFDMA) to support the high data rate service and improve the Quality of Service (QoS), even for cell edge users as the main targets in the downlink.

[0033] The system bandwidth is divided into a number of sub-carriers in an OFDMA-based system such that each user utilizes a bandwidth smaller than the systems coherence bandwidth. Data from different users is transmitted in parallel on different sub-carriers. The orthogonality amongst the sub-carriers mitigates inter-carrier interference (ICI) while the resulting large OFDM symbol time and the narrow sub-carrier bandwidth reduces the effect of inter-symbol interference (ISI). Users located at the cell edge largely suffer from co-channel interference (CCI) or inter-cell interference from base stations (BS) of neighboring cells. Mobile 3GPP LTE adopts a frequency reuse factor of one, in which each cell serves users using the entire system bandwidth.

[0034] In order to reduce interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are three potential ways to reduce interference in cellular systems but these require a more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes(CLMD) and Beamforming are three other techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beamforming sacrifice spatial dimensions and require channel state knowledge.

[0035] One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a distributed antenna systems (DAS), which also has the additional advantage of improving capacity and coverage.

[0036] Other possible strategies include Frequency Reuse techniques, which effectively reduce inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

[0037] Distributed Antenna System (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems. As opposed to a conventional cellular system, where the antenna is centrally located, a DAS network consists of antenna modules that are geographically distributed to reduce access distance. These distributed antennas are connected to an eNodeB (eNB) LTE system by dedicated wires, fiber optics, or via a radio frequency link.

[0038] DAS has advantages including throughput improvement, coverage improvement, increased cellphone battery life, and a reduction in transmitter power. Recent research has shown benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is a Virtual DAS, wherein each remote has the added flexibility of independently transmitting preselected carriers.

[0039] Frequency reuse techniques are utilized herein to reduce inter-cell interference in cellular systems. This benefits users near the cell edges owing to simplicity and practicality. There are three major frequency reuse patterns illustrated in FIG. 1 for mitigating inter-cell interference: Hard Frequency Reuse, Fractional Frequency Reuse and Soft Frequency Reuse.

[0040] Hard Frequency Reuse (HFR) splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub-bands. This inter-cell interference mitigation method is typically seen in GSM networks, when it comes to distribution of frequencies among the cells. When applied to LTE, the Resource Blocks (a group of sub-carriers) are divided into 3, 4 or 7 disjoint sets. These sets of Resource Blocks (RBs) are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies, as illustrated in FIG. 1A. FIG. 1D shows, for each case (Hard Frequency Reuse (FIG. 1A), Fractional Frequency Reuse (FIG. 1B), and Soft Frequency Reuse

(FIG. 1C)), the transmit/receive power as a function of frequency. This reduces the interference at the cell edge of any pair of cells significantly and can be considered the opposite extreme to Full Frequency Reuse in matters of frequency partitioning techniques. While user interference at the cell edge is maximally reduced, the spectrum efficiency drops by a factor equal to the reuse factor. The inter-cell interference can be reduced with a frequency reuse factor of more than one, however, it may reduce the system capacity.

[0041] Fractional Frequency Reuse (FFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. OFDMA provides the ability for each eNB to selectively allocate frequency sub-bands, data rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. FFR splits the given bandwidth into an inner and an outer region as illustrated in FIG. 1B. The spectrum allocated to the inner region is assigned to the nearby users (located close to the eNB in terms of path loss) applying a frequency reuse factor of one (i.e. the inner part is completely reused by all eNBs). While the spectrum allocated to the outer region, for users close to the cell edge (far users), is divided among the different eNBs as in hard frequency reuse techniques. This scheme is particularly useful to mitigate the inter-cell interference in the uplink, where severe interference situations can occur when the user is located close to a strong interferer from a neighbor cell.

[0042] Soft Frequency Reuse (SFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. SFR shares the overall bandwidth by all eNBs (i.e. a reuse factor of one is applied), but for transmission on each group of RBs, the eNBs are restricted to a certain power bound. FIG. 1C illustrates the power and frequency assignments in the different cells of a system with SFR for a reuse factor of 3. It can be noticed in the frequency spectrum of FIG. 1D associated with Soft Frequency Reuse (i.e., FIG. 1C), that there is a region of high-power transmissions and some regions of low-power transmissions. Using a similar strategy extending Fractional Frequency Reuse, resources in the high-power region are preferably assigned to User Equipment (UEs) located at the cell edge, while cell-center UEs are typically assigned resources in the low-power regions. SFR can utilize the entire frequency spectrum that has been allocated, increasing the system data rate and/or capacity.

[0043] Referring to FIGS. 1C and 1D, frequencies in the grey frequency band (~ upper 2/3 of the available frequencies) are transmitted/received by a DRU at a first power level in Cell 1,

providing coverage for the central portion of Cell 1. Frequencies in the horizontal stripes band are transmitted/received by the DRU at a second power level higher than the first power level, providing coverage over both the central portion of Cell 1 as well as the peripheral portions of Cell 1 since the higher power level results in a larger coverage area. In this example, each cell utilizes a single DRU, although other embodiments can utilize multiple DRUs per cell as described more fully herein. DRUs in the other cells also transmit/receive at both high power for a subset of the frequencies and low power for remaining frequencies as shown in FIG. 1D, producing the coverage maps illustrated in FIG. 1C, with low power frequencies providing centralized coverage and higher power frequencies providing a large coverage area extending to the peripheral regions of the cells. Although all three cells are transmitting/receiving using overlapping (or the same) frequencies at low power, the corresponding propagation distances for these frequencies are smaller, preventing geographic overlap between the central grey regions.

[0044] In order to reduce interference in areas where cells are adjacent, the frequencies associated with higher power are grouped into subbands, with little or no overlap between the subbands. Referring to FIG. 1D, in the SFR implementation, Cell 1 uses high power for the horizontal stripes band in approximately the first third of the frequency bandwidth, Cell 2 uses high power for the dotted band in approximately the second third of the frequency bandwidth, and Cell 3 uses high power for the vertical stripes band in approximately the last third of the frequency bandwidth. Thus, at the intersections between cells, since different portions of the available frequency band are being utilized, interference is reduced. Thus, in some embodiments, different frequency bands are utilized in adjacent cells, which is illustrated by the high power frequency bands for SFR in FIG. 1D: the first frequency band in Cell 1, the second frequency band different from the first frequency band in Cell 2, and the third frequency band different from the first frequency band and the second frequency band in Cell 3. For an additional number of cells, the subdivision of the available bandwidth can be increased as appropriate to the particular number of adjacent cells in the implementation. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0045] HFR, though simple in implementation, suffers from a reduced spectral efficiency. On the other hand, both SFR and FFR have increased (e.g., full) spectral efficiency and are a strong mechanism for inter-cell interference mitigation. A coordinated resource allocation system can be impractical in realistic settings involving a large number of eNBs, random traffic and realistic path-loss models. However, an encouraging result is that by using even limited (yet practical)

levels of coordination, significant performance benefits can still be obtained over a conventional cellular architecture. Most of the recent publications have focused on investigating SINR advantages of DAS and analyzing its performance. On the other hand, there are no studies that combine DAS with SFR in order to reduce inter-cell interference. Some publications on DAS have focused on analyzing the uplink performance because of its analytical simplicity and there are few studies on the downlink performance of DAS although the demand for high-speed data rate will be dominant in the downlink path. There are also very few publications that consider the advantages of DAS in a multi-cell context. Recent research on FFR and SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional works on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

[0046] According to embodiments of the present invention, a new architecture is provided to suppress inter-cell interference. The architecture described herein combines DAS and SFR for an OFDMA system (e.g., LTE). Embodiments of the present invention provide benefits by using DAS-SFR in a multi-cell environment. The downlink advantages of DAS-SFR are described in terms of achievable ergodic capacity for three different frequency resource allocation scenarios. The results shows that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture and achieves a non-trivial capacity increase over a HFR cellular architecture with a frequency reuse factor of 3. Other reuse factors are included within the scope of the present invention, for example, up to or more than 7 as suitable for the DAS architecture illustrated in FIG. 2.

[0047] As described herein, an analytical framework has been developed to evaluate the ergodic capacity in a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service, regardless of their geographic location, instead of simply a minimum user throughput which may be acceptable for applications like voice traffic. We present a strategy for optimally allocating frequency RBs to edge users for a DAS-SFR architecture, based on a chosen performance threshold T_p, which can be related to

network traffic load. Finally we prepare a simulation scenario to compare the analytical results with the simulation results.

[0048] Referring to the spectral plots illustrated in FIG. 1D, in the HFR system, the horizontal stripes, shaded, and vertical stripes frequency bands occupy different frequency ranges and, in combination, fill the entire spectrum. In HFR (FIG. 1A), cell 1 uses the lower frequencies (horizontal stripes), cell 2 uses the middle frequencies (shaded), and cell 3 uses the higher frequencies (vertical stripes).

[0049] Referring to FIG. 2, the DAS includes a central cell referenced as eNB0, which includes DRU0 through DRU6 that are communicating through one base station at eNB0 through a DAU. DRU0 can be considered to be Cell 1 in FIGS. 1A - 1C, DRU1 can be considered to be Cell 2 in FIGS. 1A - 1C, and DRU2 can be considered to be Cell 3 in FIGS. 1A - 1C. In other embodiments, eNB0 is considered to be Cell 1 in FIGS. 1A - 1C and eBN1, including a different set of DRUs, DRU0 through DRU6, can be considered to be Cell 2 in FIGS. 1A - 1C, etc. In FIG. 1A, Cell 1 (e.g., DRU0 of eNB0) utilizes the horizontal stripes frequency band and the other cells use different frequency bands as illustrated. In the embodiment illustrated in FIG. 2, seven different frequency bands could be utilized for high power transmission by the seven DRUs connected to each base station. For cells geographically separated from Cell 1, for example, cells in eNB7 could reuse the same frequencies (horizontal stripes) used in Cell 1 (e.g., eNB0).

[0050] Referring once again to FIG. 1B, a set of frequencies operating at reduced power compared to the frequencies discussed in relation to HFR and represented by the grey frequency bands in the FFR and SFR portion of FIG. 1D, are reused in each of the cells (i.e., Cell 1, Cell 2, and Cell 3). Because this frequency band does not geographically overlap with adjacent cells (i.e., it is used at the central portion of the cell as a result of the lower power), overlap between adjacent cells is prevented and this frequency band can be reused in adjacent cells.

[0051] For fractional frequencies, because there is a spatial separation between the grey areas in the spectra in Cell 1 and Cell 2 and Cell 3, as long as the spatial separation is significant enough, there will not be significant interference between the cells although the central portions of the cells are transmitting on the same (e.g., exact same) frequencies. By keeping a separation and allocating the horizontal stripes frequency band in Cell 1 to specific frequencies, the shaded frequency band in Cell 2 to other specific frequencies, the vertical stripes frequency band in Cell

3 to still other specific frequencies, and the like for additional cells, embodiments of the present invention make efficient use of the given spectrum. Comparing the Fractional Frequency Reuse spectrum to the Hard Frequency Reuse spectrum, it is evident that FFR uses more of the available spectrum, which enables support for more users, operation at a higher data rate, combinations thereof, or the like. In the illustrated example, the fraction of the spectrum used in each cell has increased from about a third of the spectrum (HFR) to about half of the spectrum (FFR). Other implementations can utilized different fractions of the spectrum and the present invention is not limited to the particular example illustrated in FIG. 1B and FIG. 1D.

[0052] In one embodiment, to implement the fractional frequency reuse technique illustrated in FIG. 1B using the architecture illustrated in FIG. 2, DRUs 1, 2, 3, 4, 5 and 6 of eNB0 would transmit and receive data using frequencies in the horizontal stripe frequency band and DRU0 of eNB0 would transmit and receive data using the grey frequencies. In an embodiment, the size of the area covered by DRU0 can be increased by increasing the transmit power associated with the central DRU (i.e., DRU0). In another embodiment, each DRU in eNB0 transmits and receives data at a first power level using frequencies in the grey frequency bands and at a second, higher power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands. In this embodiment, three of the seven DRUs illustrated in an eNB are illustrated by Cells 1-3.

[0053] Referring to FIG. 1C, an architecture implementing Soft Frequency Reuse is illustrated and the matching spectrum in FIG. 1D illustrates the full use the spectrum by each of the adjacent cells. In an embodiment in which multiple DRUs are utilized per cell, the horizontal stripe geographical area in Cell 1 is associated with the outer DRUs in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRUs 1-6) and the grey geographical area in Cell 1 is associated with the central DRU in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRU0). As discussed above, the size of the grey circle can be increased/decreased by increasing/decreasing the power of utilized in conjunction with DRU0. As shown in the SFR spectrum for Cell 1, data is transmitted and received over the entire allocated spectrum, including portions of the spectrum that were unused for Cell 1 in the HFR example. The increase in spectrum provides increased data rate, increased capacity, combinations thereof, or the like. In other embodiments, a single DRU in Cell 1 broadcasts at low power over the grey band and at a higher power over the horizontal stripe spectrum. Other cells demonstrate similar behavior. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0054] Comparing FFR (FIG. 1B) and SFR (FIG. 1C), the frequency bandwidth available for the peripheral DRUs or for the higher power broadcast from a DRU in the cell (i.e., horizontal stripe, dotted, or vertical stripe spectra) is increased for SFR in comparison to FFR. Additionally, the frequency bandwidth available for the central DRU or for the lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

[0055] In an embodiment, fractional frequency reuse is implemented in a DAS system with a plurality of adjacent cells, each of the cells including a plurality of remote units. A first cell utilizes a first frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and a second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs). A second cell utilizes a third frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and the second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs).

[0056] In another embodiment, soft frequency reuse is implemented in a DAS system with a plurality of adjacent cells. A first cell utilizes a first frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a second frequency band (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). A second cell utilizes a third frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a fourth frequency band, which may include multiple sub-bands (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). The third frequency band may include frequencies in the second frequency band and the multiple sub-bands of the fourth frequency band may include frequencies in the first frequency band as illustrated in FIG. 1C.

[0057] As will be appreciated by one of skill in the art, operators utilize different spectrums and, in the examples illustrated in FIG. 1D, they are contiguous. However, it should be noted that although contiguous spectra are illustrated in FIG. 1D, this is not required by embodiments of the present invention and non-contiguous spectrums may be utilized in other embodiments. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0058] Although the embodiments illustrated in FIG. 1D utilizes three frequencies, embodiments of the present invention are not limited to this particular number and additional frequencies and frequency bands can be utilized, for example, additional frequency bands used in conjunction with additional cells. In a particular embodiment, seven frequency bands, twelve frequency bands, or the like can be utilized. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0059] System Architecture (DAS-SFR)

[0060] The general architecture of a Virtualized DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRUs) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized such that each DRU allocated to a given eNB sector is simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. The DAUs assign the RBs of the various sectors to the independent DRUs. In contrast, the same area (7 DRUs) is covered by only a high-power eNB in traditional cellular system. The proposed architecture divides the entire spectral bandwidth F into 3 parts (F_1, F_2, F_3). The idea is that the eNB assigns the full-reused frequency (all 3 parts) to the central DRU and the other 6 edge DRUs work on just 1 part based on a reuse factor of Δ in such a way that neighbor cell edge DRUs don't use the same frequency part.

[0061] The total transmit power of the n-th DRU of i-th cell in f-th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by $n = 0$. Throughout this application, we assume that $P_n^{(i,f)} = P$.

[0062] We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

[0063] Resource Allocation Scenarios:

[0064] In cellular DAS-SFR with multi users, there are several possible resource allocation scenarios using multiple DRUs. Much of the research on SFR system design has focused on how to determine the size of the frequency partition, for example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users per each frequency part($F_i, i=1,2,3$).

[0065] For a typical central cell, let's assume the center DRU is assigned the full-reused frequency and the other six edge DRUs are assigned to F_1. Now, we consider three resource allocation scenarios:

[0066] - **Scenario 1:** All F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

[0067] - **Scenario 2:** F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

[0068] - **Scenario 3:** F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

[0069] We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario we investigate both the analytical and simulation results in order to verify the system's capacity improvement.

[0070] Channel Model and Received Signal

[0071] The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise. The received signal vector of the user in the 0th cell at frequency f can be expressed as:

$$y^{(0,f)} = signal + interference + noise$$
$$= \mathbf{H}^{(0,f)}\mathbf{x}^{(0,f)} + \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n} \quad (1)$$

where $\mathbf{H}^{(i,f)} \in C^{1\times 7}$, $i = 0, 1, \ldots, 18$, denotes the channel matrix between the DRUs in the i-th cell and the user in the central (0th) cell, $x^{(i,f)} = \left[x_0^{(i,f)}, x_1^{(i,f)}, \ldots, x_6^{(i,f)}\right]^T \in C^{7x1}, i - 0,1, \ldots,18$ is the transmitted signal vector of the DRUs in the i-th cell, $n^{(f)} \in C^{1x1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma^2_{n^{(f)}}\mathbf{I}_1)$.

[0072] The distributed antenna power constraint is considered, we have

$$\mathbf{E}\left[\left|x_n^{(i,f)}\right|^2\right] \le P_n^{(i,f)}, n = 0,1,\ldots,6, \quad i = 0,1,\ldots,18, \quad (2)$$

where in DAS-SFR,

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} \ne 0, P_n^{(i,f)} \ne 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \quad , f = F_1, F_2, F_3),$$

in Conventional Cellular-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 0,8,10,12,14,16,18),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 1,3,5,9,13,17),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 2,4,6,7,11,15),$$

and in Conventional cellular-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} = 0, P_n^{(i,f)} = 0 \quad when \quad (n = 1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \ and \ f = F_1, F_2, F_3),$$

where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell.

[0073] The composite fading channel matrix $\mathbf{H}^{(i,f)}, i=0,1,...,18$, encompasses not only small-scale fading but also large-scale fading, which is modeled as

$$\begin{aligned}\mathbf{H}^{(i,f)} &= \mathbf{H}_w^{(i,f)}\mathbf{L}^{(i,f)} \\ &= \left[h_0^{(i,f)}, h_1^{(i,f)}, ..., h_6^{(i,f)}\right].diag\left\{l_0^{(i,f)}, l_1^{(i,f)}, ..., l_6^{(i,f)}\right\}\end{aligned} \tag{3}$$

where $\mathbf{H}_w^{(i,f)}$ and $\mathbf{L}^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the 0th cell, respectively. $\left\{h_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are independent and identically distribute (*i.i.d*) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\left\{l_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{\left[D_n^{(i)}\right]^{-\gamma} \chi_n^{(i,f)}}, \quad n=0,1,...,6, \quad i=0,1,...,18 \tag{4}$$

where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the 0th cell and the nth DRU in the i-th cell, respectively, γ denotes the path loss exponent. $\left\{\chi_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are *i.i.d* random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi}\lambda\sigma_\chi\chi}\exp\left(-\frac{(\ln\chi)^2}{2\lambda^2\sigma_\chi^2}\right), \quad \chi>0, \tag{5}$$

where σ_χ is the shadowing standard deviation and $\lambda = \frac{\ln 10}{10}$.

[0074] Since the number of interfering source is sufficiently large and interfering source are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18} \mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n}^{(f)} \tag{6}$$

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned}Var(N^{(f)}) &= \left[\sum_{i=1}^{18}\sum_{n=0}^{6}\left[l_n^{(i,f)}\right]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2\right]\mathbf{I}_1 \\ &= \left[\sigma^{(f)}\right]^2\mathbf{I}_1\end{aligned} \tag{7}$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$\mathbf{y}^{(0)} = \mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)}\mathbf{x}^{(0,f)} + N^{(f)} \tag{8}$$

[0075] Achievable capacity of distributed antenna network

[0076] If we assume the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station can be calculated by

$$C^{(f)} = \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2 \det(\mathbf{I}_1 + \frac{1}{\left[\sigma^{(f)}\right]^2}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})\mathbf{P}^{(0,f)}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})^H)\right] \tag{9}$$

where $\mathbf{P}^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $diag\left\{P_0^{(0,f)}, P_1^{(0,f)}, ..., P_6^{(0,f)}\right\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$\begin{aligned} C^{(f)} &= \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2(1 + \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)})\right] \\ &= \int_{\gamma_f=0}^{\infty}\log_2(1+\gamma_f) f_{\gamma_f}(\gamma_f) d\gamma_f \end{aligned} \tag{10}$$

where $\gamma_f = \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}$ is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f) = \sum_{i=0}^{6}\frac{\left[\sigma^{(f)}\right]^2\pi_i}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2\gamma_f}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), \tag{11}$$

where

$$\pi_i = \prod_{k=0,k\neq i}^{6}\frac{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)} - \left[l_i^{(0,f)}\right]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$C^{(f)} = -\frac{1}{\ln 2}\sum_{i=0}^{6}\pi_i \exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), f = F_1, F_2, F_3 \tag{12}$$

where $Ei(t)$ is the exponential integral function ($Ei(t) = -\int_{-x}^{\infty} e^{-t}/t\,dt$) and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

[0077] Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$C^{(f)} = -\frac{1}{\ln 2}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) \quad , f = F_1, F_2, F_3 \tag{13}$$

[0078] Thus, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total} = C^{(F_1)} + C^{(F_2)} + C^{(F_3)} \tag{14}$$

[0079] Analytical and Simulation Results

[0080] FIG. 3 and FIG. 4 represents the ergodic capacity of cellular DAS for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position X when the path loss exponent is 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}, C^{(F_2)}, C^{(F_3)}$, and also for the total capacity C_{total}.

[0081] The transmit power of each distributed antenna module is P whereas the transmit power of eNB in the conventional cellular system is $7P$. These figures show an interesting non-monotonic relationship between capacity and the normalized distance from the base station. This is because the signal from a distributed antenna module becomes dominant around 0.6R.

[0082] FIG. 3 compares the capacity performance of the two frequency reuse techniques, SFR and HFR3, for a particular central cell. Note that in the SFR technique, all 3 frequency bands are assigned, whereas, in the HFR3 method, only the F_1 band is used. The results show that the SFR method achieves the highest throughput, owing to use of more frequency bandwidth. More specifically, the total capacity achieved using the SFR method is the highest inside the normalized distance 0.5.

[0083] A non-significant throughput reduction in the SFR technique is observed happening beyond a normalized distance 0.5, due to the interference introduced from the neighboring central DRU cells. Note that there is no interference introduced from the DRU neighboring cells

when the HFR3 method is applied. It is worth mentioning that the achieved throughput of the DAS-HFR3 is slightly lower than that of a conventional cellular (Con-HFR3) system near the eNB0 DRU0, due to the reduced transmit power.

[0084] FIG. 4 compares the capacity performance of the two frequency reuse techniques, SFR and HFR1, for a particular central cell. Note that in both SFR and HFR1 techniques, all 3 frequency bands are assigned. The achieved throughputs of the DAS-HFR1 and DAS-SFR are slightly lower than that of a conventional cellular (Con-HFR1) system near the eNB0 (DRU0), due to the reduced transmit power.

[0085] FIG. 4 illustrates that the HFR1 technique outperforms the SFR technique in terms of the achieved throughput inside the $(0,\ 0.5R)$ region, nevertheless, the SFR technique significantly improves the system performance by making up for the dead spots happening at the cell edges. Note that there is a significant amount of interference happening in the $(0.8R, R)$ region, creating dead-spots in the HFR1 technique.

[0086] Note that 80% of the users are located inside the $(0.5R, R)$ region, assuming a uniform distribution, while the other 20% are farther from the interfering cells. Therefore, it is more important to improve the system capacity inside the $(0.5R, R)$ region.

[0087] In multiuser systems, where all users are uniformly distributed in the cell, we need to consider different resource allocation scenarios which were defined above. Assuming that each cell has radius R, we define parameter α $(0<\alpha<1)$ such that the interior area is located in the $(0,\ \alpha R)$ region and the exterior area is located in the $(\alpha R, R)$ region.

[0088] In LTE systems, eNB distinguishes between the interior and exterior users based on their corresponding uplink power received at the central DRU. To implement this technique, we propose a threshold T_p as a parameter in eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa.

[0089] Note that

$$N_{\text{int}erior} = \alpha^2 N_{users},$$
$$N_{exterior} = \left(1-\alpha^2\right) N_{users}, \qquad (15)$$

where $N_{interior}$ represents the number of interior users, $N_{exterior}$ represents the number of exterior users, and N_{users} represents the total number of users. We will consider the 3 different resource allocation scenarios mentioned above, where the number of RBs per users assigned in the different regions (interior or exterior) for different Scenarios can be expressed as in TABLE 1, where $N_{RB^{(F_i)}}, i=1,2,3$ represents the number of RBs for given frequency part F_i and $N_{RB^{(F_i)}}^{tech}$ represent the number of RBs for given F_i for the different techniques.

[0090] Note that in all 3 scenarios we have applied the Round Robin scheduling technique.

[0091] If we consider the number of RBs which are assigned to the different regional users under the different scenarios, the capacity metric of the total system can be obtained by,

$$C_{metric}^{total,tech} = C_{metric}^{(tech,F_1)} + C_{metric}^{(tech,F_2)} + C_{metric}^{(tech,F_3)} \quad (16)$$

where

$C_{metric}^{(tech,F_i)} = N_{RB^{(F_i)}}^{tech}.C^{(F_i)}$, $i=1,2,3$,

$tech \in \begin{Bmatrix} DAS-SFR-SC1, DAS-SFR-SC2, DAS-SFR-SC3, \\ DAS-HFR3, Con-HFR3, DAS-HFR1, Con-HFR1 \end{Bmatrix}$.

[0092] In FIG. 5, the capacity metric is provided considering a uniform distribution of users and a Round Robin Scheduler. In this example, which illustrates the capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area, we assume α is 0.5. The achieved capacity of the DAS-SFR architecture with Scenario2 and Scenario3 is higher than that of DAS-SFR system with Scenario1, especially near the central DRU. This is due to the fact that the F_2 and F_3 RBs are not assigned to the exterior users which have very low SINR and all F_2 and F_3 RBs assigned to interior users.

[0093] Comparing Scenario2 with Scenario3, we observe that the achievable capacity for interior users in DAS-SFR architecture with Scenario2 is slightly higher than that of scenario3 due to the full frequency reuse for the interior users in Scenario2. However, in Scenario3, only the F_2 and F_3 frequency bands are used by the interior users. Conversely, the achieved capacity for exterior users in a DAS-SFR architecture with Scenario3 is slightly higher than that of Scenario 2, due to the fact that all F_1 RBs are used by the exterior users, whereas in Scenario2 the F_1 RBs are partially used by the exterior users.

[0094] Note that FIG. 5 illustrates that the DAS-HFR1 technique outperforms other techniques in terms of the achieved throughput by majority of the interior users; nevertheless, SFR technique significantly improves the system performance by making up for the dead spots which appear at the cell edges. Note that there is a significant amount of interference happening in the ($0.8R, R$) region, causing the dead spots in DAS-HFR1 technique.

[0095] In the established system environment, we evaluate the total system capacity for several cases for non-edge users (inside $(0, 0.8R)$ region) and edge users (inside ($0.8R, R$)). We assume α sweeps from 0.2 to 0.8. Remember that α manages the portion of resources allocated in Scenario2 and Scenario3.

[0096] FIG. 6 illustrates the analytical results for the non-edge users and edge users, where α varies between 0.2 and 0.8, that is, the analytical ergodic capacity for edge cell and non-edge cell users versus the parameter α.

[0097] Note that as α changes, the number of RBs assigned to the users in Scenario2 and Scenario3 changes accordingly. However, in other techniques, with changing α, number of assigned RBs to the users remains unaltered. As α increases, the edge user's throughput increases in Scenario3, due to the fact that more RBs are assigned to those users. Specifically, as α increases, less users need to use F_1 RBs in Scenario3. However, in other techniques, edge users experience a constant throughput, due to the fact that the number of RBs allocated to the edge users remains constant as α changes. Specifically, regardless of the changes in α, all F_1 RBs are assigned to all users.

[0098] As α increases, non-edge users' throughput decreases, due to the fact that the total constant number of F_2 and F_3 RBs should be assigned to more number of users accordingly. Note that the rate of decrease in user throughput for non-edge users for Scenario3 is more than that of Scenario2, as α increases. The reason behind this is that the rate of decrease in number of RBs assigned to the non-edge users in Scenario3 is more than that of Scenario2. Specifically, as was previously mentioned, since no F_1 RBs are assigned to the non-edge users in Scenario3, non-edge users' throughput in Scenario3 is less than that of Scenario2.

[0099] The capacity of the above mentioned architectures is investigated through the system level simulation. We consider the two-ring hexagonal cellular system with nineteen eNBs, such

that each cell has 7 DRUs, as in FIG. 2, where the eNBs distance is 500 meters. The 10 UEs are located in each DRU area, following a uniform distribution. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in TABLE 2.

[0100] At a TTI of simulation, the eNB in a cell gathers the CQI information of UEs and allocates the RBs to each UE using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB^{(f)}} \log\left(1 + SINR_m^{(f)}\right), \quad f = F_1, F_2, F_3 \tag{16}$$

where, $W_{RB^{(f)}}$ is the bandwidth of RBs assigned to a UE and $SINR_m^{(f)}$ is the SINR of a UE_m. The cell capacity in each region is total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^{3} \sum_{m=1}^{M} C_m^{(F_i)} \tag{17}$$

where M is the number of UEs in a group.

[0101] FIG. 7 illustrates the simulation results for the non-edge users and edge users (i.e., the simulated capacity for edge cell and non-edge cell users versus the parameter α, where α varies between 0.2 and 0.8. The results obtained through simulation corroborate the results provided by analytical methods.

[0102] The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique, since the interference signal from neighbor cells is lower than that when we use HFR1 technique. In an embodiment using Scenario3 as a resource allocation strategy, the exterior user's throughput is increased.

[0103] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention. The method 800 includes transmitting and receiving data in a first geographical area and a first frequency band (810). The method also includes transmitting and receiving data in a second geographical area and a second

frequency band (812). In an embodiment, the first geographical area is a central area of a cell including multiple DRUs and the second geographical area is a peripheral area of the cell. In another embodiment, the second geographical area includes and extends to an area larger than the first geographical area (e.g., an area surrounding the first geographical area). The method further includes transmitting and receiving data in a third geographical area and at least a portion of the first frequency band (814). At least a portion of the frequency band used for the third geographical area is thus reused in relation to the first geographical area. The method also includes transmitting and receiving data in a fourth geographical area and a third frequency band (816). In an embodiment, the third geographical area is a central area of a cell including multiple DRUs and the fourth geographical area is a peripheral area of the cell. In another embodiment, the fourth geographical area includes and surrounds the third geographical area. The third frequency band may overlap with part of the first frequency band. Accordingly, multiple cells reuse the portions of the first frequency band, which may include multiple sub-bands that are contiguous or separated in frequency domain, in multiple adjacent cells.

[0104] It should be appreciated that the specific steps illustrated in FIG. 8 provide a particular method of implementing soft frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 8 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0105] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention. The method 900 includes transmitting and receiving data in a first geographical area and a first frequency band (910) and transmitting and receiving data in a second geographical area and a second frequency band (912). In an embodiment, the second geographical area surrounds the first geographical area. As an example, the first geographical area can be a central portion of a cell that is covered by a central DRU and the second geographical area can be a peripheral portion of the cell that is covered by a plurality of peripheral DRUs.

[0106] The method further includes transmitting and receiving data in a third geographical area and the first frequency band (914) and transmitting and receiving data in a fourth geographical area and a third frequency band (916). In an embodiment, the third geographical area surrounds the fourth geographical area. As an example, the third geographical area can be a central portion of another cell that is covered by a central DRU and the fourth geographical area can be a peripheral portion of the another cell that is covered by a plurality of peripheral DRUs. Thus, the frequency band used at the central portion of the first cell is reused at the central portion of the second cell. In embodiments, the frequency bands are not limited to contiguous blocks of frequencies, but can include sub-bands each including one or more frequency. The third frequency band can be different from the second frequency band, providing differing frequencies for the differing cells at adjacent geographical areas.

[0107] It should be appreciated that the specific steps illustrated in FIG. 9 provide a particular method of implementing fractional frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 9 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0108] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

TABLE 1. Number of RBs per user

	Interior region			Exterior region		
	F_1	F_2	F_3	F_1	F_2	F_3
$N_{RB^{(F)}}^{DAS-SFR-SC1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$
$N_{RB^{(F)}}^{DAS-SFR-SC2}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-SFR-SC3}$	0	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{\left(1-\alpha^2\right) N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR3}, N_{RB^{(F)}}^{Con-HFR3}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR1}, N_{RB^{(F)}}^{Con-HFR1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$

TABLE 2. Simulation Parameters

Parameters	Value
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1+37.6 \log_{10}(R(km))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms

CommScope Ex. 1002

WHAT IS CLAIMED IS:

1. A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. The method of claim 1 wherein the DRUs comprise remote radio units.

3. The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical

footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

ABSTRACT OF THE DISCLOSURE

A method for routing and switching operator RF signals includes providing one or more Digital Remote Units (DRUs) and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

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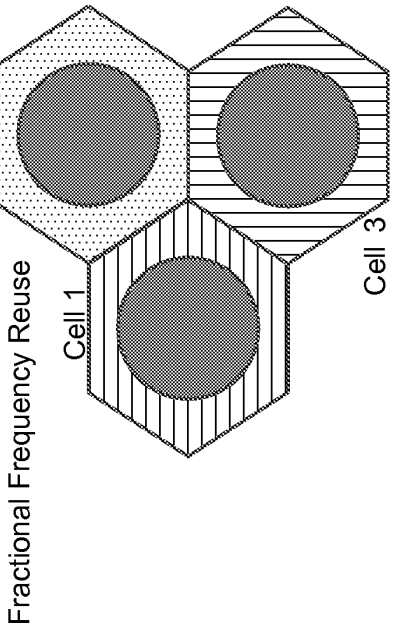


FIG. 1B

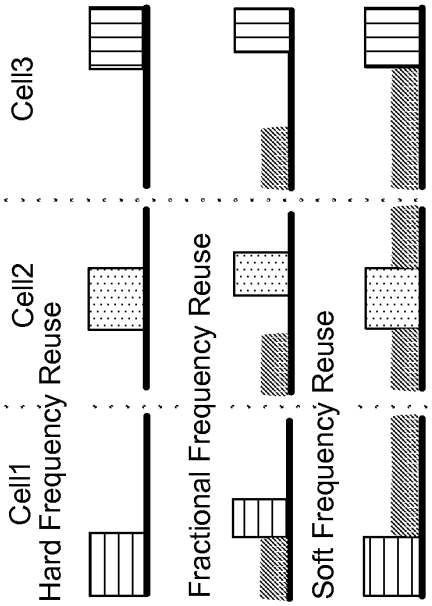


FIG. 1D

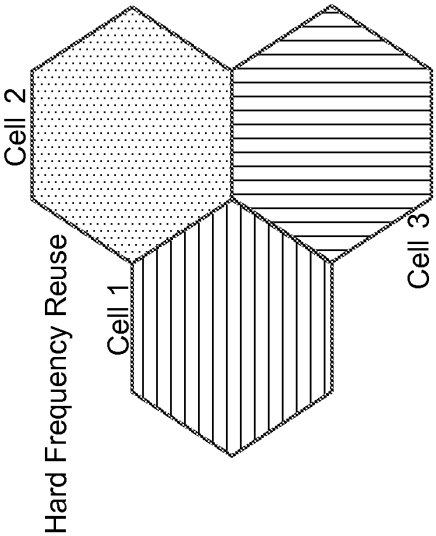


FIG. 1A

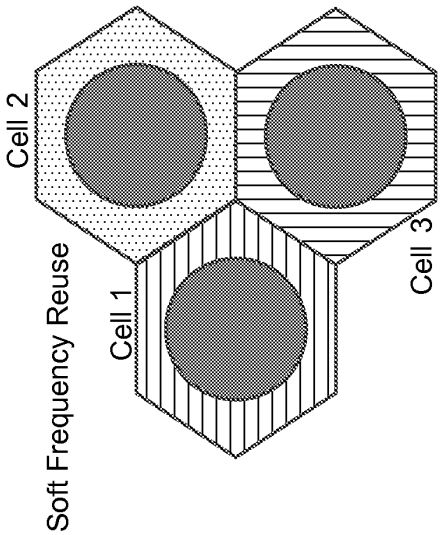


FIG. 1C

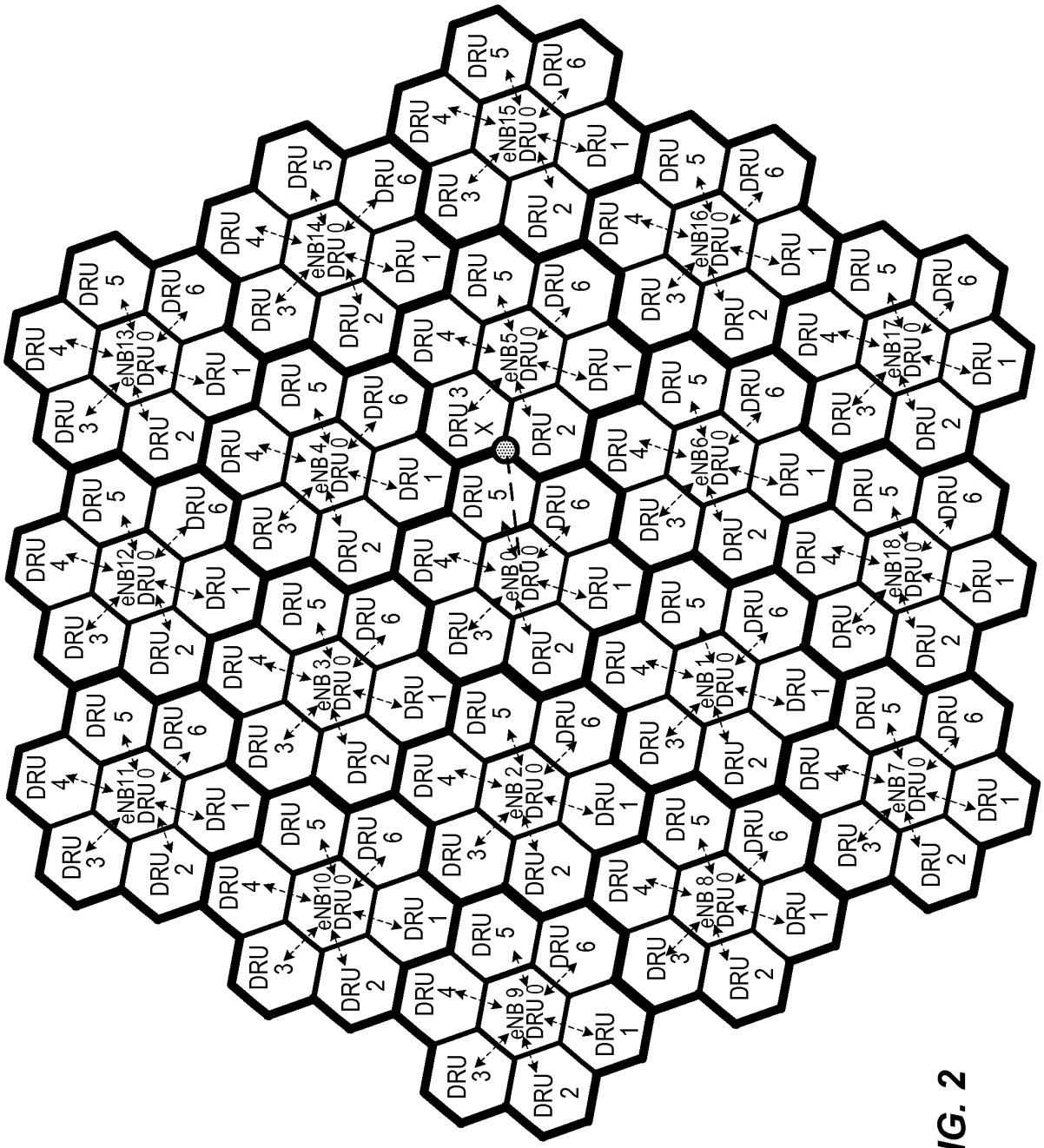

DRU 3
DRU 2
DRU 4
DRU 1
DRU 5
DRU 6
DRU 0
eNB 1
eNB 2
eNB 3
eNB 4
eNB 5
eNB 6
eNB 7
eNB 8
eNB 9
eNB10
eNB11
eNB12
eNB13
eNB14
eNB15
eNB16
eNB17
eNB18
X

FIG. 2

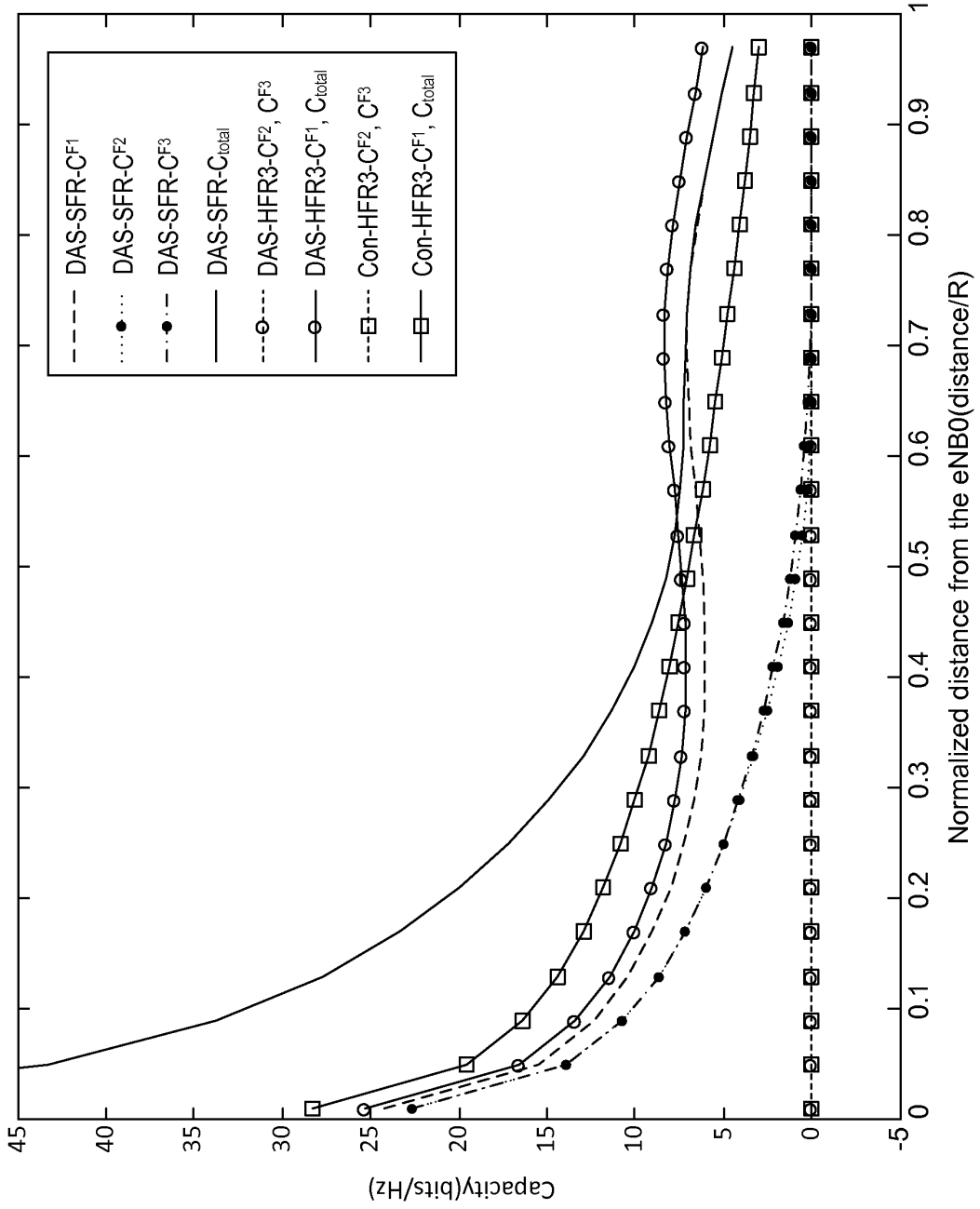

DAS-SFR-C^F1
DAS-SFR-C^F2
DAS-SFR-C^F3
DAS-SFR-C_total
DAS-HFR3-C^F2, C^F3
DAS-HFR3-C^F1, C_total
Con-HFR3-C^F2, C^F3
Con-HFR3-C^F1, C_total
Capacity(bits/Hz)
Normalized distance from the eNB0(distance/R)
45
40
35
30
25
20
15
10
5
0
-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 3

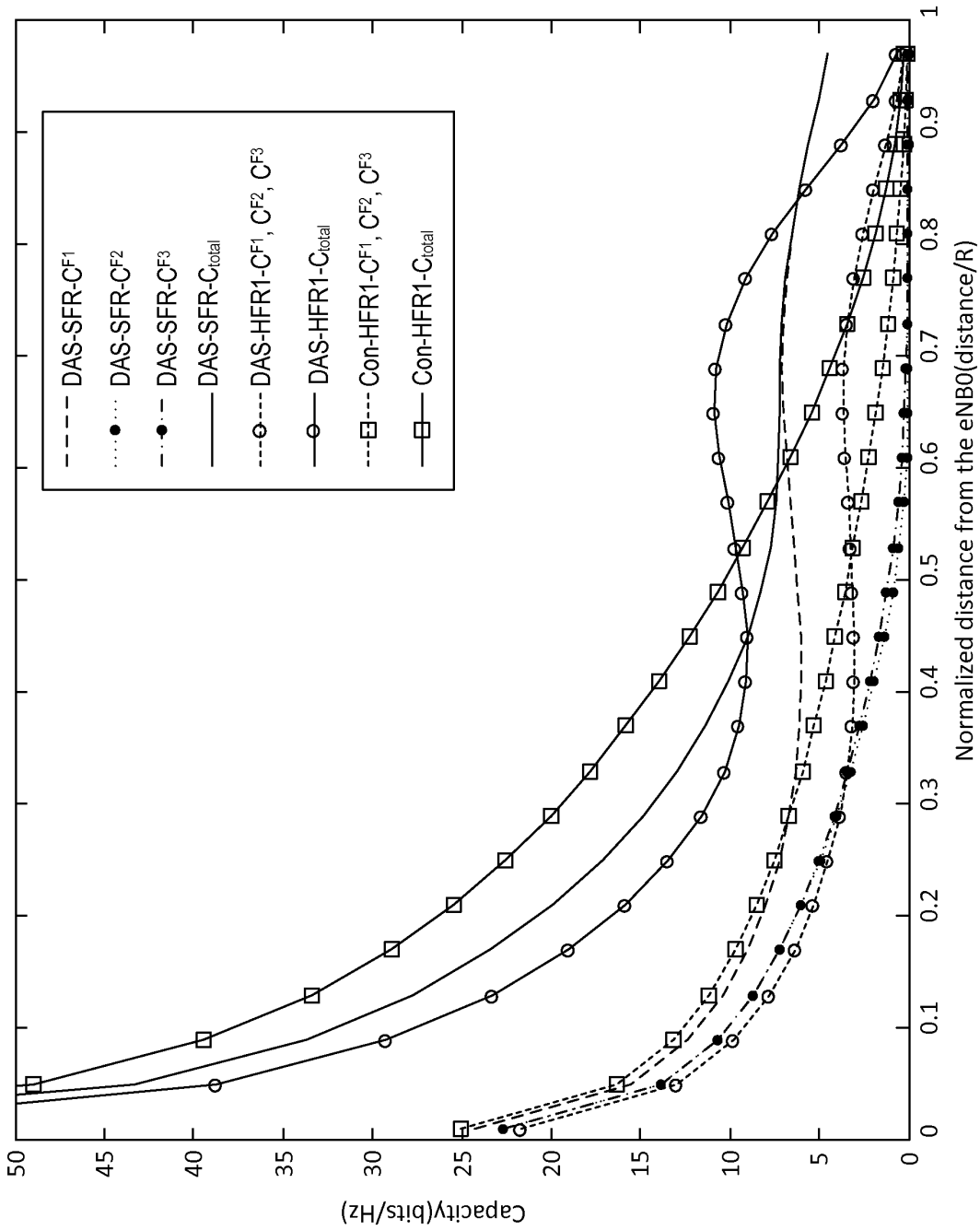

DAS-SFR-C^F1
DAS-SFR-C^F2
DAS-SFR-C^F3
DAS-SFR-C_total
DAS-HFR1-C^F1, C^F2, C^F3
DAS-HFR1-C_total
Con-HFR1-C^F1, C^F2, C^F3
Con-HFR1-C_total
Capacity(bits/Hz)
Normalized distance from the eNB0(distance/R)
0
5
10
15
20
25
30
35
40
45
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 4

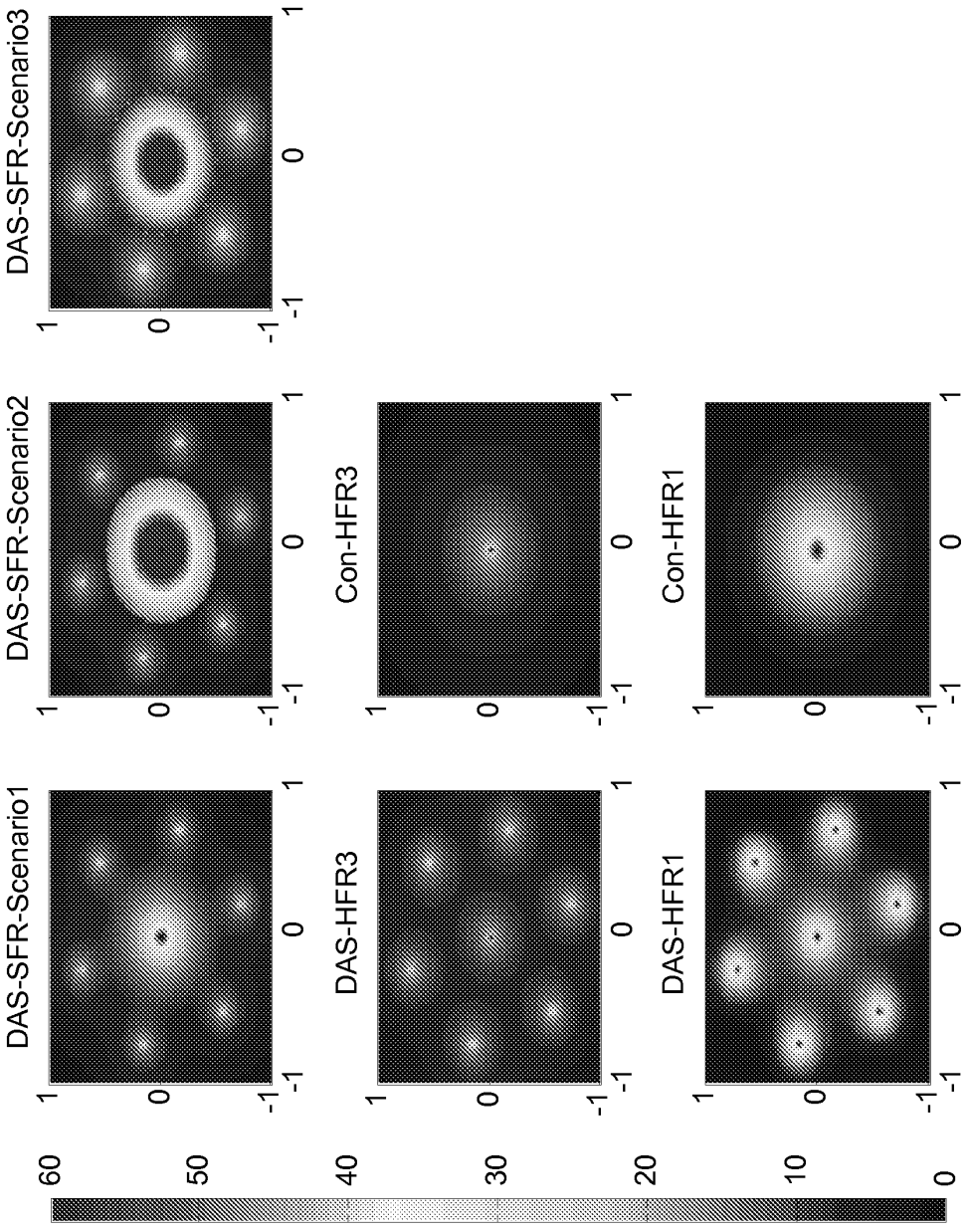

DAS-SFR-Scenario1
DAS-SFR-Scenario2
DAS-SFR-Scenario3
DAS-HFR3
Con-HFR3
DAS-HFR1
Con-HFR1
60
50
40
30
20
10
0
1
0
-1

FIG. 5

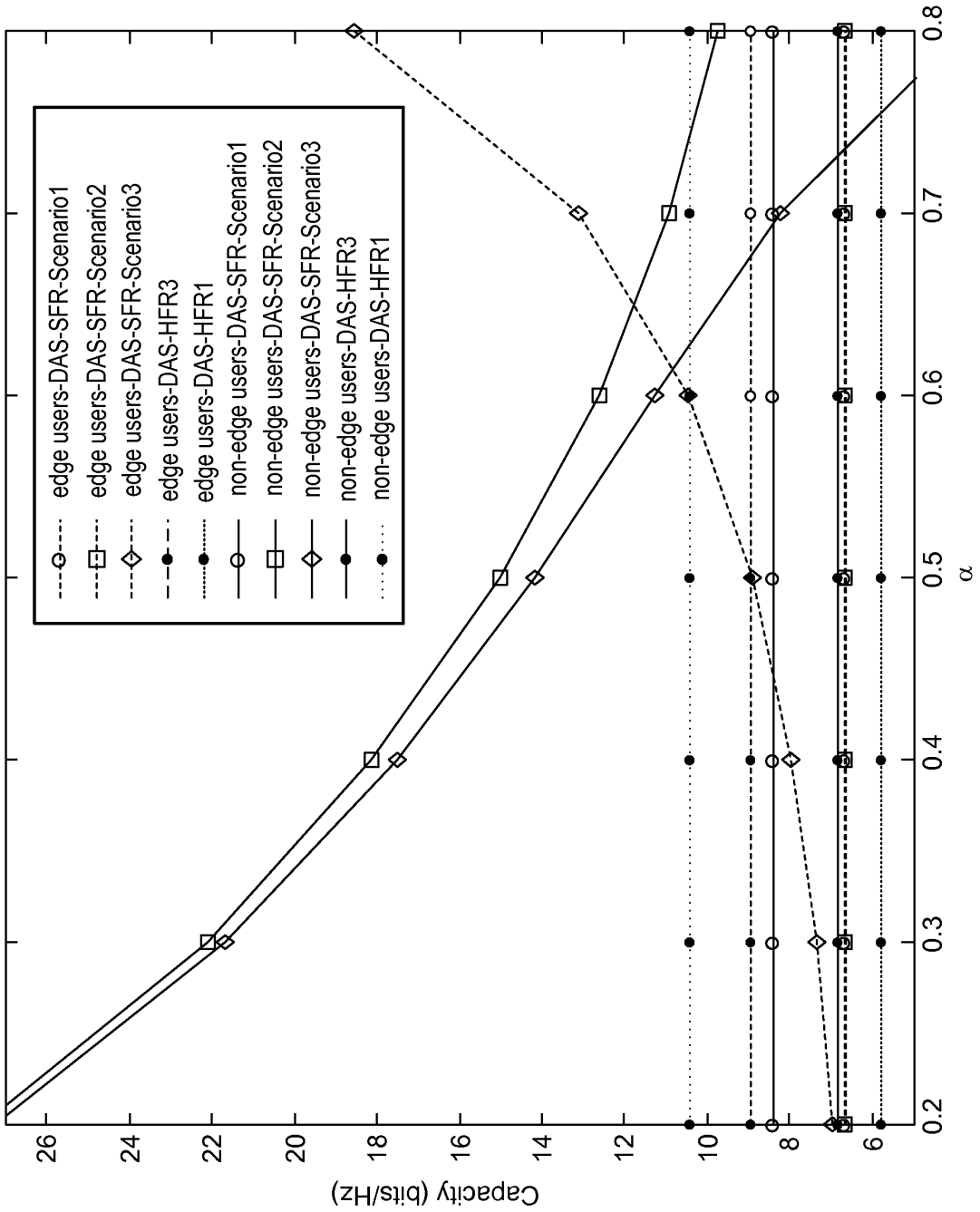

edge users-DAS-SFR-Scenario1
edge users-DAS-SFR-Scenario2
edge users-DAS-SFR-Scenario3
edge users-DAS-HFR3
edge users-DAS-HFR1
non-edge users-DAS-SFR-Scenario1
non-edge users-DAS-SFR-Scenario2
non-edge users-DAS-SFR-Scenario3
non-edge users-DAS-HFR3
non-edge users-DAS-HFR1
Capacity (bits/Hz)
α
26
24
22
20
18
16
14
12
10
8
6
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIG. 6

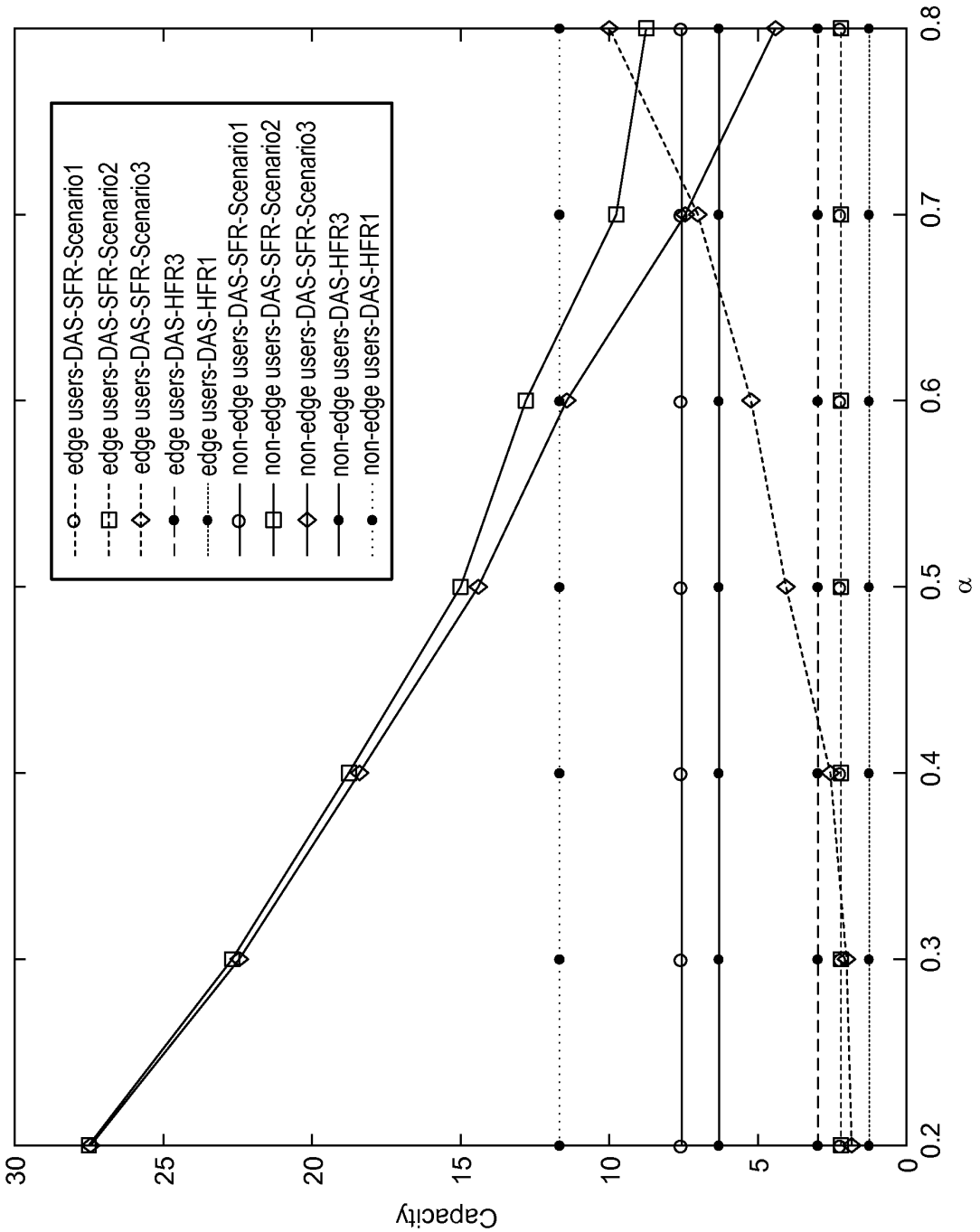

edge users-DAS-SFR-Scenario1
edge users-DAS-SFR-Scenario2
edge users-DAS-SFR-Scenario3
edge users-DAS-HFR3
edge users-DAS-HFR1
non-edge users-DAS-SFR-Scenario1
non-edge users-DAS-SFR-Scenario2
non-edge users-DAS-SFR-Scenario3
non-edge users-DAS-HFR3
non-edge users-DAS-HFR1
Capacity
α
0
5
10
15
20
25
30
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIG. 7

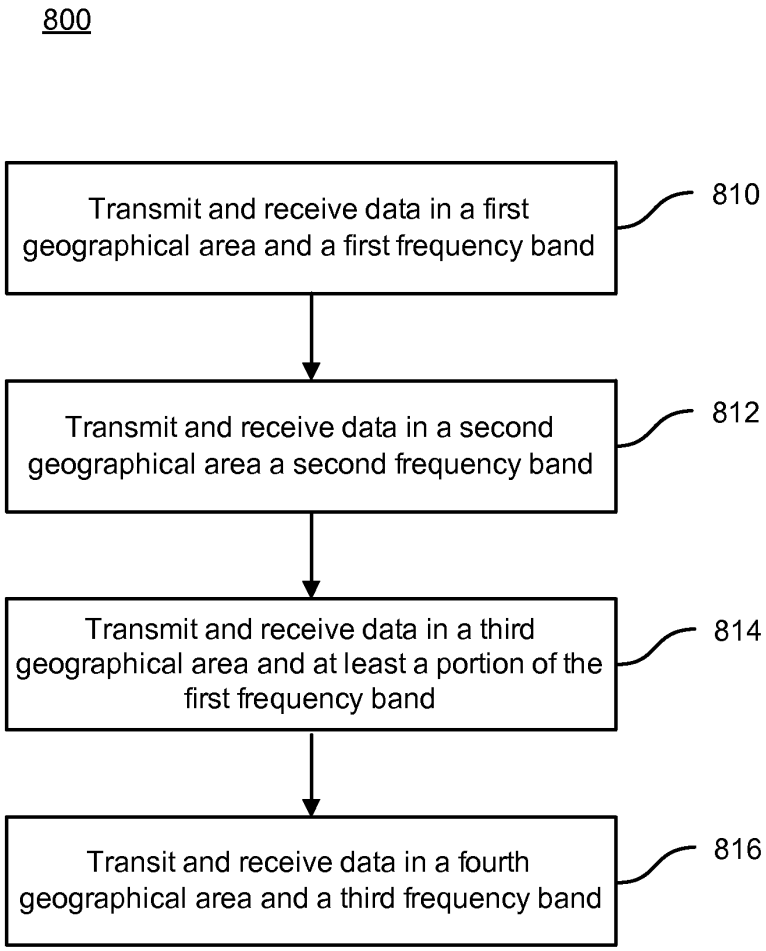

800
Transmit and receive data in a first geographical area and a first frequency band
810
Transmit and receive data in a second geographical area a second frequency band
812
Transmit and receive data in a third geographical area and at least a portion of the first frequency band
814
Transit and receive data in a fourth geographical area and a third frequency band
816

FIG. 8

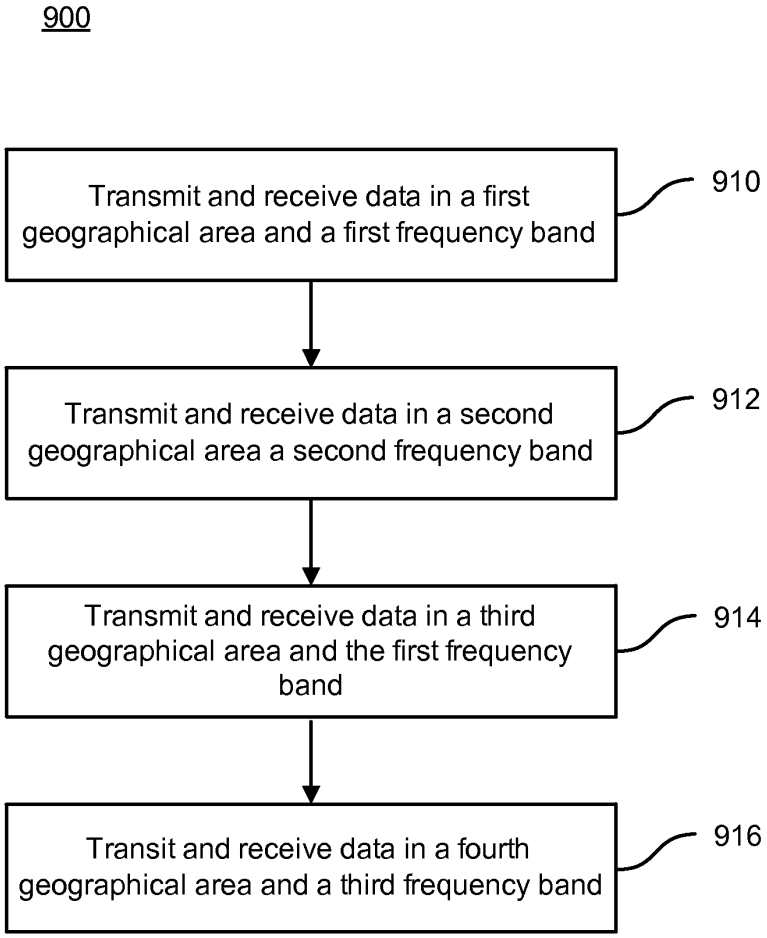

900
Transmit and receive data in a first geographical area and a first frequency band
910
Transmit and receive data in a second geographical area a second frequency band
912
Transmit and receive data in a third geographical area and the first frequency band
914
Transit and receive data in a fourth geographical area and a third frequency band
916

FIG. 9

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Seyed	Amin	Hejazi	

Residence Information (Select One) ○ US Residency ◉ Non US Residency ○ Active US Military Service

City	Burnaby, BC	Country of Residence i	CA

Mailing Address of Inventor:

Address 1	Maples Corporate Services Limited		
Address 2	P.O. Box 309, Ugland House, South Church Street		
City	George Town, Grand Cayman	**State/Province**	
Postal Code	KY1-1104	**Country** i	KY

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Shawn	Patrick	Stapleton	

Residence Information (Select One) ○ US Residency ◉ Non US Residency ○ Active US Military Service

City	Burnaby, BC	Country of Residence i	CA

Mailing Address of Inventor:

Address 1	Maples Corporate Services Limited		
Address 2	P.O. Box 309, Ugland House, South Church Street		
City	George Town, Grand Cayman	**State/Province**	
Postal Code	KY1-1104	**Country** i	KY

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).			
☐ **An Address is being provided for the correspondence Information of this application.**			
Customer Number	20350		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM		
Attorney Docket Number	91172-866895(103600US)	**Small Entity Status Claimed**	☒
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	9	**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	20350		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61649143	2012-05-18

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(d). When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) [i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(h)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country [i]	Filing Date (YYYY-MM-DD)	Access Code [i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.

Authorization to Permit Access:

☒ Authorization to Permit Access to the Instant Application by the Participating Offices

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

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Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

(•) Assignee	( ) Legal Representative under 35 U.S.C. 117	( ) Joint Inventor
( ) Person to whom the inventor is obligated to assign.	( ) Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. [X]

Organization Name	DALI SYSTEMS CO. LTD.		
Mailing Address Information:			
Address 1	Maples Corporate Services Limited		
Address 2	P.O. Box 309, Ugland House, South Church Street		
City	George Town, Grand Cayman	**State/Province**	
Country [i]	KY	Postal Code	KY1-1104
Phone Number		Fax Number	

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

Email Address	

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Non-Applicant Assignee Information:

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Assignee 1

Complete this section only if non-applicant assignee information is desired to be included on the patent application publication in accordance with 37 CFR 1.215(b). Do not include in this section an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest), as the patent application publication will include the name of the applicant(s).

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If the Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

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Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications

Signature	/Craig C. Largent/			Date (YYYY-MM-DD)	2013-05-14
First Name	Craig	Last Name	Largent	Registration Number	56400

Additional Signature may be generated within this form by selecting the Add button. Add

PTO/AIA/14 (03-13)
Approved for use through 01/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	91172-866895(103600US)
	Application Number	
Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Electronic Acknowledgement Receipt	
EFS ID:	15777683
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Craig Cody Largent
Filer Authorized By:	
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	14-MAY-2013
Filing Date:	
Time Stamp:	19:57:53
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		PatentApp_DW1036.pdf	235586 9f3b2752f3a9d8d35ddaeb5b806dbf1d46fca396	yes	35

	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Specification		1	30	
	Claims		31	34	
	Abstract		35	35	
Warnings:					
Information:					
2	Drawings-only black and white line drawings	Drawings.pdf	260184 9e4fe0191f562234feae823c2f5ea0ad476238c8	no	9
Warnings:					
Information:					
3	Application Data Sheet	ADS.pdf	1508039 643187023ea1d376f76b8418a5c9801148b56588	no	7
Warnings:					
Information:					
		Total Files Size (in bytes):	2003809		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

SCORE Placeholder Sheet for IFW Content

Application Number: 13894309 Document Date: 05/14/2013

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

- Drawings – Other than Black and White Line Drawings

Since this was an electronic submission, there is no physical artifact folder, no artifact folder is recorded in PALM, and no paper documents or physical media exist. The TIFF images in the IFW record were created from the original documents that are stored in SCORE.

To access the documents in the SCORE database, refer to instructions developed by SIRA.

At the time of document entry (noted above):

- Examiners may access SCORE content via the eDAN interface.
- Other USPTO employees can bookmark the current SCORE URL (http://es/ScoreAccessWeb/).
- External customers may access SCORE content via the Public and Private PAIR interfaces.

Form Revision Date: February 8, 2006

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FORMALITIES LETTER

OC000000061957377

Date Mailed: 06/26/2013

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
  *Applicant must submit $**70** to complete the basic filing fee for a small entity.*

The application is informal since it does not comply with the regulations for the reason(s) indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A substitute specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125, is required. The substitute specification must be submitted with markings and be accompanied by a clean version (without markings) as set forth in 37 CFR 1.125(c) and a statement that the substitute specification contains no new matter (see 37 CFR 1.125(b)). The specification, claims, and/or abstract page(s) submitted is not acceptable and cannot be scanned or properly stored because:
  - The application contains drawings, but the specification does not contain a brief description of the several views of the drawings as required by 37 CFR 1.74 and 37 CFR 1.77(b)(7).
- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 1d. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(7).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Additional claim fees of $ **40** as a small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due.
- A surcharge (for late submission of the basic filing fee, search fee, examination fee or inventor's oath or declaration) as set forth in 37 CFR 1.16(f) of $ **70** for a small entity in compliance with 37 CFR 1.27, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is $ **840** for a small entity
- $ **70** Statutory basic filing fee.
- $ **70** Surcharge.
- The application search fee has not been paid. Applicant must submit $ **300** to complete the search fee.
- The application examination fee has not been paid. Applicant must submit $ **360** to complete the examination fee for a small entity in compliance with 37 CFR 1.27.
- Total additional claim fee(s) for this application is $ **40**
  - $ **40** for **1** total claims over 20.

Items Required To Avoid Processing Delays:

Applicant is notified that the above-identified application contains the deficiencies noted below. No period for reply is set forth in this notice for correction of these deficiencies. However, if a deficiency relates to the inventor's oath or declaration, the applicant must file an oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each actual inventor no later than the expiration of the time period set in the "Notice of Allowability" to avoid abandonment. See 37 CFR 1.53(f).

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  Seyed Amin Hejazi
  Shawn Patrick Stapleton
  Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/jmilani/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/894,309

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	70		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	300		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	360		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	21 minus 20 =	* 1	x 40 =	40	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 210 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	770		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)	OR	RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/894,309	05/14/2013	2649	0.00	91172-866895(103600US)	21	3

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FILING RECEIPT

OC000000061957376

Date Mailed: 06/26/2013

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Seyed Amin Hejazi, Burnaby, CANADA;
Shawn Patrick Stapleton, Burnaby, CANADA;

Applicant(s)

DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS

Assignment For Published Patent Application

DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/649,143 05/18/2012

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access - A proper **Authorization to Permit Access to Application by Participating Offices** (PTO/SB/39 or its equivalent) has been received by the USPTO.

If Required, Foreign Filing License Granted: 06/13/2013
The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/894,309**
Projected Publication Date: To Be Determined - pending completion of Missing Parts
Non-Publication Request: No

Early Publication Request: No
** **SMALL ENTITY** **
Title

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

Preliminary Class

455

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

81172-725400

PTO/AIA/82B (07-12)
Approved for use through 11/30/2014. OMB 0651-0035
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
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POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

☒ Practitioners associated with Customer Number: 20350

OR

☐ Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number	Name	Registration Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:

☒ The address associated with Customer Number: 20350

OR

☐ Firm or Individual Name			
Address			
City		State	Zip
Country			
Telephone		Email	

Assignee Name and Address: DALI SYSTEMS CO. LTD.
Maples Corporate Services Limited
PO Box 309, Ugland House, South Church Street
George Town, Grand Cayman KY1-1104, Cayman Islands

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/SB/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of the practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee

Signature		Date	9/23/12
Name	Albert S. Lee	Telephone	604 420 3760
Title	President & CEO		

This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Dali Systems Co. Ltd.

Application No./Patent No.: 13/894,309 Filed/Issue Date: May 14, 2013

Titled: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

Dali Systems Co. Ltd. , a corporation
(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of options 1, 2, 3 or 4 below):

1. ☒ The assignee of the entire right, title, and interest; or
2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):
   ☐ The extent (by percentage) of its ownership interest is %. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.
   ☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire ownership interest.
3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.
4. ☐ The recipient, via a court proceeding or the like (*e.g.* bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

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B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

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This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450. If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

STATEMENT UNDER 37 CFR 3.73(c)

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☐ Additional documents in the chain of title are listed on a supplemental sheet.

☒ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[**NOTE**: A separate copy (*i.e.*, a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Craig C. Largent/	September 26, 2013
Signature	Date
Craig C. Largent	(650) 326-2400
Printed or Typed Name	Telephone Number
Attorney 56,400	
Title	

This collection of information is required by 37 CFR 3.73(c). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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Attorney Docket No.: 91172-866895(103600US)

ASSIGNMENT OF PATENT APPLICATION

JOINT

WHEREAS, Seyed Amin Hejazi of Burnaby, BC, Canada; and Shawn Patrick Stapleton of Burnaby, BC, Canada., hereinafter referred to as "Assignors," is the inventor of the invention described and set forth in the below-identified application for United States Letters Patent:

Title of Invention: **METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM**

Date(s) of execution of Declaration: May 30, June 13

Filing Date: May 14, 2013

Application No.: 13/894,309; and

WHEREAS, DALI SYSTEMS CO. LTD., located at Maples Corporate Services Limited, P.O. Box 309, Ugland House, South Church Street, George Town, Grand Cayman KY1-1104, Cayman Islands, hereinafter referred to as "ASSIGNEE," is desirous of acquiring an interest in the invention and application and in any U.S. Letters Patent and Registrations which may be granted on the same;

For good and valuable consideration, receipt of which is hereby acknowledged by Assignor, Assignor has assigned, and by these presents does assign to Assignee all right, title and interest in and to the invention and application and to all foreign counterparts (including patent, utility model and industrial designs), and in and to any Letters Patent and Registrations which may hereafter be granted on any patent application claiming priority from the same in the United States and all countries throughout the world, and to claim the priority from the application as provided by the Paris Convention. The right, title and interest is to be held and enjoyed by Assignee and Assignee's successors and assigns as fully and exclusively as it would have been held and enjoyed by Assignor had this Assignment not been made, for the full term of any Letters Patent and Registrations which may be granted thereon, or of any division, renewal, continuation in whole or in part, substitution, conversion, reissue, prolongation or extension thereof.

Assignors further agree that Assignors will, without charge to Assignors, but at Assignee's expense, (a) cooperate with Assignee in the prosecution of U.S. Patent applications and foreign counterparts on the invention and any improvements, (b) execute, verify, acknowledge and deliver all such further papers, including applications and instruments of transfer, and (c) perform such other acts as Assignee lawfully may request to obtain or maintain Letters Patent and Registrations for the invention and improvements in any and all countries, and to vest title thereto in Assignee, or Assignee's successors and assigns.

IN TESTIMONY WHEREOF, Assignor has signed his/her name on the date indicated.

Dated: June 13, 2013

Seyed Amin Hejazi

Dated: May 30, 2013

Shawn Patrick Stapleton

Electronic Patent Application Fee Transmittal

Application Number:	13894309
Filing Date:	14-May-2013
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Filer:	Craig Cody Largent/Kristina Alvarez
Attorney Docket Number:	91172-866895(103600US)

Filed as Small Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility filing Fee (Electronic filing)	4011	1	70	70
Utility Search Fee	2111	1	300	300
Utility Examination Fee	2311	1	360	360
Pages:				
Claims:				
Claims in excess of 20	2202	1	40	40
Miscellaneous-Filing:				
Late Filing Fee for Oath or Declaration	2051	1	70	70

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Extension - 1 month with $0 paid	2251	1	100	100
Miscellaneous:				
		Total in USD ($)		**940**

Electronic Acknowledgement Receipt	
EFS ID:	16972207
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Craig Cody Largent/Kristina Alvarez
Filer Authorized By:	Craig Cody Largent
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	26-SEP-2013
Filing Date:	14-MAY-2013
Time Stamp:	21:18:56
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$940
RAM confirmation Number	7869
Deposit Account	201430
Authorized User	LARGENT, CRAIG C.
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees) Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)	

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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		CleanVerSpec.pdf	241924 7f09d93f734896bacd87ea07abb4b731bd7c34ec	yes	35

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Specification	1	30
	Claims	31	34
	Abstract	35	35

Warnings:					
Information:					
2		MarkedUpSpec.pdf	242720 0fe0f3ca08f4ea5921a23b3c3854801373f1ab62	yes	35

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Specification	1	30
	Claims	31	34
	Abstract	35	35

Warnings:					
Information:					
3	Oath or Declaration filed	Declaration103600US.pdf	558212 9b1b18b0378c2e17c7747ec4ec306ee4bab2b9c7	no	2
Warnings:					
Information:					
4	Power of Attorney	PwrAtty.pdf	276352 3bb8fa7bb835ce3fe7c8aafd6e1b1ab7801fe1fa	no	1
Warnings:					
Information:					

5	Assignee showing of ownership per 37 CFR 3.73.	373c.pdf	377235 b28ec7230dc9dd431d0befb807a2ea9f47889bee	no	3
Warnings:					
Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	40405 59b9d0c5e3aba767f644ed1e65880a99d3335679	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	1736848		

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National Stage of an International Application under 35 U.S.C. 371
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New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Attorney Docket No.: 91172-866895(103600US)
Client Reference No.: DW-1036

-Clean Version of Specification-

PATENT APPLICATION

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

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METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/649,143, filed on May 18, 2012, entitled "Method and System for Soft Frequency Reuse in a Distributed Antenna System," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] Wireless communication systems employing Distributed Antenna Systems (DAS) are available. A DAS typically includes one or more host units, optical fiber cable or other suitable transport infrastructure, and multiple remote antenna units. A radio base station is often employed at the host unit location commonly known as a base station hotel, and the DAS provides a means for distribution of the base station's downlink and uplink signals among multiple remote antenna units. The DAS architecture with routing of signals to and from remote antenna units can be either fixed or reconfigurable.

[0003] A DAS is advantageous from a signal strength and throughput perspective because its remote antenna units are physically close to wireless subscribers. The benefits of a DAS include reducing average downlink transmit power and reducing average uplink transmit power, as well as enhancing quality of service and data throughput.

[0004] Despite the progress made in wireless communications systems, a need exists for improved methods and systems related to wireless communications.

SUMMARY OF THE INVENTION

[0005] The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS) as part of a distributed wireless network. More specifically, the present invention relates to a DAS utilizing Soft Frequency Reuse or Fractional Frequency Reuse techniques. In a particular embodiment, the present invention has been applied to the

reuse of communications frequencies in central portions of adjacent DAS cells, improving system data rates and performance. The methods and systems described herein are applicable to a variety of communications systems including systems utilizing various communications standards.

[0006] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies, and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU in a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU in a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

[0007] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

[0008] According to a specific embodiment of the present invention, a communications system is provided. The communications system includes a host unit and a first communications unit

coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint. The communications system also includes a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

[0009] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU of a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a plurality of additional DRUs of the first cell are operable to communicate using a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint surrounding the first geographic footprint. A first DRU of a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a plurality of additional DRUs of the second cell are operable to communication using a third set of frequencies characterized by a third frequency band different from the first frequency band over a fourth geographic range surrounding the third geographic range.

[0010] The DRUs can comprise remote radio units. The method may also include communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU. One or more of the plurality of BTSs can be coupled to the DAU using a plurality of BTS sector RF connections. The method may further include transporting signals between one or more DRUs and the at least one DAU.

[0011] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units in an array configuration and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized

by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic range surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint surrounding the third geographical footprint.

[0012] In an embodiment, the set of communications units include a plurality of remote units in communication with a host unit. The first geographic footprint can be centered on the first communications unit. The second geographic footprint can be a peripheral footprint centered on the first communications unit. The third geographical footprint can be centered on the second communications unit. The fourth geographical footprint can be a peripheral footprint centered on the second communications unit. The second geographical footprint can abut the fourth geographical footprint. The method can also include transmitting, and receiving, from a third communications unit of the set of communications units, a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint surrounding the fifth geographical footprint.

[0013] According to yet another embodiment, a communications system is provided. The communications system includes a first communications unit operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint and a second communications unit operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and one or more of the second set of frequencies in a region associated with a fourth geographical footprint.

[0014] The first communications unit can include a central DRU and a plurality of peripheral DRUs disposed adjacent the central DRU. The system can also include a DAU communicatively coupled to the central DRU and the plurality of peripheral DRUs. In an embodiment, the system includes a DAU communicatively coupled to the central DRU. Additionally, a second DAU can

be communicatively coupled to the plurality of peripheral DRUs. In an embodiment, the second geographical footprint at least partially surrounds the first geographical footprint. In another embodiment, the fourth geographical footprint at least partially surrounds the third geographical footprint or the second geographical footprint at least partially overlaps the fourth geographical footprint.

[0015] According to a specific embodiment, a frequency sharing system for a distributed antenna system is provided. The frequency sharing system includes a first frequency band characterized by a first frequency range and associated with a first geographic area associated with a first communications unit and a second frequency band characterized by a second frequency range different from the first frequency range and associated with a second geographic area at least partially surrounding the first geographic area. The frequency sharing system also includes a third frequency band overlapping at least a portion of the second frequency band and associated with a third geographic area associated with a second communications unit and a fourth frequency band overlapping at least a portion of the first frequency band and associated with a fourth geographic area at least partially surrounding the third geographic area.

[0016] The first geographic area can be characterized by a first border and the second geographic area can be characterized by a second border, wherein a predetermined distance separates the first border and the second border. The first frequency band and the second frequency band can be contiguous frequency bands. In an embodiment, the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent the first frequency band.

[0017] According to another specific embodiment, a communications system is provided and includes a first communications unit operable to transmit and receive communications using a first set of frequencies over a first predetermined area and a second communications unit operable to transmit and receive communications using a second set of frequencies over a second predetermined area. The first communications unit is operable to transmit and receive communications using a third set of frequencies over a third predetermined area and the second communications unit is operable to transmit and receive communications using at least a portion of the third set of frequencies over a fourth predetermined area.

[0018] The first communications unit can include a plurality of DRUs, at least one of the plurality of DRUs being coupled to a DAU. The third predetermined area can be at least

partially surrounded by the first predetermined area and the fourth predetermined area can be at least partially surrounded by the second predetermined area. In an embodiment, the first set of frequencies, the second set of frequencies, and the third set of frequencies are distinct frequencies. The first communications unit and the second communications unit can be disposed in an array configuration. The first predetermined area overlaps at least a portion of the second predetermined area in some implementations and the third predetermined area includes a location of the first communications unit and the fourth predetermined area includes a location of the second communications unit. The first communications unit can include a first plurality of digital remote units and the second communications unit comprises a second plurality of digital remote units. The first set of frequencies can be associated with a first number of the first plurality of digital remote units and the third set of frequencies can be associated with another of the first plurality of digital remote units. The second set of frequencies can be associated with a first number of the second plurality of digital remote units and the third set of frequencies can be associated with another of the second plurality of digital remote units.

[0019] Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIGS. 1A - 1C illustrate different frequency reuse techniques according to embodiments of the present invention;

[0020.A] FIG. 1D illustrates, for each case Hard Frequency Reuse, Fractional Reuse, and Soft Frequency Reuse, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0021] FIG. 2 illustrates the structure of a Distributed Antenna System (DAS) according to an embodiment of the present invention;

[0022] FIG. 3 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to an embodiment of the present invention;

[0023] FIG. 4 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to another embodiment of the present invention;

[0024] FIG. 5 illustrates a capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area according to an embodiment of the present invention;

[0025] FIG. 6 is a plot illustrating analytical ergodic capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention; and

[0026] FIG. 7 is a plot illustrating simulation capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention.

[0027] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention; and

[0028] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0029] Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency.

[0030] Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the transmission scheme for the next generation wireless communication systems. However, the downlink performance of cellular networks is known to be strongly limited by inter-cell interference in OFDMA based systems. In order to mitigate this interference, a number of techniques have recently been proposed, e.g. the Soft Frequency Reuse (SFR) scheme and Distributed Antenna System (DAS). According to embodiments of the present invention, these two techniques are combined in a unique cell architecture, which can be referred to as DAS-SFR. In an implementation of this architecture, which is described herein, the antennas are distributed in a hexagonal cell such that the central antenna is responsible for serving a special area using multiple frequency bands (e.g., all of the frequency bands) while the remaining antennas utilize

only a subset of the frequency bands based on a frequency reuse factor. The inventors have analytically quantified the performance of the downlink multi-cell DAS-SFR in terms of the individual user's throughput under three different resource allocation scenarios. The results show that DAS-SFR reduces inter-cell interference in a multi-cell environment for users near the cell boundaries as compared to a Hard Frequency Reuse (HFR) scheme with a frequency reuse factor of 1. The results also show that DAS-SFR significantly increases the system capacity as compared to the HFR scheme with a frequency reuse factor of 3.

[0031] In DAS-SFR, by controlling the amount of resources allocated to users located in different areas, embodiments of the present invention increase the frequency efficiency and also improve the data rate for cell edge users. If the throughput requirement for the interior users is small, more resources can be assigned to the exterior users.

[0032] In the next generation wireless communication systems that use the 3GPP LTE (Long Term Evolution) standard, there is tremendous pressure to support a high data rate transmission. These systems are based on Orthogonal Frequency Division Multiple Access (OFDMA) to support the high data rate service and improve the Quality of Service (QoS), even for cell edge users as the main targets in the downlink.

[0033] The system bandwidth is divided into a number of sub-carriers in an OFDMA-based system such that each user utilizes a bandwidth smaller than the systems coherence bandwidth. Data from different users is transmitted in parallel on different sub-carriers. The orthogonality amongst the sub-carriers mitigates inter-carrier interference (ICI) while the resulting large OFDM symbol time and the narrow sub-carrier bandwidth reduces the effect of inter-symbol interference (ISI). Users located at the cell edge largely suffer from co-channel interference (CCI) or inter-cell interference from base stations (BS) of neighboring cells. Mobile 3GPP LTE adopts a frequency reuse factor of one, in which each cell serves users using the entire system bandwidth.

[0034] In order to reduce interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are three potential ways to reduce interference in cellular systems but these require a more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes(CLMD) and Beamforming are three other

techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beamforming sacrifice spatial dimensions and require channel state knowledge.

[0035] One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a distributed antenna systems (DAS), which also has the additional advantage of improving capacity and coverage.

[0036] Other possible strategies include Frequency Reuse techniques, which effectively reduce inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

[0037] Distributed Antenna System (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems. As opposed to a conventional cellular system, where the antenna is centrally located, a DAS network consists of antenna modules that are geographically distributed to reduce access distance. These distributed antennas are connected to an eNodeB (eNB) LTE system by dedicated wires, fiber optics, or via a radio frequency link.

[0038] DAS has advantages including throughput improvement, coverage improvement, increased cellphone battery life, and a reduction in transmitter power. Recent research has shown benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is a Virtual DAS, wherein each remote has the added flexibility of independently transmitting preselected carriers.

[0039] Frequency reuse techniques are utilized herein to reduce inter-cell interference in cellular systems. This benefits users near the cell edges owing to simplicity and practicality. There are three major frequency reuse patterns illustrated in FIG. 1 for mitigating inter-cell interference: Hard Frequency Reuse, Fractional Frequency Reuse and Soft Frequency Reuse.

[0040] Hard Frequency Reuse (HFR) splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub-bands. This inter-cell interference mitigation method is typically seen in GSM networks, when it comes to distribution of frequencies among the cells. When applied to LTE, the Resource Blocks (a group of sub-carriers) are divided into 3, 4 or 7 disjoint sets. These sets of Resource

Blocks (RBs) are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies, as illustrated in FIG. 1A. FIG. 1D shows, for each case (Hard Frequency Reuse (FIG. 1A), Fractional Frequency Reuse (FIG. 1B), and Soft Frequency Reuse (FIG. 1C)), the transmit/receive power as a function of frequency. This reduces the interference at the cell edge of any pair of cells significantly and can be considered the opposite extreme to Full Frequency Reuse in matters of frequency partitioning techniques. While user interference at the cell edge is maximally reduced, the spectrum efficiency drops by a factor equal to the reuse factor. The inter-cell interference can be reduced with a frequency reuse factor of more than one, however, it may reduce the system capacity.

[0041] Fractional Frequency Reuse (FFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. OFDMA provides the ability for each eNB to selectively allocate frequency sub-bands, data rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. FFR splits the given bandwidth into an inner and an outer region as illustrated in FIG. 1B. The spectrum allocated to the inner region is assigned to the nearby users (located close to the eNB in terms of path loss) applying a frequency reuse factor of one (i.e. the inner part is completely reused by all eNBs). While the spectrum allocated to the outer region, for users close to the cell edge (far users), is divided among the different eNBs as in hard frequency reuse techniques. This scheme is particularly useful to mitigate the inter-cell interference in the uplink, where severe interference situations can occur when the user is located close to a strong interferer from a neighbor cell.

[0042] Soft Frequency Reuse (SFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. SFR shares the overall bandwidth by all eNBs (i.e. a reuse factor of one is applied), but for transmission on each group of RBs, the eNBs are restricted to a certain power bound. FIG. 1C illustrates the power and frequency assignments in the different cells of a system with SFR for a reuse factor of 3. It can be noticed in the frequency spectrum of FIG. 1D associated with Soft Frequency Reuse (i.e., FIG. 1C), that there is a region of high-power transmissions and some regions of low-power transmissions. Using a similar strategy extending Fractional Frequency Reuse, resources in the high-power region are preferably assigned to User Equipment (UEs) located at the cell edge, while cell-center UEs are typically assigned resources in the low-power regions. SFR can utilize the entire frequency spectrum that has been allocated, increasing the system data rate and/or capacity.

[0043] Referring to FIGS. 1C and 1D, frequencies in the grey frequency band (~ upper 2/3 of the available frequencies) are transmitted/received by a DRU at a first power level in Cell 1, providing coverage for the central portion of Cell 1. Frequencies in the horizontal stripes band are transmitted/received by the DRU at a second power level higher than the first power level, providing coverage over both the central portion of Cell 1 as well as the peripheral portions of Cell 1 since the higher power level results in a larger coverage area. In this example, each cell utilizes a single DRU, although other embodiments can utilize multiple DRUs per cell as described more fully herein. DRUs in the other cells also transmit/receive at both high power for a subset of the frequencies and low power for remaining frequencies as shown in FIG. 1D, producing the coverage maps illustrated in FIG. 1C, with low power frequencies providing centralized coverage and higher power frequencies providing a large coverage area extending to the peripheral regions of the cells. Although all three cells are transmitting/receiving using overlapping (or the same) frequencies at low power, the corresponding propagation distances for these frequencies are smaller, preventing geographic overlap between the central grey regions.

[0044] In order to reduce interference in areas where cells are adjacent, the frequencies associated with higher power are grouped into subbands, with little or no overlap between the subbands. Referring to FIG. 1D, in the SFR implementation, Cell 1 uses high power for the horizontal stripes band in approximately the first third of the frequency bandwidth, Cell 2 uses high power for the dotted band in approximately the second third of the frequency bandwidth, and Cell 3 uses high power for the vertical stripes band in approximately the last third of the frequency bandwidth. Thus, at the intersections between cells, since different portions of the available frequency band are being utilized, interference is reduced. Thus, in some embodiments, different frequency bands are utilized in adjacent cells, which is illustrated by the high power frequency bands for SFR in FIG. 1D: the first frequency band in Cell 1, the second frequency band different from the first frequency band in Cell 2, and the third frequency band different from the first frequency band and the second frequency band in Cell 3. For an additional number of cells, the subdivision of the available bandwidth can be increased as appropriate to the particular number of adjacent cells in the implementation. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0045] HFR, though simple in implementation, suffers from a reduced spectral efficiency. On the other hand, both SFR and FFR have increased (e.g., full) spectral efficiency and are a strong mechanism for inter-cell interference mitigation. A coordinated resource allocation system can

be impractical in realistic settings involving a large number of eNBs, random traffic and realistic path-loss models. However, an encouraging result is that by using even limited (yet practical) levels of coordination, significant performance benefits can still be obtained over a conventional cellular architecture. Most of the recent publications have focused on investigating SINR advantages of DAS and analyzing its performance. On the other hand, there are no studies that combine DAS with SFR in order to reduce inter-cell interference. Some publications on DAS have focused on analyzing the uplink performance because of its analytical simplicity and there are few studies on the downlink performance of DAS although the demand for high-speed data rate will be dominant in the downlink path. There are also very few publications that consider the advantages of DAS in a multi-cell context. Recent research on FFR and SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional works on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

[0046] According to embodiments of the present invention, a new architecture is provided to suppress inter-cell interference. The architecture described herein combines DAS and SFR for an OFDMA system (e.g., LTE). Embodiments of the present invention provide benefits by using DAS-SFR in a multi-cell environment. The downlink advantages of DAS-SFR are described in terms of achievable ergodic capacity for three different frequency resource allocation scenarios. The results shows that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture and achieves a non-trivial capacity increase over a HFR cellular architecture with a frequency reuse factor of 3. Other reuse factors are included within the scope of the present invention, for example, up to or more than 7 as suitable for the DAS architecture illustrated in FIG. 2.

[0047] As described herein, an analytical framework has been developed to evaluate the ergodic capacity in a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service, regardless of their geographic location, instead of simply a minimum user throughput which may be acceptable for applications like voice traffic. We present a strategy for optimally allocating frequency RBs to edge users for

a DAS-SFR architecture, based on a chosen performance threshold T_p, which can be related to network traffic load. Finally we prepare a simulation scenario to compare the analytical results with the simulation results.

[0048] Referring to the spectral plots illustrated in FIG. 1D, in the HFR system, the horizontal stripes, shaded, and vertical stripes frequency bands occupy different frequency ranges and, in combination, fill the entire spectrum. In HFR (FIG. 1A), cell 1 uses the lower frequencies (horizontal stripes), cell 2 uses the middle frequencies (shaded), and cell 3 uses the higher frequencies (vertical stripes).

[0049] Referring to FIG. 2, the DAS includes a central cell referenced as eNB0, which includes DRU0 through DRU6 that are communicating through one base station at eNB0 through a DAU. DRU0 can be considered to be Cell 1 in FIGS. 1A - 1C, DRU1 can be considered to be Cell 2 in FIGS. 1A - 1C, and DRU2 can be considered to be Cell 3 in FIGS. 1A - 1C. In other embodiments, eNB0 is considered to be Cell 1 in FIGS. 1A - 1C and eBN1, including a different set of DRUs, DRU0 through DRU6, can be considered to be Cell 2 in FIGS. 1A - 1C, etc. In FIG. 1A, Cell 1 (e.g., DRU0 of eNB0) utilizes the horizontal stripes frequency band and the other cells use different frequency bands as illustrated. In the embodiment illustrated in FIG. 2, seven different frequency bands could be utilized for high power transmission by the seven DRUs connected to each base station. For cells geographically separated from Cell 1, for example, cells in eNB7 could reuse the same frequencies (horizontal stripes) used in Cell 1 (e.g., eNB0).

[0050] Referring once again to FIG. 1B, a set of frequencies operating at reduced power compared to the frequencies discussed in relation to HFR and represented by the grey frequency bands in the FFR and SFR portion of FIG. 1D, are reused in each of the cells (i.e., Cell 1, Cell 2, and Cell 3). Because this frequency band does not geographically overlap with adjacent cells (i.e., it is used at the central portion of the cell as a result of the lower power), overlap between adjacent cells is prevented and this frequency band can be reused in adjacent cells.

[0051] For fractional frequencies, because there is a spatial separation between the grey areas in the spectra in Cell 1 and Cell 2 and Cell 3, as long as the spatial separation is significant enough, there will not be significant interference between the cells although the central portions of the cells are transmitting on the same (e.g., exact same) frequencies. By keeping a separation

and allocating the horizontal stripes frequency band in Cell 1 to specific frequencies, the shaded frequency band in Cell 2 to other specific frequencies, the vertical stripes frequency band in Cell 3 to still other specific frequencies, and the like for additional cells, embodiments of the present invention make efficient use of the given spectrum. Comparing the Fractional Frequency Reuse spectrum to the Hard Frequency Reuse spectrum, it is evident that FFR uses more of the available spectrum, which enables support for more users, operation at a higher data rate, combinations thereof, or the like. In the illustrated example, the fraction of the spectrum used in each cell has increased from about a third of the spectrum (HFR) to about half of the spectrum (FFR). Other implementations can utilized different fractions of the spectrum and the present invention is not limited to the particular example illustrated in FIG. 1B and FIG. 1D.

[0052] In one embodiment, to implement the fractional frequency reuse technique illustrated in FIG. 1B using the architecture illustrated in FIG. 2, DRUs 1, 2, 3, 4, 5 and 6 of eNB0 would transmit and receive data using frequencies in the horizontal stripe frequency band and DRU0 of eNB0 would transmit and receive data using the grey frequencies. In an embodiment, the size of the area covered by DRU0 can be increased by increasing the transmit power associated with the central DRU (i.e., DRU0). In another embodiment, each DRU in eNB0 transmits and receives data at a first power level using frequencies in the grey frequency bands and at a second, higher power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands. In this embodiment, three of the seven DRUs illustrated in an eNB are illustrated by Cells 1-3.

[0053] Referring to FIG. 1C, an architecture implementing Soft Frequency Reuse is illustrated and the matching spectrum in FIG. 1D illustrates the full use the spectrum by each of the adjacent cells. In an embodiment in which multiple DRUs are utilized per cell, the horizontal stripe geographical area in Cell 1 is associated with the outer DRUs in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRUs 1-6) and the grey geographical area in Cell 1 is associated with the central DRU in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRU0). As discussed above, the size of the grey circle can be increased/decreased by increasing/decreasing the power of utilized in conjunction with DRU0. As shown in the SFR spectrum for Cell 1, data is transmitted and received over the entire allocated spectrum, including portions of the spectrum that were unused for Cell 1 in the HFR example. The increase in spectrum provides increased data rate, increased capacity, combinations thereof, or the like. In other embodiments, a single DRU in Cell 1 broadcasts at low power over the grey band and at a

higher power over the horizontal stripe spectrum. Other cells demonstrate similar behavior. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0054] Comparing FFR (FIG. 1B) and SFR (FIG. 1C), the frequency bandwidth available for the peripheral DRUs or for the higher power broadcast from a DRU in the cell (i.e., horizontal stripe, dotted, or vertical stripe spectra) is increased for SFR in comparison to FFR. Additionally, the frequency bandwidth available for the central DRU or for the lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

[0055] In an embodiment, fractional frequency reuse is implemented in a DAS system with a plurality of adjacent cells, each of the cells including a plurality of remote units. A first cell utilizes a first frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and a second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs). A second cell utilizes a third frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and the second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs).

[0056] In another embodiment, soft frequency reuse is implemented in a DAS system with a plurality of adjacent cells. A first cell utilizes a first frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a second frequency band (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). A second cell utilizes a third frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a fourth frequency band, which may include multiple sub-bands (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). The third frequency band may include frequencies in the second frequency band and the multiple sub-bands of the fourth frequency band may include frequencies in the first frequency band as illustrated in FIG. 1C.

[0057] As will be appreciated by one of skill in the art, operators utilize different spectrums and, in the examples illustrated in FIG. 1D, they are contiguous. However, it should be noted that although contiguous spectra are illustrated in FIG. 1D, this is not required by embodiments

of the present invention and non-contiguous spectrums may be utilized in other embodiments. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0058] Although the embodiments illustrated in FIG. 1D utilizes three frequencies, embodiments of the present invention are not limited to this particular number and additional frequencies and frequency bands can be utilized, for example, additional frequency bands used in conjunction with additional cells. In a particular embodiment, seven frequency bands, twelve frequency bands, or the like can be utilized. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0059] System Architecture (DAS-SFR)

[0060] The general architecture of a Virtualized DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRUs) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized such that each DRU allocated to a given eNB sector is simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. The DAUs assign the RBs of the various sectors to the independent DRUs. In contrast, the same area (7 DRUs) is covered by only a high-power eNB in traditional cellular system. The proposed architecture divides the entire spectral bandwidth F into 3 parts (F_1, F_2, F_3). The idea is that the eNB assigns the full-reused frequency (all 3 parts) to the central DRU and the other 6 edge DRUs work on just 1 part based on a reuse factor of Δ in such a way that neighbor cell edge DRUs don't use the same frequency part.

[0061] The total transmit power of the n-th DRU of i-th cell in f-th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by $n = 0$. Throughout this application, we assume that $P_n^{(i,f)} = P$.

[0062] We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

[0063] Resource Allocation Scenarios:

[0064] In cellular DAS-SFR with multi users, there are several possible resource allocation scenarios using multiple DRUs. Much of the research on SFR system design has focused on how to determine the size of the frequency partition, for example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users per each frequency part($F_i, i=1,2,3$).

[0065] For a typical central cell, let's assume the center DRU is assigned the full-reused frequency and the other six edge DRUs are assigned to F_1. Now, we consider three resource allocation scenarios:

[0066] - **Scenario 1:** All F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

[0067] - **Scenario 2:** F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

[0068] - **Scenario 3:** F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

[0069] We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario we investigate both the analytical and simulation results in order to verify the system's capacity improvement.

[0070] Channel Model and Received Signal

[0071] The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise. The received signal vector of the user in the 0th cell at frequency f can be expressed as:

$$y^{(0,f)} = signal + interference + noise$$
$$= \mathbf{H}^{(0,f)}\mathbf{x}^{(0,f)} + \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n} \quad (1)$$

where $\mathbf{H}^{(i,f)} \in C^{1\times 7}$, $i = 0, 1, \ldots, 18$, denotes the channel matrix between the DRUs in the i-th cell and the user in the central (0th) cell, $x^{(i,f)} = \left[x_0^{(i,f)}, x_1^{(i,f)}, \ldots, x_6^{(i,f)}\right]^T \in C^{7x1}, i - 0,1, \ldots,18$ is the transmitted signal vector of the DRUs in the i-th cell, $n^{(f)} \in C^{1x1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma^2_{n^{(f)}}\mathbf{I}_1)$.

[0072] The distributed antenna power constraint is considered, we have

$$\mathbf{E}\left[\left|x_n^{(i,f)}\right|^2\right] \le P_n^{(i,f)}, n = 0,1,\ldots,6, \quad i = 0,1,\ldots,18, \quad (2)$$

where in DAS-SFR,

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} \neq 0, P_n^{(i,f)} \neq 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \quad , f = F_1, F_2, F_3),$$

in Conventional Cellular-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 0,8,10,12,14,16,18),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 1,3,5,9,13,17),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18) \ or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 2,4,6,7,11,15),$$

and in Conventional cellular-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} = 0, P_n^{(i,f)} = 0 \quad when \quad (n = 1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \ and \ f = F_1, F_2, F_3),$$

where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell.

[0073] The composite fading channel matrix $\mathbf{H}^{(i,f)}, i=0,1,...,18$, encompasses not only small-scale fading but also large-scale fading, which is modeled as

$$\begin{aligned}\mathbf{H}^{(i,f)} &= \mathbf{H}_w^{(i,f)}\mathbf{L}^{(i,f)} \\ &= \left[h_0^{(i,f)}, h_1^{(i,f)}, ..., h_6^{(i,f)}\right].diag\left\{l_0^{(i,f)}, l_1^{(i,f)}, ..., l_6^{(i,f)}\right\}\end{aligned} \tag{3}$$

where $\mathbf{H}_w^{(i,f)}$ and $\mathbf{L}^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the 0th cell, respectively. $\left\{h_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are independent and identically distribute (*i.i.d*) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\left\{l_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{\left[D_n^{(i)}\right]^{-\gamma}\chi_n^{(i,f)}}, \quad n=0,1,...,6, \quad i=0,1,...,18 \tag{4}$$

where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the 0th cell and the nth DRU in the i-th cell, respectively, γ denotes the path loss exponent. $\left\{\chi_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are *i.i.d* random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi}\lambda\sigma_\chi\chi}\exp\left(-\frac{(\ln\chi)^2}{2\lambda^2\sigma_\chi^2}\right), \quad \chi>0, \tag{5}$$

where σ_χ is the shadowing standard deviation and $\lambda=\frac{\ln 10}{10}$.

[0074] Since the number of interfering source is sufficiently large and interfering source are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n}^{(f)} \tag{6}$$

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned}Var(N^{(f)}) &= \left[\sum_{i=1}^{18}\sum_{n=0}^{6}\left[l_n^{(i,f)}\right]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2\right]\mathbf{I}_1 \\ &= \left[\sigma^{(f)}\right]^2\mathbf{I}_1\end{aligned} \tag{7}$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$\mathbf{y}^{(0)} = \mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)}\mathbf{x}^{(0,f)} + N^{(f)} \tag{8}$$

[0075] Achievable capacity of distributed antenna network

[0076] If we assume the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station can be calculated by

$$C^{(f)} = \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2 \det(\mathbf{I}_1 + \frac{1}{\left[\sigma^{(f)}\right]^2}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})\mathbf{P}^{(0,f)}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})^H)\right] \tag{9}$$

where $\mathbf{P}^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $diag\left\{P_0^{(0,f)}, P_1^{(0,f)}, ..., P_6^{(0,f)}\right\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$\begin{aligned} C^{(f)} &= \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2(1 + \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)})\right] \\ &= \int_{\gamma_f=0}^{\infty}\log_2(1+\gamma_f) f_{\gamma_f}(\gamma_f) d\gamma_f \end{aligned} \tag{10}$$

where $\gamma_f = \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}$ is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f) = \sum_{i=0}^{6}\frac{\left[\sigma^{(f)}\right]^2\pi_i}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2\gamma_f}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), \tag{11}$$

where

$$\pi_i = \prod_{k=0,k\neq i}^{6}\frac{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)} - \left[l_i^{(0,f)}\right]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$C^{(f)} = -\frac{1}{\ln 2}\sum_{i=0}^{6}\pi_i \exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), f = F_1, F_2, F_3 \tag{12}$$

where $Ei(t)$ is the exponential integral function ($Ei(t) = -\int_{-x}^{\infty} e^{-t}/t\,dt$) and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

[0077] Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$C^{(f)} = -\frac{1}{\ln 2}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) \quad , f = F_1, F_2, F_3 \tag{13}$$

[0078] Thus, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total} = C^{(F_1)} + C^{(F_2)} + C^{(F_3)} \tag{14}$$

[0079] Analytical and Simulation Results

[0080] FIG. 3 and FIG. 4 represents the ergodic capacity of cellular DAS for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position X when the path loss exponent is 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}, C^{(F_2)}, C^{(F_3)}$, and also for the total capacity C_{total}.

[0081] The transmit power of each distributed antenna module is P whereas the transmit power of eNB in the conventional cellular system is $7P$. These figures show an interesting non-monotonic relationship between capacity and the normalized distance from the base station. This is because the signal from a distributed antenna module becomes dominant around 0.6R.

[0082] FIG. 3 compares the capacity performance of the two frequency reuse techniques, SFR and HFR3, for a particular central cell. Note that in the SFR technique, all 3 frequency bands are assigned, whereas, in the HFR3 method, only the F_1 band is used. The results show that the SFR method achieves the highest throughput, owing to use of more frequency bandwidth. More specifically, the total capacity achieved using the SFR method is the highest inside the normalized distance 0.5.

[0083] A non-significant throughput reduction in the SFR technique is observed happening beyond a normalized distance 0.5, due to the interference introduced from the neighboring central DRU cells. Note that there is no interference introduced from the DRU neighboring cells

when the HFR3 method is applied. It is worth mentioning that the achieved throughput of the DAS-HFR3 is slightly lower than that of a conventional cellular (Con-HFR3) system near the eNB0 DRU0, due to the reduced transmit power.

[0084] FIG. 4 compares the capacity performance of the two frequency reuse techniques, SFR and HFR1, for a particular central cell. Note that in both SFR and HFR1 techniques, all 3 frequency bands are assigned. The achieved throughputs of the DAS-HFR1 and DAS-SFR are slightly lower than that of a conventional cellular (Con-HFR1) system near the eNB0 (DRU0), due to the reduced transmit power.

[0085] FIG. 4 illustrates that the HFR1 technique outperforms the SFR technique in terms of the achieved throughput inside the $(0,\ 0.5R)$ region, nevertheless, the SFR technique significantly improves the system performance by making up for the dead spots happening at the cell edges. Note that there is a significant amount of interference happening in the $(0.8R, R)$ region, creating dead-spots in the HFR1 technique.

[0086] Note that 80% of the users are located inside the $(0.5R, R)$ region, assuming a uniform distribution, while the other 20% are farther from the interfering cells. Therefore, it is more important to improve the system capacity inside the $(0.5R, R)$ region.

[0087] In multiuser systems, where all users are uniformly distributed in the cell, we need to consider different resource allocation scenarios which were defined above. Assuming that each cell has radius R, we define parameter α $(0<\alpha<1)$ such that the interior area is located in the $(0,\ \alpha R)$ region and the exterior area is located in the $(\alpha R, R)$ region.

[0088] In LTE systems, eNB distinguishes between the interior and exterior users based on their corresponding uplink power received at the central DRU. To implement this technique, we propose a threshold T_p as a parameter in eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa.

[0089] Note that

$$N_{\text{int}erior} = \alpha^2 N_{users},$$
$$N_{exterior} = \left(1-\alpha^2\right) N_{users}, \qquad (15)$$

where $N_{interior}$ represents the number of interior users, $N_{exterior}$ represents the number of exterior users, and N_{users} represents the total number of users. We will consider the 3 different resource allocation scenarios mentioned above, where the number of RBs per users assigned in the different regions (interior or exterior) for different Scenarios can be expressed as in TABLE 1, where $N_{RB^{(F_i)}}, i=1,2,3$ represents the number of RBs for given frequency part F_i and $N_{RB^{(F_i)}}^{tech}$ represent the number of RBs for given F_i for the different techniques.

[0090] Note that in all 3 scenarios we have applied the Round Robin scheduling technique.

[0091] If we consider the number of RBs which are assigned to the different regional users under the different scenarios, the capacity metric of the total system can be obtained by,

$$C_{metric}^{total,tech} = C_{metric}^{(tech,F_1)} + C_{metric}^{(tech,F_2)} + C_{metric}^{(tech,F_3)} \quad (16)$$

where

$C_{metric}^{(tech,F_i)} = N_{RB^{(F_i)}}^{tech}.C^{(F_i)}$, $i=1,2,3$,

$tech \in \begin{Bmatrix} DAS-SFR-SC1, DAS-SFR-SC2, DAS-SFR-SC3, \\ DAS-HFR3, Con-HFR3, DAS-HFR1, Con-HFR1 \end{Bmatrix}$.

[0092] In FIG. 5, the capacity metric is provided considering a uniform distribution of users and a Round Robin Scheduler. In this example, which illustrates the capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area, we assume α is 0.5. The achieved capacity of the DAS-SFR architecture with Scenario2 and Scenario3 is higher than that of DAS-SFR system with Scenario1, especially near the central DRU. This is due to the fact that the F_2 and F_3 RBs are not assigned to the exterior users which have very low SINR and all F_2 and F_3 RBs assigned to interior users.

[0093] Comparing Scenario2 with Scenario3, we observe that the achievable capacity for interior users in DAS-SFR architecture with Scenario2 is slightly higher than that of scenario3 due to the full frequency reuse for the interior users in Scenario2. However, in Scenario3, only the F_2 and F_3 frequency bands are used by the interior users. Conversely, the achieved capacity for exterior users in a DAS-SFR architecture with Scenario3 is slightly higher than that of Scenario 2, due to the fact that all F_1 RBs are used by the exterior users, whereas in Scenario2 the F_1 RBs are partially used by the exterior users.

[0094] Note that FIG. 5 illustrates that the DAS-HFR1 technique outperforms other techniques in terms of the achieved throughput by majority of the interior users; nevertheless, SFR technique significantly improves the system performance by making up for the dead spots which appear at the cell edges. Note that there is a significant amount of interference happening in the ($0.8R, R$) region, causing the dead spots in DAS-HFR1 technique.

[0095] In the established system environment, we evaluate the total system capacity for several cases for non-edge users (inside $(0, 0.8R)$ region) and edge users (inside ($0.8R, R$)). We assume α sweeps from 0.2 to 0.8. Remember that α manages the portion of resources allocated in Scenario2 and Scenario3.

[0096] FIG. 6 illustrates the analytical results for the non-edge users and edge users, where α varies between 0.2 and 0.8, that is, the analytical ergodic capacity for edge cell and non-edge cell users versus the parameter α.

[0097] Note that as α changes, the number of RBs assigned to the users in Scenario2 and Scenario3 changes accordingly. However, in other techniques, with changing α, number of assigned RBs to the users remains unaltered. As α increases, the edge user's throughput increases in Scenario3, due to the fact that more RBs are assigned to those users. Specifically, as α increases, less users need to use F_1 RBs in Scenario3. However, in other techniques, edge users experience a constant throughput, due to the fact that the number of RBs allocated to the edge users remains constant as α changes. Specifically, regardless of the changes in α, all F_1 RBs are assigned to all users.

[0098] As α increases, non-edge users' throughput decreases, due to the fact that the total constant number of F_2 and F_3 RBs should be assigned to more number of users accordingly. Note that the rate of decrease in user throughput for non-edge users for Scenario3 is more than that of Scenario2, as α increases. The reason behind this is that the rate of decrease in number of RBs assigned to the non-edge users in Scenario3 is more than that of Scenario2. Specifically, as was previously mentioned, since no F_1 RBs are assigned to the non-edge users in Scenario3, non-edge users' throughput in Scenario3 is less than that of Scenario2.

[0099] The capacity of the above mentioned architectures is investigated through the system level simulation. We consider the two-ring hexagonal cellular system with nineteen eNBs, such

that each cell has 7 DRUs, as in FIG. 2, where the eNBs distance is 500 meters. The 10 UEs are located in each DRU area, following a uniform distribution. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in TABLE 2.

[0100] At a TTI of simulation, the eNB in a cell gathers the CQI information of UEs and allocates the RBs to each UE using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB^{(f)}} \log\left(1 + SINR_m^{(f)}\right), \quad f = F_1, F_2, F_3 \tag{16}$$

where, $W_{RB^{(f)}}$ is the bandwidth of RBs assigned to a UE and $SINR_m^{(f)}$ is the SINR of a UE_m. The cell capacity in each region is total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^{3} \sum_{m=1}^{M} C_m^{(F_i)} \tag{17}$$

where M is the number of UEs in a group.

[0101] FIG. 7 illustrates the simulation results for the non-edge users and edge users (i.e., the simulated capacity for edge cell and non-edge cell users versus the parameter α, where α varies between 0.2 and 0.8. The results obtained through simulation corroborate the results provided by analytical methods.

[0102] The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique, since the interference signal from neighbor cells is lower than that when we use HFR1 technique. In an embodiment using Scenario3 as a resource allocation strategy, the exterior user's throughput is increased.

[0103] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention. The method 800 includes transmitting and receiving data in a first geographical area and a first frequency band (810). The method also includes transmitting and receiving data in a second geographical area and a second

frequency band (812). In an embodiment, the first geographical area is a central area of a cell including multiple DRUs and the second geographical area is a peripheral area of the cell. In another embodiment, the second geographical area includes and extends to an area larger than the first geographical area (e.g., an area surrounding the first geographical area). The method further includes transmitting and receiving data in a third geographical area and at least a portion of the first frequency band (814). At least a portion of the frequency band used for the third geographical area is thus reused in relation to the first geographical area. The method also includes transmitting and receiving data in a fourth geographical area and a third frequency band (816). In an embodiment, the third geographical area is a central area of a cell including multiple DRUs and the fourth geographical area is a peripheral area of the cell. In another embodiment, the fourth geographical area includes and surrounds the third geographical area. The third frequency band may overlap with part of the first frequency band. Accordingly, multiple cells reuse the portions of the first frequency band, which may include multiple sub-bands that are contiguous or separated in frequency domain, in multiple adjacent cells.

[0104] It should be appreciated that the specific steps illustrated in FIG. 8 provide a particular method of implementing soft frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 8 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0105] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention. The method 900 includes transmitting and receiving data in a first geographical area and a first frequency band (910) and transmitting and receiving data in a second geographical area and a second frequency band (912). In an embodiment, the second geographical area surrounds the first geographical area. As an example, the first geographical area can be a central portion of a cell that is covered by a central DRU and the second geographical area can be a peripheral portion of the cell that is covered by a plurality of peripheral DRUs.

[0106] The method further includes transmitting and receiving data in a third geographical area and the first frequency band (914) and transmitting and receiving data in a fourth geographical area and a third frequency band (916). In an embodiment, the third geographical area surrounds the fourth geographical area. As an example, the third geographical area can be a central portion of another cell that is covered by a central DRU and the fourth geographical area can be a peripheral portion of the another cell that is covered by a plurality of peripheral DRUs. Thus, the frequency band used at the central portion of the first cell is reused at the central portion of the second cell. In embodiments, the frequency bands are not limited to contiguous blocks of frequencies, but can include sub-bands each including one or more frequency. The third frequency band can be different from the second frequency band, providing differing frequencies for the differing cells at adjacent geographical areas.

[0107] It should be appreciated that the specific steps illustrated in FIG. 9 provide a particular method of implementing fractional frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 9 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0108] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

TABLE 1. Number of RBs per user

	Interior region			Exterior region		
	F_1	F_2	F_3	F_1	F_2	F_3
$N_{RB^{(F)}}^{DAS-SFR-SC1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$
$N_{RB^{(F)}}^{DAS-SFR-SC2}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-SFR-SC3}$	0	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{\left(1-\alpha^2\right) N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR3}, N_{RB^{(F)}}^{Con-HFR3}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR1}, N_{RB^{(F)}}^{Con-HFR1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$

TABLE 2. Simulation Parameters

Parameters	Value
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1+37.6 \log_{10}(R(km))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms

 CommScope Ex. 1002

WHAT IS CLAIMED IS:

1. A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. The method of claim 1 wherein the DRUs comprise remote radio units.

3. The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical

footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

ABSTRACT OF THE DISCLOSURE

A method for routing and switching operator RF signals includes providing one or more Digital Remote Units (DRUs) and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

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PATENT APPLICATION

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

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METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/649,143, filed on May 18, 2012, entitled "Method and System for Soft Frequency Reuse in a Distributed Antenna System," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] Wireless communication systems employing Distributed Antenna Systems (DAS) are available. A DAS typically includes one or more host units, optical fiber cable or other suitable transport infrastructure, and multiple remote antenna units. A radio base station is often employed at the host unit location commonly known as a base station hotel, and the DAS provides a means for distribution of the base station's downlink and uplink signals among multiple remote antenna units. The DAS architecture with routing of signals to and from remote antenna units can be either fixed or reconfigurable.

[0003] A DAS is advantageous from a signal strength and throughput perspective because its remote antenna units are physically close to wireless subscribers. The benefits of a DAS include reducing average downlink transmit power and reducing average uplink transmit power, as well as enhancing quality of service and data throughput.

[0004] Despite the progress made in wireless communications systems, a need exists for improved methods and systems related to wireless communications.

SUMMARY OF THE INVENTION

[0005] The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS) as part of a distributed wireless network. More specifically, the present invention relates to a DAS utilizing Soft Frequency Reuse or Fractional Frequency Reuse techniques. In a particular embodiment, the present invention has been applied to the

reuse of communications frequencies in central portions of adjacent DAS cells, improving system data rates and performance. The methods and systems described herein are applicable to a variety of communications systems including systems utilizing various communications standards.

[0006] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies, and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU in a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU in a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

[0007] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

[0008] According to a specific embodiment of the present invention, a communications system is provided. The communications system includes a host unit and a first communications unit

coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint. The communications system also includes a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

[0009] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU of a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a plurality of additional DRUs of the first cell are operable to communicate using a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint surrounding the first geographic footprint. A first DRU of a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a plurality of additional DRUs of the second cell are operable to communication using a third set of frequencies characterized by a third frequency band different from the first frequency band over a fourth geographic range surrounding the third geographic range.

[0010] The DRUs can comprise remote radio units. The method may also include communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU. One or more of the plurality of BTSs can be coupled to the DAU using a plurality of BTS sector RF connections. The method may further include transporting signals between one or more DRUs and the at least one DAU.

[0011] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units in an array configuration and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized

by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic range surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint surrounding the third geographical footprint.

[0012] In an embodiment, the set of communications units include a plurality of remote units in communication with a host unit. The first geographic footprint can be centered on the first communications unit. The second geographic footprint can be a peripheral footprint centered on the first communications unit. The third geographical footprint can be centered on the second communications unit. The fourth geographical footprint can be a peripheral footprint centered on the second communications unit. The second geographical footprint can abut the fourth geographical footprint. The method can also include transmitting, and receiving, from a third communications unit of the set of communications units, a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint surrounding the fifth geographical footprint.

[0013] According to yet another embodiment, a communications system is provided. The communications system includes a first communications unit operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint and a second communications unit operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and one or more of the second set of frequencies in a region associated with a fourth geographical footprint.

[0014] The first communications unit can include a central DRU and a plurality of peripheral DRUs disposed adjacent the central DRU. The system can also include a DAU communicatively coupled to the central DRU and the plurality of peripheral DRUs. In an embodiment, the system includes a DAU communicatively coupled to the central DRU. Additionally, a second DAU can

be communicatively coupled to the plurality of peripheral DRUs. In an embodiment, the second geographical footprint at least partially surrounds the first geographical footprint. In another embodiment, the fourth geographical footprint at least partially surrounds the third geographical footprint or the second geographical footprint at least partially overlaps the fourth geographical footprint.

[0015] According to a specific embodiment, a frequency sharing system for a distributed antenna system is provided. The frequency sharing system includes a first frequency band characterized by a first frequency range and associated with a first geographic area associated with a first communications unit and a second frequency band characterized by a second frequency range different from the first frequency range and associated with a second geographic area at least partially surrounding the first geographic area. The frequency sharing system also includes a third frequency band overlapping at least a portion of the second frequency band and associated with a third geographic area associated with a second communications unit and a fourth frequency band overlapping at least a portion of the first frequency band and associated with a fourth geographic area at least partially surrounding the third geographic area.

[0016] The first geographic area can be characterized by a first border and the second geographic area can be characterized by a second border, wherein a predetermined distance separates the first border and the second border. The first frequency band and the second frequency band can be contiguous frequency bands. In an embodiment, the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent the first frequency band.

[0017] According to another specific embodiment, a communications system is provided and includes a first communications unit operable to transmit and receive communications using a first set of frequencies over a first predetermined area and a second communications unit operable to transmit and receive communications using a second set of frequencies over a second predetermined area. The first communications unit is operable to transmit and receive communications using a third set of frequencies over a third predetermined area and the second communications unit is operable to transmit and receive communications using at least a portion of the third set of frequencies over a fourth predetermined area.

[0018] The first communications unit can include a plurality of DRUs, at least one of the plurality of DRUs being coupled to a DAU. The third predetermined area can be at least

partially surrounded by the first predetermined area and the fourth predetermined area can be at least partially surrounded by the second predetermined area. In an embodiment, the first set of frequencies, the second set of frequencies, and the third set of frequencies are distinct frequencies. The first communications unit and the second communications unit can be disposed in an array configuration. The first predetermined area overlaps at least a portion of the second predetermined area in some implementations and the third predetermined area includes a location of the first communications unit and the fourth predetermined area includes a location of the second communications unit. The first communications unit can include a first plurality of digital remote units and the second communications unit comprises a second plurality of digital remote units. The first set of frequencies can be associated with a first number of the first plurality of digital remote units and the third set of frequencies can be associated with another of the first plurality of digital remote units. The second set of frequencies can be associated with a first number of the second plurality of digital remote units and the third set of frequencies can be associated with another of the second plurality of digital remote units.

[0019] Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIGS. 1A - 1C illustrate different frequency reuse techniques according to embodiments of the present invention;

[0020.A] FIG. 1D illustrates, for each case Hard Frequency Reuse, Fractional Reuse, and Soft Frequency Reuse, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0021] FIG. 2 illustrates the structure of a Distributed Antenna System (DAS) according to an embodiment of the present invention;

[0022] FIG. 3 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to an embodiment of the present invention;

[0023] FIG. 4 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to another embodiment of the present invention;

[0024] FIG. 5 illustrates a capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area according to an embodiment of the present invention;

[0025] FIG. 6 is a plot illustrating analytical ergodic capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention; and

[0026] FIG. 7 is a plot illustrating simulation capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention.

[0027] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention; and

[0028] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0029] Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency.

[0030] Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the transmission scheme for the next generation wireless communication systems. However, the downlink performance of cellular networks is known to be strongly limited by inter-cell interference in OFDMA based systems. In order to mitigate this interference, a number of techniques have recently been proposed, e.g. the Soft Frequency Reuse (SFR) scheme and Distributed Antenna System (DAS). According to embodiments of the present invention, these two techniques are combined in a unique cell architecture, which can be referred to as DAS-SFR. In an implementation of this architecture, which is described herein, the antennas are distributed in a hexagonal cell such that the central antenna is responsible for serving a special area using multiple frequency bands (e.g., all of the frequency bands) while the remaining antennas utilize

only a subset of the frequency bands based on a frequency reuse factor. The inventors have analytically quantified the performance of the downlink multi-cell DAS-SFR in terms of the individual user's throughput under three different resource allocation scenarios. The results show that DAS-SFR reduces inter-cell interference in a multi-cell environment for users near the cell boundaries as compared to a Hard Frequency Reuse (HFR) scheme with a frequency reuse factor of 1. The results also show that DAS-SFR significantly increases the system capacity as compared to the HFR scheme with a frequency reuse factor of 3.

[0031] In DAS-SFR, by controlling the amount of resources allocated to users located in different areas, embodiments of the present invention increase the frequency efficiency and also improve the data rate for cell edge users. If the throughput requirement for the interior users is small, more resources can be assigned to the exterior users.

[0032] In the next generation wireless communication systems that use the 3GPP LTE (Long Term Evolution) standard, there is tremendous pressure to support a high data rate transmission. These systems are based on Orthogonal Frequency Division Multiple Access (OFDMA) to support the high data rate service and improve the Quality of Service (QoS), even for cell edge users as the main targets in the downlink.

[0033] The system bandwidth is divided into a number of sub-carriers in an OFDMA-based system such that each user utilizes a bandwidth smaller than the systems coherence bandwidth. Data from different users is transmitted in parallel on different sub-carriers. The orthogonality amongst the sub-carriers mitigates inter-carrier interference (ICI) while the resulting large OFDM symbol time and the narrow sub-carrier bandwidth reduces the effect of inter-symbol interference (ISI). Users located at the cell edge largely suffer from co-channel interference (CCI) or inter-cell interference from base stations (BS) of neighboring cells. Mobile 3GPP LTE adopts a frequency reuse factor of one, in which each cell serves users using the entire system bandwidth.

[0034] In order to reduce interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are three potential ways to reduce interference in cellular systems but these require a more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes(CLMD) and Beamforming are three other

techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beamforming sacrifice spatial dimensions and require channel state knowledge.

[0035] One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a distributed antenna systems (DAS), which also has the additional advantage of improving capacity and coverage.

[0036] Other possible strategies include Frequency Reuse techniques, which effectively reduce inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

[0037] Distributed Antenna System (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems. As opposed to a conventional cellular system, where the antenna is centrally located, a DAS network consists of antenna modules that are geographically distributed to reduce access distance. These distributed antennas are connected to an eNodeB (eNB) LTE system by dedicated wires, fiber optics, or via a radio frequency link.

[0038] DAS has advantages including throughput improvement, coverage improvement, increased cellphone battery life, and a reduction in transmitter power. Recent research has shown benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is a Virtual DAS, wherein each remote has the added flexibility of independently transmitting preselected carriers.

[0039] Frequency reuse techniques are utilized herein to reduce inter-cell interference in cellular systems. This benefits users near the cell edges owing to simplicity and practicality. There are three major frequency reuse patterns illustrated in FIG. 1 for mitigating inter-cell interference: Hard Frequency Reuse, Fractional Frequency Reuse and Soft Frequency Reuse.

[0040] Hard Frequency Reuse (HFR) splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub-bands. This inter-cell interference mitigation method is typically seen in GSM networks, when it comes to distribution of frequencies among the cells. When applied to LTE, the Resource Blocks (a group of sub-carriers) are divided into 3, 4 or 7 disjoint sets. These sets of Resource

Blocks (RBs) are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies, as illustrated in FIG. 1A. FIG. 1D shows, for each case (Hard Frequency Reuse (FIG. 1A), Fractional Frequency Reuse (FIG. 1B), and Soft Frequency Reuse (FIG. 1C)), the transmit/receive power as a function of frequency. This reduces the interference at the cell edge of any pair of cells significantly and can be considered the opposite extreme to Full Frequency Reuse in matters of frequency partitioning techniques. While user interference at the cell edge is maximally reduced, the spectrum efficiency drops by a factor equal to the reuse factor. The inter-cell interference can be reduced with a frequency reuse factor of more than one, however, it may reduce the system capacity.

[0041] Fractional Frequency Reuse (FFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. OFDMA provides the ability for each eNB to selectively allocate frequency sub-bands, data rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. FFR splits the given bandwidth into an inner and an outer region as illustrated in FIG. 1B. The spectrum allocated to the inner region is assigned to the nearby users (located close to the eNB in terms of path loss) applying a frequency reuse factor of one (i.e. the inner part is completely reused by all eNBs). While the spectrum allocated to the outer region, for users close to the cell edge (far users), is divided among the different eNBs as in hard frequency reuse techniques. This scheme is particularly useful to mitigate the inter-cell interference in the uplink, where severe interference situations can occur when the user is located close to a strong interferer from a neighbor cell.

[0042] Soft Frequency Reuse (SFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. SFR shares the overall bandwidth by all eNBs (i.e. a reuse factor of one is applied), but for transmission on each group of RBs, the eNBs are restricted to a certain power bound. FIG. 1C illustrates the power and frequency assignments in the different cells of a system with SFR for a reuse factor of 3. It can be noticed in the frequency spectrum of FIG. 1D associated with Soft Frequency Reuse (i.e., FIG. 1C), that there is a region of high-power transmissions and some regions of low-power transmissions. Using a similar strategy extending Fractional Frequency Reuse, resources in the high-power region are preferably assigned to User Equipment (UEs) located at the cell edge, while cell-center UEs are typically assigned resources in the low-power regions. SFR can utilize the entire frequency spectrum that has been allocated, increasing the system data rate and/or capacity.

[0043] Referring to FIGS. 1C and 1D, frequencies in the grey frequency band (~ upper 2/3 of the available frequencies) are transmitted/received by a DRU at a first power level in Cell 1, providing coverage for the central portion of Cell 1. Frequencies in the horizontal stripes band are transmitted/received by the DRU at a second power level higher than the first power level, providing coverage over both the central portion of Cell 1 as well as the peripheral portions of Cell 1 since the higher power level results in a larger coverage area. In this example, each cell utilizes a single DRU, although other embodiments can utilize multiple DRUs per cell as described more fully herein. DRUs in the other cells also transmit/receive at both high power for a subset of the frequencies and low power for remaining frequencies as shown in FIG. 1D, producing the coverage maps illustrated in FIG. 1C, with low power frequencies providing centralized coverage and higher power frequencies providing a large coverage area extending to the peripheral regions of the cells. Although all three cells are transmitting/receiving using overlapping (or the same) frequencies at low power, the corresponding propagation distances for these frequencies are smaller, preventing geographic overlap between the central grey regions.

[0044] In order to reduce interference in areas where cells are adjacent, the frequencies associated with higher power are grouped into subbands, with little or no overlap between the subbands. Referring to FIG. 1D, in the SFR implementation, Cell 1 uses high power for the horizontal stripes band in approximately the first third of the frequency bandwidth, Cell 2 uses high power for the dotted band in approximately the second third of the frequency bandwidth, and Cell 3 uses high power for the vertical stripes band in approximately the last third of the frequency bandwidth. Thus, at the intersections between cells, since different portions of the available frequency band are being utilized, interference is reduced. Thus, in some embodiments, different frequency bands are utilized in adjacent cells, which is illustrated by the high power frequency bands for SFR in FIG. 1D: the first frequency band in Cell 1, the second frequency band different from the first frequency band in Cell 2, and the third frequency band different from the first frequency band and the second frequency band in Cell 3. For an additional number of cells, the subdivision of the available bandwidth can be increased as appropriate to the particular number of adjacent cells in the implementation. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0045] HFR, though simple in implementation, suffers from a reduced spectral efficiency. On the other hand, both SFR and FFR have increased (e.g., full) spectral efficiency and are a strong mechanism for inter-cell interference mitigation. A coordinated resource allocation system can

be impractical in realistic settings involving a large number of eNBs, random traffic and realistic path-loss models. However, an encouraging result is that by using even limited (yet practical) levels of coordination, significant performance benefits can still be obtained over a conventional cellular architecture. Most of the recent publications have focused on investigating SINR advantages of DAS and analyzing its performance. On the other hand, there are no studies that combine DAS with SFR in order to reduce inter-cell interference. Some publications on DAS have focused on analyzing the uplink performance because of its analytical simplicity and there are few studies on the downlink performance of DAS although the demand for high-speed data rate will be dominant in the downlink path. There are also very few publications that consider the advantages of DAS in a multi-cell context. Recent research on FFR and SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional works on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

[0046] According to embodiments of the present invention, a new architecture is provided to suppress inter-cell interference. The architecture described herein combines DAS and SFR for an OFDMA system (e.g., LTE). Embodiments of the present invention provide benefits by using DAS-SFR in a multi-cell environment. The downlink advantages of DAS-SFR are described in terms of achievable ergodic capacity for three different frequency resource allocation scenarios. The results shows that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture and achieves a non-trivial capacity increase over a HFR cellular architecture with a frequency reuse factor of 3. Other reuse factors are included within the scope of the present invention, for example, up to or more than 7 as suitable for the DAS architecture illustrated in FIG. 2.

[0047] As described herein, an analytical framework has been developed to evaluate the ergodic capacity in a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service, regardless of their geographic location, instead of simply a minimum user throughput which may be acceptable for applications like voice traffic. We present a strategy for optimally allocating frequency RBs to edge users for

a DAS-SFR architecture, based on a chosen performance threshold T_p, which can be related to network traffic load. Finally we prepare a simulation scenario to compare the analytical results with the simulation results.

[0048] Referring to the spectral plots illustrated in FIG. 1D, in the HFR system, the horizontal stripes, shaded, and vertical stripes frequency bands occupy different frequency ranges and, in combination, fill the entire spectrum. In HFR (FIG. 1A), cell 1 uses the lower frequencies (horizontal stripes), cell 2 uses the middle frequencies (shaded), and cell 3 uses the higher frequencies (vertical stripes).

[0049] Referring to FIG. 2, the DAS includes a central cell referenced as eNB0, which includes DRU0 through DRU6 that are communicating through one base station at eNB0 through a DAU. DRU0 can be considered to be Cell 1 in FIGS. 1A - 1C, DRU1 can be considered to be Cell 2 in FIGS. 1A - 1C, and DRU2 can be considered to be Cell 3 in FIGS. 1A - 1C. In other embodiments, eNB0 is considered to be Cell 1 in FIGS. 1A - 1C and eBN1, including a different set of DRUs, DRU0 through DRU6, can be considered to be Cell 2 in FIGS. 1A - 1C, etc. In FIG. 1A, Cell 1 (e.g., DRU0 of eNB0) utilizes the horizontal stripes frequency band and the other cells use different frequency bands as illustrated. In the embodiment illustrated in FIG. 2, seven different frequency bands could be utilized for high power transmission by the seven DRUs connected to each base station. For cells geographically separated from Cell 1, for example, cells in eNB7 could reuse the same frequencies (horizontal stripes) used in Cell 1 (e.g., eNB0).

[0050] Referring once again to FIG. 1B, a set of frequencies operating at reduced power compared to the frequencies discussed in relation to HFR and represented by the grey frequency bands in the FFR and SFR portion of FIG. 1D, are reused in each of the cells (i.e., Cell 1, Cell 2, and Cell 3). Because this frequency band does not geographically overlap with adjacent cells (i.e., it is used at the central portion of the cell as a result of the lower power), overlap between adjacent cells is prevented and this frequency band can be reused in adjacent cells.

[0051] For fractional frequencies, because there is a spatial separation between the grey areas in the spectra in Cell 1 and Cell 2 and Cell 3, as long as the spatial separation is significant enough, there will not be significant interference between the cells although the central portions of the cells are transmitting on the same (e.g., exact same) frequencies. By keeping a separation

and allocating the horizontal stripes frequency band in Cell 1 to specific frequencies, the shaded frequency band in Cell 2 to other specific frequencies, the vertical stripes frequency band in Cell 3 to still other specific frequencies, and the like for additional cells, embodiments of the present invention make efficient use of the given spectrum. Comparing the Fractional Frequency Reuse spectrum to the Hard Frequency Reuse spectrum, it is evident that FFR uses more of the available spectrum, which enables support for more users, operation at a higher data rate, combinations thereof, or the like. In the illustrated example, the fraction of the spectrum used in each cell has increased from about a third of the spectrum (HFR) to about half of the spectrum (FFR). Other implementations can utilized different fractions of the spectrum and the present invention is not limited to the particular example illustrated in FIG. 1B and FIG. 1D.

[0052] In one embodiment, to implement the fractional frequency reuse technique illustrated in FIG. 1B using the architecture illustrated in FIG. 2, DRUs 1, 2, 3, 4, 5 and 6 of eNB0 would transmit and receive data using frequencies in the horizontal stripe frequency band and DRU0 of eNB0 would transmit and receive data using the grey frequencies. In an embodiment, the size of the area covered by DRU0 can be increased by increasing the transmit power associated with the central DRU (i.e., DRU0). In another embodiment, each DRU in eNB0 transmits and receives data at a first power level using frequencies in the grey frequency bands and at a second, higher power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands. In this embodiment, three of the seven DRUs illustrated in an eNB are illustrated by Cells 1-3.

[0053] Referring to FIG. 1C, an architecture implementing Soft Frequency Reuse is illustrated and the matching spectrum in FIG. 1D illustrates the full use the spectrum by each of the adjacent cells. In an embodiment in which multiple DRUs are utilized per cell, the horizontal stripe geographical area in Cell 1 is associated with the outer DRUs in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRUs 1-6) and the grey geographical area in Cell 1 is associated with the central DRU in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRU0). As discussed above, the size of the grey circle can be increased/decreased by increasing/decreasing the power of utilized in conjunction with DRU0. As shown in the SFR spectrum for Cell 1, data is transmitted and received over the entire allocated spectrum, including portions of the spectrum that were unused for Cell 1 in the HFR example. The increase in spectrum provides increased data rate, increased capacity, combinations thereof, or the like. In other embodiments, a single DRU in Cell 1 broadcasts at low power over the grey band and at a

higher power over the horizontal stripe spectrum. Other cells demonstrate similar behavior. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0054] Comparing FFR (FIG. 1B) and SFR (FIG. 1C), the frequency bandwidth available for the peripheral DRUs or for the higher power broadcast from a DRU in the cell (i.e., horizontal stripe, dotted, or vertical stripe spectra) is increased for SFR in comparison to FFR. Additionally, the frequency bandwidth available for the central DRU or for the lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

[0055] In an embodiment, fractional frequency reuse is implemented in a DAS system with a plurality of adjacent cells, each of the cells including a plurality of remote units. A first cell utilizes a first frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and a second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs). A second cell utilizes a third frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and the second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs).

[0056] In another embodiment, soft frequency reuse is implemented in a DAS system with a plurality of adjacent cells. A first cell utilizes a first frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a second frequency band (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). A second cell utilizes a third frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a fourth frequency band, which may include multiple sub-bands (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). The third frequency band may include frequencies in the second frequency band and the multiple sub-bands of the fourth frequency band may include frequencies in the first frequency band as illustrated in FIG. 1C.

[0057] As will be appreciated by one of skill in the art, operators utilize different spectrums and, in the examples illustrated in FIG. 1D, they are contiguous. However, it should be noted that although contiguous spectra are illustrated in FIG. 1D, this is not required by embodiments

of the present invention and non-contiguous spectrums may be utilized in other embodiments. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0058] Although the embodiments illustrated in FIG. 1D utilizes three frequencies, embodiments of the present invention are not limited to this particular number and additional frequencies and frequency bands can be utilized, for example, additional frequency bands used in conjunction with additional cells. In a particular embodiment, seven frequency bands, twelve frequency bands, or the like can be utilized. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0059] System Architecture (DAS-SFR)

[0060] The general architecture of a Virtualized DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRUs) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized such that each DRU allocated to a given eNB sector is simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. The DAUs assign the RBs of the various sectors to the independent DRUs. In contrast, the same area (7 DRUs) is covered by only a high-power eNB in traditional cellular system. The proposed architecture divides the entire spectral bandwidth F into 3 parts (F_1, F_2, F_3). The idea is that the eNB assigns the full-reused frequency (all 3 parts) to the central DRU and the other 6 edge DRUs work on just 1 part based on a reuse factor of Δ in such a way that neighbor cell edge DRUs don't use the same frequency part.

[0061] The total transmit power of the n-th DRU of i-th cell in f-th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by $n = 0$. Throughout this application, we assume that $P_n^{(i,f)} = P$.

[0062] We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

[0063] Resource Allocation Scenarios:

[0064] In cellular DAS-SFR with multi users, there are several possible resource allocation scenarios using multiple DRUs. Much of the research on SFR system design has focused on how to determine the size of the frequency partition, for example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users per each frequency part($F_i, i=1,2,3$).

[0065] For a typical central cell, let's assume the center DRU is assigned the full-reused frequency and the other six edge DRUs are assigned to F_1. Now, we consider three resource allocation scenarios:

[0066] - **Scenario 1:** All F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

[0067] - **Scenario 2:** F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

[0068] - **Scenario 3:** F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

[0069] We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario we investigate both the analytical and simulation results in order to verify the system's capacity improvement.

[0070] Channel Model and Received Signal

[0071] The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise. The received signal vector of the user in the 0th cell at frequency f can be expressed as:

$$y^{(0,f)} = signal + interference + noise$$
$$= \mathbf{H}^{(0,f)}\mathbf{x}^{(0,f)} + \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n} \quad (1)$$

where $\mathbf{H}^{(i,f)} \in C^{1\times 7}$, $i = 0, 1, \ldots, 18$, denotes the channel matrix between the DRUs in the i-th cell and the user in the central (0th) cell, $x^{(i,f)} = \left[x_0^{(i,f)}, x_1^{(i,f)}, \ldots, x_6^{(i,f)}\right]^T \in C^{7x1}, i - 0,1, \ldots,18$ is the transmitted signal vector of the DRUs in the i-th cell, $n^{(f)} \in C^{1x1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma^2_{n^{(f)}}\mathbf{I}_1)$.

[0072] The distributed antenna power constraint is considered, we have

$$\mathbf{E}\left[\left|x_n^{(i,f)}\right|^2\right] \le P_n^{(i,f)}, n = 0,1,\ldots,6, \quad i = 0,1,\ldots,18, \quad (2)$$

where in DAS-SFR,

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} \neq 0, P_n^{(i,f)} \neq 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \quad , f = F_1, F_2, F_3),$$

in Conventional Cellular-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17) \; or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 0,8,10,12,14,16,18),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18) \; or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 1,3,5,9,13,17),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18) \; or$$
$$(n = 1,2,\ldots,6 \quad and \quad i = 2,4,6,7,11,15),$$

and in Conventional cellular-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} = 0, P_n^{(i,f)} = 0 \quad when \quad (n = 1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \; and \; f = F_1, F_2, F_3),$$

where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell.

[0073] The composite fading channel matrix $\mathbf{H}^{(i,f)}, i=0,1,...,18$, encompasses not only small-scale fading but also large-scale fading, which is modeled as

$$\begin{aligned}\mathbf{H}^{(i,f)} &= \mathbf{H}_w^{(i,f)}\mathbf{L}^{(i,f)} \\ &= \left[h_0^{(i,f)}, h_1^{(i,f)}, ..., h_6^{(i,f)}\right].diag\left\{l_0^{(i,f)}, l_1^{(i,f)}, ..., l_6^{(i,f)}\right\}\end{aligned} \tag{3}$$

where $\mathbf{H}_w^{(i,f)}$ and $\mathbf{L}^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the 0th cell, respectively. $\left\{h_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are independent and identically distribute (*i.i.d*) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\left\{l_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{\left[D_n^{(i)}\right]^{-\gamma}\chi_n^{(i,f)}}, \quad n=0,1,...,6, \quad i=0,1,...,18 \tag{4}$$

where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the 0th cell and the nth DRU in the i-th cell, respectively, γ denotes the path loss exponent. $\left\{\chi_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are *i.i.d* random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi}\lambda\sigma_\chi\chi}\exp\left(-\frac{(\ln\chi)^2}{2\lambda^2\sigma_\chi^2}\right), \quad \chi>0, \tag{5}$$

where σ_χ is the shadowing standard deviation and $\lambda=\frac{\ln 10}{10}$.

[0074] Since the number of interfering source is sufficiently large and interfering source are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n}^{(f)} \tag{6}$$

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned}Var(N^{(f)}) &= \left[\sum_{i=1}^{18}\sum_{n=0}^{6}\left[l_n^{(i,f)}\right]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2\right]\mathbf{I}_1 \\ &= \left[\sigma^{(f)}\right]^2\mathbf{I}_1\end{aligned} \tag{7}$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$\mathbf{y}^{(0)} = \mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)}\mathbf{x}^{(0,f)} + N^{(f)} \tag{8}$$

[0075] Achievable capacity of distributed antenna network

[0076] If we assume the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station can be calculated by

$$C^{(f)} = \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2 \det(\mathbf{I}_1 + \frac{1}{\left[\sigma^{(f)}\right]^2}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})\mathbf{P}^{(0,f)}(\mathbf{H}_w^{(0,f)}\mathbf{L}^{(0,f)})^H)\right] \tag{9}$$

where $\mathbf{P}^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $diag\left\{P_0^{(0,f)}, P_1^{(0,f)}, ..., P_6^{(0,f)}\right\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$\begin{aligned} C^{(f)} &= \mathbf{E}_{\mathbf{H}_w^{(0,f)}}\left[\log_2(1 + \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)})\right] \\ &= \int_{\gamma_f=0}^{\infty}\log_2(1+\gamma_f) f_{\gamma_f}(\gamma_f) d\gamma_f \end{aligned} \tag{10}$$

where $\gamma_f = \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}$ is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f) = \sum_{i=0}^{6}\frac{\left[\sigma^{(f)}\right]^2\pi_i}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2\gamma_f}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), \tag{11}$$

where

$$\pi_i = \prod_{k=0,k\neq i}^{6}\frac{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)} - \left[l_i^{(0,f)}\right]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$C^{(f)} = -\frac{1}{\ln 2}\sum_{i=0}^{6}\pi_i \exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), f = F_1, F_2, F_3 \tag{12}$$

where $Ei(t)$ is the exponential integral function ($Ei(t) = -\int_{-x}^{\infty} e^{-t}/t\,dt$) and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

[0077] Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$C^{(f)} = -\frac{1}{\ln 2}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right) \quad , f = F_1, F_2, F_3 \tag{13}$$

[0078] Thus, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total} = C^{(F_1)} + C^{(F_2)} + C^{(F_3)} \tag{14}$$

[0079] Analytical and Simulation Results

[0080] FIG. 3 and FIG. 4 represents the ergodic capacity of cellular DAS for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position X when the path loss exponent is 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}, C^{(F_2)}, C^{(F_3)}$, and also for the total capacity C_{total}.

[0081] The transmit power of each distributed antenna module is P whereas the transmit power of eNB in the conventional cellular system is $7P$. These figures show an interesting non-monotonic relationship between capacity and the normalized distance from the base station. This is because the signal from a distributed antenna module becomes dominant around 0.6R.

[0082] FIG. 3 compares the capacity performance of the two frequency reuse techniques, SFR and HFR3, for a particular central cell. Note that in the SFR technique, all 3 frequency bands are assigned, whereas, in the HFR3 method, only the F_1 band is used. The results show that the SFR method achieves the highest throughput, owing to use of more frequency bandwidth. More specifically, the total capacity achieved using the SFR method is the highest inside the normalized distance 0.5.

[0083] A non-significant throughput reduction in the SFR technique is observed happening beyond a normalized distance 0.5, due to the interference introduced from the neighboring central DRU cells. Note that there is no interference introduced from the DRU neighboring cells

when the HFR3 method is applied. It is worth mentioning that the achieved throughput of the DAS-HFR3 is slightly lower than that of a conventional cellular (Con-HFR3) system near the eNB0 DRU0, due to the reduced transmit power.

[0084] FIG. 4 compares the capacity performance of the two frequency reuse techniques, SFR and HFR1, for a particular central cell. Note that in both SFR and HFR1 techniques, all 3 frequency bands are assigned. The achieved throughputs of the DAS-HFR1 and DAS-SFR are slightly lower than that of a conventional cellular (Con-HFR1) system near the eNB0 (DRU0), due to the reduced transmit power.

[0085] FIG. 4 illustrates that the HFR1 technique outperforms the SFR technique in terms of the achieved throughput inside the $(0,\ 0.5R)$ region, nevertheless, the SFR technique significantly improves the system performance by making up for the dead spots happening at the cell edges. Note that there is a significant amount of interference happening in the $(0.8R, R)$ region, creating dead-spots in the HFR1 technique.

[0086] Note that 80% of the users are located inside the $(0.5R, R)$ region, assuming a uniform distribution, while the other 20% are farther from the interfering cells. Therefore, it is more important to improve the system capacity inside the $(0.5R, R)$ region.

[0087] In multiuser systems, where all users are uniformly distributed in the cell, we need to consider different resource allocation scenarios which were defined above. Assuming that each cell has radius R, we define parameter α $(0<\alpha<1)$ such that the interior area is located in the $(0,\ \alpha R)$ region and the exterior area is located in the $(\alpha R, R)$ region.

[0088] In LTE systems, eNB distinguishes between the interior and exterior users based on their corresponding uplink power received at the central DRU. To implement this technique, we propose a threshold T_p as a parameter in eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa.

[0089] Note that

$$N_{\text{int}erior} = \alpha^2 N_{users},$$
$$N_{exterior} = \left(1-\alpha^2\right) N_{users}, \qquad (15)$$

where $N_{interior}$ represents the number of interior users, $N_{exterior}$ represents the number of exterior users, and N_{users} represents the total number of users. We will consider the 3 different resource allocation scenarios mentioned above, where the number of RBs per users assigned in the different regions (interior or exterior) for different Scenarios can be expressed as in TABLE 1, where $N_{RB^{(F_i)}}, i=1,2,3$ represents the number of RBs for given frequency part F_i and $N_{RB^{(F_i)}}^{tech}$ represent the number of RBs for given F_i for the different techniques.

[0090] Note that in all 3 scenarios we have applied the Round Robin scheduling technique.

[0091] If we consider the number of RBs which are assigned to the different regional users under the different scenarios, the capacity metric of the total system can be obtained by,

$$C_{metric}^{total,tech} = C_{metric}^{(tech,F_1)} + C_{metric}^{(tech,F_2)} + C_{metric}^{(tech,F_3)} \quad (16)$$

where

$C_{metric}^{(tech,F_i)} = N_{RB^{(F_i)}}^{tech}.C^{(F_i)}$, $i=1,2,3$,

$tech \in \begin{Bmatrix} DAS-SFR-SC1, DAS-SFR-SC2, DAS-SFR-SC3, \\ DAS-HFR3, Con-HFR3, DAS-HFR1, Con-HFR1 \end{Bmatrix}$.

[0092] In FIG. 5, the capacity metric is provided considering a uniform distribution of users and a Round Robin Scheduler. In this example, which illustrates the capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area, we assume α is 0.5. The achieved capacity of the DAS-SFR architecture with Scenario2 and Scenario3 is higher than that of DAS-SFR system with Scenario1, especially near the central DRU. This is due to the fact that the F_2 and F_3 RBs are not assigned to the exterior users which have very low SINR and all F_2 and F_3 RBs assigned to interior users.

[0093] Comparing Scenario2 with Scenario3, we observe that the achievable capacity for interior users in DAS-SFR architecture with Scenario2 is slightly higher than that of scenario3 due to the full frequency reuse for the interior users in Scenario2. However, in Scenario3, only the F_2 and F_3 frequency bands are used by the interior users. Conversely, the achieved capacity for exterior users in a DAS-SFR architecture with Scenario3 is slightly higher than that of Scenario 2, due to the fact that all F_1 RBs are used by the exterior users, whereas in Scenario2 the F_1 RBs are partially used by the exterior users.

[0094] Note that FIG. 5 illustrates that the DAS-HFR1 technique outperforms other techniques in terms of the achieved throughput by majority of the interior users; nevertheless, SFR technique significantly improves the system performance by making up for the dead spots which appear at the cell edges. Note that there is a significant amount of interference happening in the ($0.8R, R$) region, causing the dead spots in DAS-HFR1 technique.

[0095] In the established system environment, we evaluate the total system capacity for several cases for non-edge users (inside $(0, 0.8R)$ region) and edge users (inside ($0.8R, R$)). We assume α sweeps from 0.2 to 0.8. Remember that α manages the portion of resources allocated in Scenario2 and Scenario3.

[0096] FIG. 6 illustrates the analytical results for the non-edge users and edge users, where α varies between 0.2 and 0.8, that is, the analytical ergodic capacity for edge cell and non-edge cell users versus the parameter α.

[0097] Note that as α changes, the number of RBs assigned to the users in Scenario2 and Scenario3 changes accordingly. However, in other techniques, with changing α, number of assigned RBs to the users remains unaltered. As α increases, the edge user's throughput increases in Scenario3, due to the fact that more RBs are assigned to those users. Specifically, as α increases, less users need to use F_1 RBs in Scenario3. However, in other techniques, edge users experience a constant throughput, due to the fact that the number of RBs allocated to the edge users remains constant as α changes. Specifically, regardless of the changes in α, all F_1 RBs are assigned to all users.

[0098] As α increases, non-edge users' throughput decreases, due to the fact that the total constant number of F_2 and F_3 RBs should be assigned to more number of users accordingly. Note that the rate of decrease in user throughput for non-edge users for Scenario3 is more than that of Scenario2, as α increases. The reason behind this is that the rate of decrease in number of RBs assigned to the non-edge users in Scenario3 is more than that of Scenario2. Specifically, as was previously mentioned, since no F_1 RBs are assigned to the non-edge users in Scenario3, non-edge users' throughput in Scenario3 is less than that of Scenario2.

[0099] The capacity of the above mentioned architectures is investigated through the system level simulation. We consider the two-ring hexagonal cellular system with nineteen eNBs, such

that each cell has 7 DRUs, as in FIG. 2, where the eNBs distance is 500 meters. The 10 UEs are located in each DRU area, following a uniform distribution. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in TABLE 2.

[0100] At a TTI of simulation, the eNB in a cell gathers the CQI information of UEs and allocates the RBs to each UE using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB^{(f)}} \log\left(1 + SINR_m^{(f)}\right), \quad f = F_1, F_2, F_3 \tag{16}$$

where, $W_{RB^{(f)}}$ is the bandwidth of RBs assigned to a UE and $SINR_m^{(f)}$ is the SINR of a UE_m. The cell capacity in each region is total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^{3} \sum_{m=1}^{M} C_m^{(F_i)} \tag{17}$$

where M is the number of UEs in a group.

[0101] FIG. 7 illustrates the simulation results for the non-edge users and edge users (i.e., the simulated capacity for edge cell and non-edge cell users versus the parameter α, where α varies between 0.2 and 0.8. The results obtained through simulation corroborate the results provided by analytical methods.

[0102] The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique, since the interference signal from neighbor cells is lower than that when we use HFR1 technique. In an embodiment using Scenario3 as a resource allocation strategy, the exterior user's throughput is increased.

[0103] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention. The method 800 includes transmitting and receiving data in a first geographical area and a first frequency band (810). The method also includes transmitting and receiving data in a second geographical area and a second

frequency band (812). In an embodiment, the first geographical area is a central area of a cell including multiple DRUs and the second geographical area is a peripheral area of the cell. In another embodiment, the second geographical area includes and extends to an area larger than the first geographical area (e.g., an area surrounding the first geographical area). The method further includes transmitting and receiving data in a third geographical area and at least a portion of the first frequency band (814). At least a portion of the frequency band used for the third geographical area is thus reused in relation to the first geographical area. The method also includes transmitting and receiving data in a fourth geographical area and a third frequency band (816). In an embodiment, the third geographical area is a central area of a cell including multiple DRUs and the fourth geographical area is a peripheral area of the cell. In another embodiment, the fourth geographical area includes and surrounds the third geographical area. The third frequency band may overlap with part of the first frequency band. Accordingly, multiple cells reuse the portions of the first frequency band, which may include multiple sub-bands that are contiguous or separated in frequency domain, in multiple adjacent cells.

[0104] It should be appreciated that the specific steps illustrated in FIG. 8 provide a particular method of implementing soft frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 8 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0105] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention. The method 900 includes transmitting and receiving data in a first geographical area and a first frequency band (910) and transmitting and receiving data in a second geographical area and a second frequency band (912). In an embodiment, the second geographical area surrounds the first geographical area. As an example, the first geographical area can be a central portion of a cell that is covered by a central DRU and the second geographical area can be a peripheral portion of the cell that is covered by a plurality of peripheral DRUs.

[0106] The method further includes transmitting and receiving data in a third geographical area and the first frequency band (914) and transmitting and receiving data in a fourth geographical area and a third frequency band (916). In an embodiment, the third geographical area surrounds the fourth geographical area. As an example, the third geographical area can be a central portion of another cell that is covered by a central DRU and the fourth geographical area can be a peripheral portion of the another cell that is covered by a plurality of peripheral DRUs. Thus, the frequency band used at the central portion of the first cell is reused at the central portion of the second cell. In embodiments, the frequency bands are not limited to contiguous blocks of frequencies, but can include sub-bands each including one or more frequency. The third frequency band can be different from the second frequency band, providing differing frequencies for the differing cells at adjacent geographical areas.

[0107] It should be appreciated that the specific steps illustrated in FIG. 9 provide a particular method of implementing fractional frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 9 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0108] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

TABLE 1. Number of RBs per user

	Interior region			Exterior region		
	F_1	F_2	F_3	F_1	F_2	F_3
$N_{RB^{(F)}}^{DAS-SFR-SC1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$
$N_{RB^{(F)}}^{DAS-SFR-SC2}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-SFR-SC3}$	0	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{\left(1-\alpha^2\right) N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR3}, N_{RB^{(F)}}^{Con-HFR3}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR1}, N_{RB^{(F)}}^{Con-HFR1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$

TABLE 2. Simulation Parameters

Parameters	Value
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1+37.6 \log_{10}(R(km))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms

WHAT IS CLAIMED IS:

1. A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. The method of claim 1 wherein the DRUs comprise remote radio units.

3. The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical

footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

ABSTRACT OF THE DISCLOSURE

A method for routing and switching operator RF signals includes providing one or more Digital Remote Units (DRUs) and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

65399089v1

PTO/AIA/01 (08-12)
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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 13/894,309 filed on May 14, 2013

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: Shawn Patrick Stapleton Date (Optional): _____

Signature: _____

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PTO/AIA/01 (06-12)
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☐ The attached application, or

☒ United States application or PCT international application number 13/894,309 filed on May 14, 2013

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

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LEGAL NAME OF INVENTOR

Inventor: Seyed Amin Hejazi Date (Optional): 13 Jun. 2013

Signature: _____

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

WITHDRAWAL NOTICE

OC000000066830348

Date Mailed: 03/07/2014

Letter Regarding a New Notice and/or the Status of the Application

If a new notice or Filing Receipt is enclosed, applicant may disregard the previous notice mailed on 06/26/2013. The time period for reply runs from the mail date of the new notice. Within the time period for reply, applicant is required to file a reply in compliance with the requirements set forth in the new notice to avoid abandonment of the application.

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web. https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If the reply is not filed electronically via EFS-Web, the reply must be accompanied by a copy of the new notice.

If the Office previously granted a petition to withdraw the holding of abandonment or a petition to revive under 37 CFR 1.137, the status of the application has been returned to pending status.

/nton/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/894,309

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	70		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	300		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	360		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	21 minus 20 =	* 1	x 40 =	40	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 210 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	770		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)	OR	RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/894,309	05/14/2013	2649	840	91172-866895(103600US)	21	3

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FILING RECEIPT

OC000000066830420

Date Mailed: 03/07/2014

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Seyed Amin Hejazi, Burnaby, CANADA;
Shawn Patrick Stapleton, Burnaby, CANADA;

Applicant(s)

DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS

Assignment For Published Patent Application

DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS

Power of Attorney: The patent practitioners associated with Customer Number 20350

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/649,143 05/18/2012

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access - A proper **Authorization to Permit Access to Application by Participating Offices** (PTO/SB/39 or its equivalent) has been received by the USPTO.

If Required, Foreign Filing License Granted: 06/13/2013
The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/894,309**
Projected Publication Date: To Be Determined - pending completion of Corrected Papers
Non-Publication Request: No

Early Publication Request: No
** **SMALL ENTITY** **
Title

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

Preliminary Class

455

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

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Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FORMALITIES LETTER

OC000000066830421

Date Mailed: 03/07/2014

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Filing Date Granted

An application number and filing date have been accorded to this application. The application is informal since it does not comply with the regulations for the reason(s) indicated below. Applicant is given TWO MONTHS from the date of this Notice within which to correct the informalities indicated below. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

The required item(s) identified below must be timely submitted to avoid abandonment:

- A substitute specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125, is required. The substitute specification must be submitted with markings and be accompanied by a clean version (without markings) as set forth in 37 CFR 1.125(c) and a statement that the substitute specification contains no new matter (see 37 CFR 1.125(b)). The specification, claims, and/or abstract page(s) submitted is not acceptable and cannot be scanned or properly stored because:
  - The application contains drawings, but the specification does not contain a brief description of the several views of the drawings as required by 37 CFR 1.74 and 37 CFR 1.77(b)(9).
- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 1d. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(9).

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

POA ACCEPTANCE LETTER

OC000000066830396

Date Mailed: 03/07/2014

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 09/26/2013.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

/nton/

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I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on May 7, 2014.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /Kristina Alvarez/
Kristina Alvarez

PATENT
Attorney Docket No.: 91172-866895-103600US
Client Ref. No.: DW-1036

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:
Seyed Amin Hejazi
Application No.: 13/894,309
Filed: May 14, 2013
For: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
Customer No.: 20350

Confirmation No.: 4407
Examiner: Unassigned
Technology Center/Art Unit: 2649

SUBMISSION OF SUBSTITUTE SPECIFICATION AND STATEMENT PURSUANT TO 37 CFR 1.125(b)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

In response to the Notice to File Missing Parts of Nonprovisional Application mailed March 7, 2014, please replace the specification with the accompanying substitute specification. A substitute specification with markings as well as a clean version are provided. Support for the addition of paragraphs [0020.A] - [0020.C] and figure captions for FIGS. 1E and 1F are provided, for example, in paragraph [0040] of the application as filed.

Applicants hereby state that the substitute specification contains no new matter.

Respectfully submitted,

/Craig C. Largent/
Craig C. Largent
Reg. No. 56,400

KILPATRICK TOWNSEND & STOCKTON LLP
66260344V.1

Electronic Acknowledgement Receipt	
EFS ID:	18970130
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Craig Cody Largent/Kristina Alvarez
Filer Authorized By:	Craig Cody Largent
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	07-MAY-2014
Filing Date:	14-MAY-2013
Time Stamp:	16:23:03
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Drawings-only black and white line drawings	ReplacementSheet_Page1_Figs 1Dto1F.pdf	55845 09f2289f98d30616103c4771fc725df0bf53a9b2	no	1

Warnings:
Information:

2		Specification_MarkedUpVersion.pdf	240203 22bf5058f05a874501dad87c46b70d22c233a89e	yes	36
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Specification		1	31	
	Claims		32	35	
	Abstract		36	36	
Warnings:					
Information:					
3		Specification_CleanVersion.pdf	237977 23e79ae946ceeb7bc58a1db80312cdbf6fab8187	yes	36
	Multipart Description/PDF files in .zip description				
	Document Description		**Start**	**End**	
	Specification		1	31	
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4	Miscellaneous Incoming Letter	Communication_103600US.pdf	64715 ff5572443cc09257628a0672885b921a8d87269d	no	1
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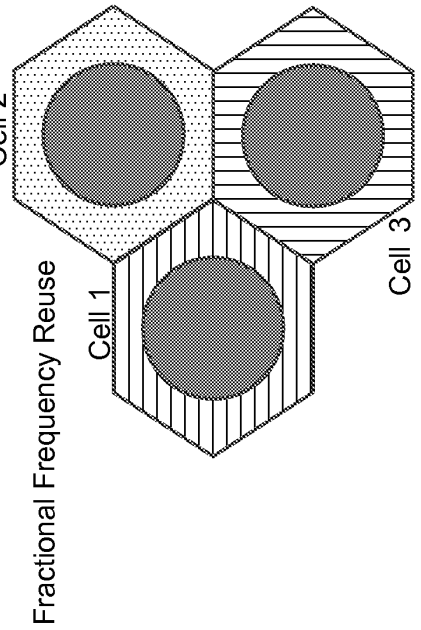


FIG. 1A

FIG. 1B

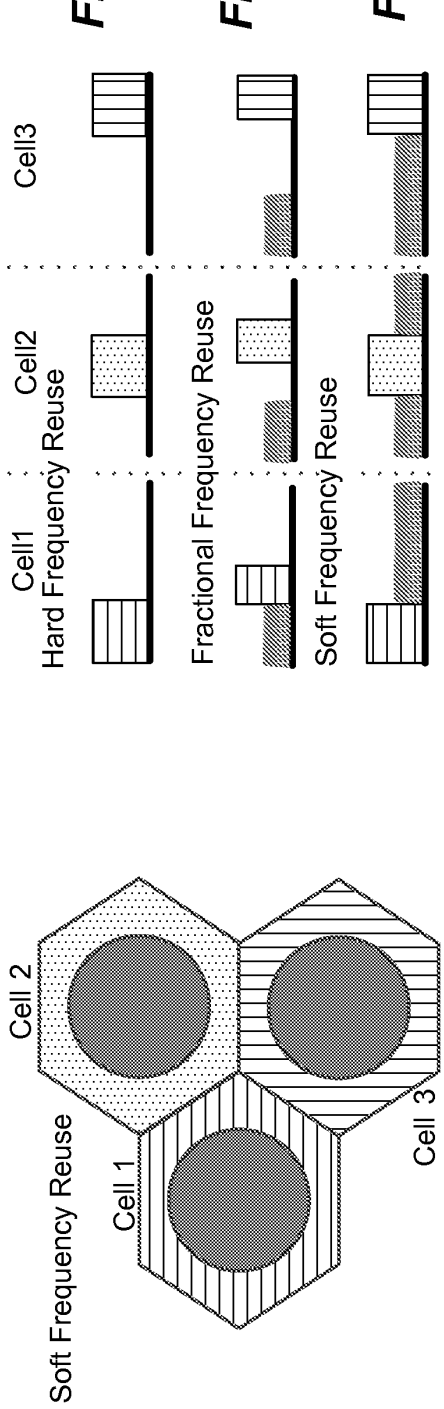


FIG. 1C

FIG. 1D

FIG. 1E

FIG. 1F

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-Marked Up Version of Specification-

PATENT APPLICATION

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

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METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/649,143, filed on May 18, 2012, entitled "Method and System for Soft Frequency Reuse in a Distributed Antenna System," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] Wireless communication systems employing Distributed Antenna Systems (DAS) are available. A DAS typically includes one or more host units, optical fiber cable or other suitable transport infrastructure, and multiple remote antenna units. A radio base station is often employed at the host unit location commonly known as a base station hotel, and the DAS provides a means for distribution of the base station's downlink and uplink signals among multiple remote antenna units. The DAS architecture with routing of signals to and from remote antenna units can be either fixed or reconfigurable.

[0003] A DAS is advantageous from a signal strength and throughput perspective because its remote antenna units are physically close to wireless subscribers. The benefits of a DAS include reducing average downlink transmit power and reducing average uplink transmit power, as well as enhancing quality of service and data throughput.

[0004] Despite the progress made in wireless communications systems, a need exists for improved methods and systems related to wireless communications.

SUMMARY OF THE INVENTION

[0005] The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS) as part of a distributed wireless network. More specifically, the present invention relates to a DAS utilizing Soft Frequency Reuse or Fractional Frequency Reuse techniques. In a particular embodiment, the present invention has been applied to the

reuse of communications frequencies in central portions of adjacent DAS cells, improving system data rates and performance. The methods and systems described herein are applicable to a variety of communications systems including systems utilizing various communications standards.

[0006] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies, and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU in a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU in a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

[0007] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

[0008] According to a specific embodiment of the present invention, a communications system is provided. The communications system includes a host unit and a first communications unit

coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint. The communications system also includes a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

[0009] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU of a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a plurality of additional DRUs of the first cell are operable to communicate using a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint surrounding the first geographic footprint. A first DRU of a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a plurality of additional DRUs of the second cell are operable to communication using a third set of frequencies characterized by a third frequency band different from the first frequency band over a fourth geographic range surrounding the third geographic range.

[0010] The DRUs can comprise remote radio units. The method may also include communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU. One or more of the plurality of BTSs can be coupled to the DAU using a plurality of BTS sector RF connections. The method may further include transporting signals between one or more DRUs and the at least one DAU.

[0011] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units in an array configuration and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized

by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic range surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint surrounding the third geographical footprint.

[0012] In an embodiment, the set of communications units include a plurality of remote units in communication with a host unit. The first geographic footprint can be centered on the first communications unit. The second geographic footprint can be a peripheral footprint centered on the first communications unit. The third geographical footprint can be centered on the second communications unit. The fourth geographical footprint can be a peripheral footprint centered on the second communications unit. The second geographical footprint can abut the fourth geographical footprint. The method can also include transmitting, and receiving, from a third communications unit of the set of communications units, a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint surrounding the fifth geographical footprint.

[0013] According to yet another embodiment, a communications system is provided. The communications system includes a first communications unit operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint and a second communications unit operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and one or more of the second set of frequencies in a region associated with a fourth geographical footprint.

[0014] The first communications unit can include a central DRU and a plurality of peripheral DRUs disposed adjacent the central DRU. The system can also include a DAU communicatively coupled to the central DRU and the plurality of peripheral DRUs. In an embodiment, the system includes a DAU communicatively coupled to the central DRU. Additionally, a second DAU can

be communicatively coupled to the plurality of peripheral DRUs. In an embodiment, the second geographical footprint at least partially surrounds the first geographical footprint. In another embodiment, the fourth geographical footprint at least partially surrounds the third geographical footprint or the second geographical footprint at least partially overlaps the fourth geographical footprint.

[0015] According to a specific embodiment, a frequency sharing system for a distributed antenna system is provided. The frequency sharing system includes a first frequency band characterized by a first frequency range and associated with a first geographic area associated with a first communications unit and a second frequency band characterized by a second frequency range different from the first frequency range and associated with a second geographic area at least partially surrounding the first geographic area. The frequency sharing system also includes a third frequency band overlapping at least a portion of the second frequency band and associated with a third geographic area associated with a second communications unit and a fourth frequency band overlapping at least a portion of the first frequency band and associated with a fourth geographic area at least partially surrounding the third geographic area.

[0016] The first geographic area can be characterized by a first border and the second geographic area can be characterized by a second border, wherein a predetermined distance separates the first border and the second border. The first frequency band and the second frequency band can be contiguous frequency bands. In an embodiment, the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent the first frequency band.

[0017] According to another specific embodiment, a communications system is provided and includes a first communications unit operable to transmit and receive communications using a first set of frequencies over a first predetermined area and a second communications unit operable to transmit and receive communications using a second set of frequencies over a second predetermined area. The first communications unit is operable to transmit and receive communications using a third set of frequencies over a third predetermined area and the second communications unit is operable to transmit and receive communications using at least a portion of the third set of frequencies over a fourth predetermined area.

[0018] The first communications unit can include a plurality of DRUs, at least one of the plurality of DRUs being coupled to a DAU. The third predetermined area can be at least

partially surrounded by the first predetermined area and the fourth predetermined area can be at least partially surrounded by the second predetermined area. In an embodiment, the first set of frequencies, the second set of frequencies, and the third set of frequencies are distinct frequencies. The first communications unit and the second communications unit can be disposed in an array configuration. The first predetermined area overlaps at least a portion of the second predetermined area in some implementations and the third predetermined area includes a location of the first communications unit and the fourth predetermined area includes a location of the second communications unit. The first communications unit can include a first plurality of digital remote units and the second communications unit comprises a second plurality of digital remote units. The first set of frequencies can be associated with a first number of the first plurality of digital remote units and the third set of frequencies can be associated with another of the first plurality of digital remote units. The second set of frequencies can be associated with a first number of the second plurality of digital remote units and the third set of frequencies can be associated with another of the second plurality of digital remote units.

[0019] Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIGS. 1A - 1C illustrate different frequency reuse techniques according to embodiments of the present invention;

[0020.A] ~~FIG. 1D illustrates, for each case Hard Frequency Reuse, Fractional Reuse, and Soft Frequency Reuse, the transmit/receive power as a function of frequency according to embodiments of the present invention;~~FIG. 1D illustrates, for the Hard Frequency Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0020.B] FIG. 1E illustrates, for the Fractional Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0020.C] FIG. 1F illustrates, for the Soft Frequency Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0021] FIG. 2 illustrates the structure of a Distributed Antenna System (DAS) according to an embodiment of the present invention;

[0022] FIG. 3 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to an embodiment of the present invention;

[0023] FIG. 4 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to another embodiment of the present invention;

[0024] FIG. 5 illustrates a capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area according to an embodiment of the present invention;

[0025] FIG. 6 is a plot illustrating analytical ergodic capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention; and

[0026] FIG. 7 is a plot illustrating simulation capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention.

[0027] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention; and

[0028] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0029] Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency.

[0030] Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the transmission scheme for the next generation wireless communication systems. However, the downlink performance of cellular networks is known to be strongly limited by inter-cell interference in OFDMA based systems. In order to mitigate this interference, a number of techniques have recently been proposed, e.g. the Soft Frequency Reuse (SFR) scheme and

Distributed Antenna System (DAS). According to embodiments of the present invention, these two techniques are combined in a unique cell architecture, which can be referred to as DAS-SFR. In an implementation of this architecture, which is described herein, the antennas are distributed in a hexagonal cell such that the central antenna is responsible for serving a special area using multiple frequency bands (e.g., all of the frequency bands) while the remaining antennas utilize only a subset of the frequency bands based on a frequency reuse factor. The inventors have analytically quantified the performance of the downlink multi-cell DAS-SFR in terms of the individual user's throughput under three different resource allocation scenarios. The results show that DAS-SFR reduces inter-cell interference in a multi-cell environment for users near the cell boundaries as compared to a Hard Frequency Reuse (HFR) scheme with a frequency reuse factor of 1. The results also show that DAS-SFR significantly increases the system capacity as compared to the HFR scheme with a frequency reuse factor of 3.

[0031] In DAS-SFR, by controlling the amount of resources allocated to users located in different areas, embodiments of the present invention increase the frequency efficiency and also improve the data rate for cell edge users. If the throughput requirement for the interior users is small, more resources can be assigned to the exterior users.

[0032] In the next generation wireless communication systems that use the 3GPP LTE (Long Term Evolution) standard, there is tremendous pressure to support a high data rate transmission. These systems are based on Orthogonal Frequency Division Multiple Access (OFDMA) to support the high data rate service and improve the Quality of Service (QoS), even for cell edge users as the main targets in the downlink.

[0033] The system bandwidth is divided into a number of sub-carriers in an OFDMA-based system such that each user utilizes a bandwidth smaller than the systems coherence bandwidth. Data from different users is transmitted in parallel on different sub-carriers. The orthogonality amongst the sub-carriers mitigates inter-carrier interference (ICI) while the resulting large OFDM symbol time and the narrow sub-carrier bandwidth reduces the effect of inter-symbol interference (ISI). Users located at the cell edge largely suffer from co-channel interference (CCI) or inter-cell interference from base stations (BS) of neighboring cells. Mobile 3GPP LTE adopts a frequency reuse factor of one, in which each cell serves users using the entire system bandwidth.

[0034] In order to reduce interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are three potential ways to reduce interference in cellular systems but these require a more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes(CLMD) and Beamforming are three other techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beamforming sacrifice spatial dimensions and require channel state knowledge.

[0035] One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a distributed antenna systems (DAS), which also has the additional advantage of improving capacity and coverage.

[0036] Other possible strategies include Frequency Reuse techniques, which effectively reduce inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

[0037] Distributed Antenna System (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems. As opposed to a conventional cellular system, where the antenna is centrally located, a DAS network consists of antenna modules that are geographically distributed to reduce access distance. These distributed antennas are connected to an eNodeB (eNB) LTE system by dedicated wires, fiber optics, or via a radio frequency link.

[0038] DAS has advantages including throughput improvement, coverage improvement, increased cellphone battery life, and a reduction in transmitter power. Recent research has shown benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is a Virtual DAS, wherein each remote has the added flexibility of independently transmitting preselected carriers.

[0039] Frequency reuse techniques are utilized herein to reduce inter-cell interference in cellular systems. This benefits users near the cell edges owing to simplicity and practicality. There are three major frequency reuse patterns illustrated in ~~FIG. 1~~FIGS. 1A-1E for mitigating

inter-cell interference: Hard Frequency Reuse, Fractional Frequency Reuse and Soft Frequency Reuse.

[0040] Hard Frequency Reuse (HFR) splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub-bands. This inter-cell interference mitigation method is typically seen in GSM networks, when it comes to distribution of frequencies among the cells. When applied to LTE, the Resource Blocks (a group of sub-carriers) are divided into 3, 4 or 7 disjoint sets. These sets of Resource Blocks (RBs) are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies, as illustrated in FIG. 1A. ~~FIG. 1D shows~~ FIGS. 1D, 1E, and 1F show, for each case (Hard Frequency Reuse (FIG. 1A and FIG. 1D), Fractional Frequency Reuse (FIG. 1B and FIG. 1E), and Soft Frequency Reuse (FIG. 1C and FIG. 1F)), the transmit/receive power as a function of frequency. This reduces the interference at the cell edge of any pair of cells significantly and can be considered the opposite extreme to Full Frequency Reuse in matters of frequency partitioning techniques. While user interference at the cell edge is maximally reduced, the spectrum efficiency drops by a factor equal to the reuse factor. The inter-cell interference can be reduced with a frequency reuse factor of more than one, however, it may reduce the system capacity.

[0041] Fractional Frequency Reuse (FFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. OFDMA provides the ability for each eNB to selectively allocate frequency sub-bands, data rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. FFR splits the given bandwidth into an inner and an outer region as illustrated in FIG. 1B. The spectrum allocated to the inner region is assigned to the nearby users (located close to the eNB in terms of path loss) applying a frequency reuse factor of one (i.e. the inner part is completely reused by all eNBs). While the spectrum allocated to the outer region, for users close to the cell edge (far users), is divided among the different eNBs as in hard frequency reuse techniques. This scheme is particularly useful to mitigate the inter-cell interference in the uplink, where severe interference situations can occur when the user is located close to a strong interferer from a neighbor cell.

[0042] Soft Frequency Reuse (SFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. SFR shares the overall bandwidth by all eNBs (i.e. a reuse

factor of one is applied), but for transmission on each group of RBs, the eNBs are restricted to a certain power bound. FIG. 1C illustrates the power and frequency assignments in the different cells of a system with SFR for a reuse factor of 3. It can be noticed in the frequency spectrum of FIG. [[1D]] 1F associated with Soft Frequency Reuse (i.e., FIG. 1C), that there is a region of high-power transmissions and some regions of low-power transmissions. Using a similar strategy extending Fractional Frequency Reuse, resources in the high-power region are preferably assigned to User Equipment (UEs) located at the cell edge, while cell-center UEs are typically assigned resources in the low-power regions. SFR can utilize the entire frequency spectrum that has been allocated, increasing the system data rate and/or capacity.

[0043] Referring to FIGS. 1C-1F ~~and 1D~~, frequencies in the grey frequency band (~ upper 2/3 of the available frequencies) are transmitted/received by a DRU at a first power level in Cell 1, providing coverage for the central portion of Cell 1. Frequencies in the horizontal stripes band are transmitted/received by the DRU at a second power level higher than the first power level, providing coverage over both the central portion of Cell 1 as well as the peripheral portions of Cell 1 since the higher power level results in a larger coverage area. In this example, each cell utilizes a single DRU, although other embodiments can utilize multiple DRUs per cell as described more fully herein. DRUs in the other cells also transmit/receive at both high power for a subset of the frequencies and low power for remaining frequencies as shown in FIG. 1D, producing the coverage maps illustrated in FIG. 1C, with low power frequencies providing centralized coverage and higher power frequencies providing a large coverage area extending to the peripheral regions of the cells. Although all three cells are transmitting/receiving using overlapping (or the same) frequencies at low power, the corresponding propagation distances for these frequencies are smaller, preventing geographic overlap between the central grey regions.

[0044] In order to reduce interference in areas where cells are adjacent, the frequencies associated with higher power are grouped into subbands, with little or no overlap between the subbands. Referring to FIG. IF [[1D]], in the SFR implementation, Cell 1 uses high power for the horizontal stripes band in approximately the first third of the frequency bandwidth, Cell 2 uses high power for the dotted band in approximately the second third of the frequency bandwidth, and Cell 3 uses high power for the vertical stripes band in approximately the last third of the frequency bandwidth. Thus, at the intersections between cells, since different portions of the available frequency band are being utilized, interference is reduced. Thus, in some embodiments, different frequency bands are utilized in adjacent cells, which is illustrated

by the high power frequency bands for SFR in FIG. IF [[1D]]: the first frequency band in Cell 1, the second frequency band different from the first frequency band in Cell 2, and the third frequency band different from the first frequency band and the second frequency band in Cell 3. For an additional number of cells, the subdivision of the available bandwidth can be increased as appropriate to the particular number of adjacent cells in the implementation. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0045] HFR, though simple in implementation, suffers from a reduced spectral efficiency. On the other hand, both SFR and FFR have increased (e.g., full) spectral efficiency and are a strong mechanism for inter-cell interference mitigation. A coordinated resource allocation system can be impractical in realistic settings involving a large number of eNBs, random traffic and realistic path-loss models. However, an encouraging result is that by using even limited (yet practical) levels of coordination, significant performance benefits can still be obtained over a conventional cellular architecture. Most of the recent publications have focused on investigating SINR advantages of DAS and analyzing its performance. On the other hand, there are no studies that combine DAS with SFR in order to reduce inter-cell interference. Some publications on DAS have focused on analyzing the uplink performance because of its analytical simplicity and there are few studies on the downlink performance of DAS although the demand for high-speed data rate will be dominant in the downlink path. There are also very few publications that consider the advantages of DAS in a multi-cell context. Recent research on FFR and SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional works on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

[0046] According to embodiments of the present invention, a new architecture is provided to suppress inter-cell interference. The architecture described herein combines DAS and SFR for an OFDMA system (e.g., LTE). Embodiments of the present invention provide benefits by using DAS-SFR in a multi-cell environment. The downlink advantages of DAS-SFR are described in terms of achievable ergodic capacity for three different frequency resource allocation scenarios. The results shows that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture and achieves a non-trivial capacity increase over a HFR cellular architecture with a frequency reuse factor of 3. Other reuse factors are included within the scope of the present

invention, for example, up to or more than 7 as suitable for the DAS architecture illustrated in FIG. 2.

[0047] As described herein, an analytical framework has been developed to evaluate the ergodic capacity in a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service, regardless of their geographic location, instead of simply a minimum user throughput which may be acceptable for applications like voice traffic. We present a strategy for optimally allocating frequency RBs to edge users for a DAS-SFR architecture, based on a chosen performance threshold T_p, which can be related to network traffic load. Finally we prepare a simulation scenario to compare the analytical results with the simulation results.

[0048] Referring to the spectral plots illustrated in FIG. 1D, in the HFR system, the horizontal stripes, shaded, and vertical stripes frequency bands occupy different frequency ranges and, in combination, fill the entire spectrum. In HFR (FIG. 1A), cell 1 uses the lower frequencies (horizontal stripes), cell 2 uses the middle frequencies (shaded), and cell 3 uses the higher frequencies (vertical stripes).

[0049] Referring to FIG. 2, the DAS includes a central cell referenced as eNB0, which includes DRU0 through DRU6 that are communicating through one base station at eNB0 through a DAU. DRU0 can be considered to be Cell 1 in FIGS. 1A - 1C, DRU1 can be considered to be Cell 2 in FIGS. 1A - 1C, and DRU2 can be considered to be Cell 3 in FIGS. 1A-1C. In other embodiments, eNB0 is considered to be Cell 1 in FIGS. 1A - 1C and eBN1, including a different set of DRUs, DRU0 through DRU6, can be considered to be Cell 2 in FIGS. 1A - 1C, etc. In FIG. 1A, Cell 1 (e.g., DRU0 of eNB0) utilizes the horizontal stripes frequency band and the other cells use different frequency bands as illustrated. In the embodiment illustrated in FIG. 2, seven different frequency bands could be utilized for high power transmission by the seven DRUs connected to each base station. For cells geographically separated from Cell 1, for example, cells in eNB7 could reuse the same frequencies (horizontal stripes) used in Cell 1 (e.g., eNB0).

[0050] Referring once again to FIG. 1B, a set of frequencies operating at reduced power compared to the frequencies discussed in relation to HFR and represented by the grey frequency

bands in the FFR and SFR portion of ~~FIG. 1D~~ FIGS. 1E and 1F, respectively, are reused in each of the cells (i.e., Cell 1, Cell 2, and Cell 3). Because this frequency band does not geographically overlap with adjacent cells (i.e., it is used at the central portion of the cell as a result of the lower power), overlap between adjacent cells is prevented and this frequency band can be reused in adjacent cells.

[0051] For fractional frequencies, because there is a spatial separation between the grey areas in the spectra in Cell 1 and Cell 2 and Cell 3, as long as the spatial separation is significant enough, there will not be significant interference between the cells although the central portions of the cells are transmitting on the same (e.g., exact same) frequencies. By keeping a separation and allocating the horizontal stripes frequency band in Cell 1 to specific frequencies, the shaded frequency band in Cell 2 to other specific frequencies, the vertical stripes frequency band in Cell 3 to still other specific frequencies, and the like for additional cells, embodiments of the present invention make efficient use of the given spectrum. Comparing the Fractional Frequency Reuse spectrum to the Hard Frequency Reuse spectrum, it is evident that FFR uses more of the available spectrum, which enables support for more users, operation at a higher data rate, combinations thereof, or the like. In the illustrated example, the fraction of the spectrum used in each cell has increased from about a third of the spectrum (HFR) to about half of the spectrum (FFR). Other implementations can utilized different fractions of the spectrum and the present invention is not limited to the particular example illustrated in FIG. 1B and FIG. 1E [[1D]].

[0052] In one embodiment, to implement the fractional frequency reuse technique illustrated in FIG. 1B using the architecture illustrated in FIG. 2, DRUs 1, 2, 3, 4, 5 and 6 of eNB0 would transmit and receive data using frequencies in the horizontal stripe frequency band and DRU0 of eNB0 would transmit and receive data using the grey frequencies. In an embodiment, the size of the area covered by DRU0 can be increased by increasing the transmit power associated with the central DRU (i.e., DRU0). In another embodiment, each DRU in eNB0 transmits and receives data at a first power level using frequencies in the grey frequency bands and at a second, higher power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands. In this embodiment, three of the seven DRUs illustrated in an eNB are illustrated by Cells 1-3.

[0053] Referring to FIG. 1C, an architecture implementing Soft Frequency Reuse is illustrated and the matching spectrum in FIG. 1F [[1D]] illustrates the full use the spectrum by each of the

adjacent cells. In an embodiment in which multiple DRUs are utilized per cell, the horizontal stripe geographical area in Cell 1 is associated with the outer DRUs in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRUs 1-6) and the grey geographical area in Cell 1 is associated with the central DRU in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRU0). As discussed above, the size of the grey circle can be increased/decreased by increasing/decreasing the power of utilized in conjunction with DRU0. As shown in the SFR spectrum for Cell 1, data is transmitted and received over the entire allocated spectrum, including portions of the spectrum that were unused for Cell 1 in the HFR example. The increase in spectrum provides increased data rate, increased capacity, combinations thereof, or the like. In other embodiments, a single DRU in Cell 1 broadcasts at low power over the grey band and at a higher power over the horizontal stripe spectrum. Other cells demonstrate similar behavior. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0054] Comparing FFR (FIG. 1B) and SFR (FIG. 1C), the frequency bandwidth available for the peripheral DRUs or for the higher power broadcast from a DRU in the cell (i.e., horizontal stripe, dotted, or vertical stripe spectra) is increased for SFR in comparison to FFR. Additionally, the frequency bandwidth available for the central DRU or for the lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

[0055] In an embodiment, fractional frequency reuse is implemented in a DAS system with a plurality of adjacent cells, each of the cells including a plurality of remote units. A first cell utilizes a first frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and a second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs). A second cell utilizes a third frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and the second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs).

[0056] In another embodiment, soft frequency reuse is implemented in a DAS system with a plurality of adjacent cells. A first cell utilizes a first frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a second frequency band (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). A second cell utilizes a third frequency band

at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a fourth frequency band, which may include multiple sub-bands (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). The third frequency band may include frequencies in the second frequency band and the multiple sub-bands of the fourth frequency band may include frequencies in the first frequency band as illustrated in FIG. 1C.

[0057] As will be appreciated by one of skill in the art, operators utilize different spectrums and, in the examples illustrated in ~~FIG. 1D~~ FIGS. 1D-1F, they are contiguous. However, it should be noted that although contiguous spectra are illustrated in ~~FIG. 1D~~ FIGS. 1D-1F, this is not required by embodiments of the present invention and non-contiguous spectrums may be utilized in other embodiments. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0058] Although the embodiments illustrated in ~~FIG. 1D ulitizes~~ FIGS. 1D-1F utilize three frequencies, embodiments of the present invention are not limited to this particular number and additional frequencies and frequency bands can be utilized, for example, additional frequency bands used in conjunction with additional cells. In a particular embodiment, seven frequency bands, twelve frequency bands, or the like can be utilized. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0059] System Architecture (DAS-SFR)

[0060] The general architecture of a Virtualized DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRUs) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized such that each DRU allocated to a given eNB sector is simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. The DAUs assign the RBs of the various sectors to the independent DRUs. In contrast, the same area (7 DRUs) is covered by only a high-power eNB in traditional cellular system. The proposed architecture divides the entire spectral bandwidth F into 3 parts (F_1, F_2, F_3). The idea is that the eNB assigns the full-reused frequency (all 3 parts) to the central DRU and the other 6

edge DRUs work on just 1 part based on a reuse factor of Δ in such a way that neighbor cell edge DRUs don't use the same frequency part.

[0061] The total transmit power of the *n*-th DRU of *i*-th cell in *f*-th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by *n* = 0. Throughout this application, we assume that $P_n^{(i,f)} = P$.

[0062] We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

[0063] Resource Allocation Scenarios:

[0064] In cellular DAS-SFR with multi users, there are several possible resource allocation scenarios using multiple DRUs. Much of the research on SFR system design has focused on how to determine the size of the frequency partition, for example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users per each frequency part($F_i, i = 1,2,3$).

[0065] For a typical central cell, let's assume the center DRU is assigned the full-reused frequency and the other six edge DRUs are assigned to F_1. Now, we consider three resource allocation scenarios:

[0066] - **Scenario 1:** All F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

[0067] - **Scenario 2:** F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

[0068] - **Scenario 3:** F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs

are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

[0069] We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario we investigate both the analytical and simulation results in order to verify the system's capacity improvement.

[0070] Channel Model and Received Signal

[0071] The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise. The received signal vector of the user in the 0th cell at frequency f can be expressed as:

$$\begin{aligned} y^{(0,f)} &= signal + interference + noise \\ &= \mathbf{H}^{(0,f)}\mathbf{x}^{(0,f)} + \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n} \end{aligned} \tag{1}$$

where $\mathbf{H}^{(i,f)} \in C^{1\times 7}$, $i = 0, 1, \ldots, 18$, denotes the channel matrix between the DRUs in the i-th cell and the user in the central (0th) cell, $x^{(i,f)} = \left[x_0^{(i,f)}, x_1^{(i,f)}, \ldots, x_6^{(i,f)}\right]^T \in C^{7x1}, i - 0,1, \ldots,18$ is the transmitted signal vector of the DRUs in the i-th cell, $n^{(f)} \in C^{1x1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma^2_{n^{(f)}}\mathbf{I}_1)$.

[0072] The distributed antenna power constraint is considered, we have

$$\mathbf{E}\left[\left|x_n^{(i,f)}\right|^2\right] \le P_n^{(i,f)}, n = 0,1,\ldots,6, \quad i = 0,1,\ldots,18, \tag{2}$$

where in DAS-SFR,

$$\begin{aligned} &x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17), \\ &x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18), \\ &x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18), \end{aligned}$$

in DAS-HFR3 (frequency reuse factor 3),

$$\begin{aligned} &x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17), \\ &x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18), \\ &x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \ (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18), \end{aligned}$$

in DAS-HFR1 (frequency reuse factor 1),

$x_n^{(i,f)} \neq 0, P_n^{(i,f)} \neq 0 \quad when \quad (n = 0,1,...,6 \quad and \quad i = 0,1,...,18 \quad , f = F_1, F_2, F_3),$

in Conventional Cellular-HFR3 (frequency reuse factor 3),

$$\begin{aligned} x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad & (n = 0,1,...,6 \quad and \quad i = 1,2,...,7,9,11,13,15,17) \; or \\ & (n = 1,2,...,6 \quad and \quad i = 0,8,10,12,14,16,18), \\ x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad & (n = 0,1,...,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18) \; or \\ & (n = 1,2,...,6 \quad and \quad i = 1,3,5,9,13,17), \\ x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad & (n = 0,1,...,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18) \; or \\ & (n = 1,2,...,6 \quad and \quad i = 2,4,6,7,11,15), \end{aligned}$$

and in Conventional cellular-HFR1 (frequency reuse factor 1),

$x_n^{(i,f)} = 0, P_n^{(i,f)} = 0 \quad when \quad (n = 1,...,6 \quad and \quad i = 0,1,...,18 \; and \; f = F_1, F_2, F_3),$

where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell.

[0073] The composite fading channel matrix $\mathbf{H}^{(i,f)}, i = 0,1,...,18$, encompasses not only small-scale fading but also large-scale fading, which is modeled as

$$\begin{aligned} \mathbf{H}^{(i,f)} &= \mathbf{H}_w^{(i,f)} \mathbf{L}^{(i,f)} \\ &= \left[h_0^{(i,f)}, h_1^{(i,f)}, ..., h_6^{(i,f)} \right] . diag\left\{ l_0^{(i,f)}, l_1^{(i,f)}, ..., l_6^{(i,f)} \right\} \end{aligned} \tag{3}$$

where $\mathbf{H}_w^{(i,f)}$ and $\mathbf{L}^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the 0th cell, respectively. $\left\{ h_j^{(i,f)} \middle| j = 0,1,...,6; i = 0,1,...,18; f = F_1, F_2, F_3 \right\}$ are independent and identically distribute (*i.i.d*) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\left\{ l_j^{(i,f)} \middle| j = 0,1,...,6; i = 0,1,...,18; f = F_1, F_2, F_3 \right\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{\left[D_n^{(i)} \right]^{-\gamma} \chi_n^{(i,f)}}, \quad n = 0,1,...,6, \quad i = 0,1,...,18 \tag{4}$$

where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the 0th cell and the nth DRU in the i-th cell, respectively, γ denotes the path loss exponent. $\left\{ \chi_j^{(i,f)} \middle| j = 0,1,...,6; i = 0,1,...,18; f = F_1, F_2, F_3 \right\}$ are *i.i.d* random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi}\lambda\sigma_\chi \chi} \exp\left(-\frac{(\ln \chi)^2}{2\lambda^2 \sigma_\chi^2} \right), \quad \chi > 0, \tag{5}$$

where σ_χ is the shadowing standard deviation and $\lambda = \frac{\ln 10}{10}$.

[0074] Since the number of interfering source is sufficiently large and interfering source are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18} \mathbf{H}^{(i,f)} \mathbf{x}^{(i,f)} + \mathbf{n}^{(f)} \tag{6}$$

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned} Var(N^{(f)}) &= \left[\sum_{i=1}^{18} \sum_{n=0}^{6} \left[l_n^{(i,f)} \right]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2 \right] \mathbf{I}_1 \\ &= \left[\sigma^{(f)} \right]^2 \mathbf{I}_1 \end{aligned} \tag{7}$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$\mathbf{y}^{(0)} = \mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)} \mathbf{x}^{(0,f)} + N^{(f)} \tag{8}$$

[0075] Achievable capacity of distributed antenna network

[0076] If we assume the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station can be calculated by

$$C^{(f)} = \mathbf{E}_{\mathbf{H}_w^{(0,f)}} \left[\log_2 \det(\mathbf{I}_1 + \frac{1}{\left[\sigma^{(f)} \right]^2} (\mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)}) \mathbf{P}^{(0,f)} (\mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)})^H) \right] \tag{9}$$

where $\mathbf{P}^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $diag\left\{ P_0^{(0,f)}, P_1^{(0,f)}, ..., P_6^{(0,f)} \right\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$\begin{aligned} C^{(f)} &= \mathbf{E}_{\mathbf{H}_w^{(0,f)}} \left[\log_2 (1 + \frac{1}{\left[\sigma^{(f)} \right]^2} \sum_{i=0}^{6} \left| h_i^{(0,f)} \right|^2 \left[l_i^{(0,f)} \right]^2 P_i^{(0,f)}) \right] \\ &= \int_{\gamma_f = 0}^{\infty} \log_2 (1 + \gamma_f) f_{\gamma_f} (\gamma_f) d\gamma_f \end{aligned} \tag{10}$$

where $\gamma_f = \frac{1}{\left[\sigma^{(f)}\right]^2}\sum_{i=0}^{6}\left|h_i^{(0,f)}\right|^2\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}$ is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f) = \sum_{i=0}^{6}\frac{\left[\sigma^{(f)}\right]^2\pi_i}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2\gamma_f}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), \tag{11}$$

where

$$\pi_i = \prod_{k=0,k\neq i}^{6}\frac{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)} - \left[l_i^{(0,f)}\right]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$C^{(f)} = -\frac{1}{\ln 2}\sum_{i=0}^{6}\pi_i\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right)Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), f = F_1, F_2, F_3 \tag{12}$$

where $Ei(t)$ is the exponential integral function ($Ei(t) = -\int_{-x}^{\infty} e^{-t}/t\,dt$) and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

[0077] Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$C^{(f)} = -\frac{1}{\ln 2}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right)Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), f = F_1, F_2, F_3 \tag{13}$$

[0078] Thus, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total} = C^{(F_1)} + C^{(F_2)} + C^{(F_3)} \tag{14}$$

[0079] Analytical and Simulation Results

[0080] FIG. 3 and FIG. 4 represents the ergodic capacity of cellular DAS for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position X when the path loss exponent is 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}, C^{(F_2)}, C^{(F_3)}$, and also for the total capacity C_{total}.

[0081] The transmit power of each distributed antenna module is *P* whereas the transmit power of eNB in the conventional cellular system is 7*P*. These figures show an interesting non-monotonic relationship between capacity and the normalized distance from the base station. This is because the signal from a distributed antenna module becomes dominant around 0.6R.

[0082] FIG. 3 compares the capacity performance of the two frequency reuse techniques, SFR and HFR3, for a particular central cell. Note that in the SFR technique, all 3 frequency bands are assigned, whereas, in the HFR3 method, only the F_1 band is used. The results show that the SFR method achieves the highest throughput, owing to use of more frequency bandwidth. More specifically, the total capacity achieved using the SFR method is the highest inside the normalized distance 0.5.

[0083] A non-significant throughput reduction in the SFR technique is observed happening beyond a normalized distance 0.5, due to the interference introduced from the neighboring central DRU cells. Note that there is no interference introduced from the DRU neighboring cells when the HFR3 method is applied. It is worth mentioning that the achieved throughput of the DAS-HFR3 is slightly lower than that of a conventional cellular (Con-HFR3) system near the eNB0 DRU0, due to the reduced transmit power.

[0084] FIG. 4 compares the capacity performance of the two frequency reuse techniques, SFR and HFR1, for a particular central cell. Note that in both SFR and HFR1 techniques, all 3 frequency bands are assigned. The achieved throughputs of the DAS-HFR1 and DAS-SFR are slightly lower than that of a conventional cellular (Con-HFR1) system near the eNB0 (DRU0), due to the reduced transmit power.

[0085] FIG. 4 illustrates that the HFR1 technique outperforms the SFR technique in terms of the achieved throughput inside the $(0,\ 0.5R)$ region, nevertheless, the SFR technique significantly improves the system performance by making up for the dead spots happening at the cell edges. Note that there is a significant amount of interference happening in the $(0.8R, R)$ region, creating dead-spots in the HFR1 technique.

[0086] Note that 80% of the users are located inside the $(0.5R, R)$ region, assuming a uniform distribution, while the other 20% are farther from the interfering cells. Therefore, it is more important to improve the system capacity inside the $(0.5R, R)$ region.

[0087] In multiuser systems, where all users are uniformly distributed in the cell, we need to consider different resource allocation scenarios which were defined above. Assuming that each cell has radius R, we define parameter α ($0<\alpha<1$) such that the interior area is located in the $(0, \alpha R)$ region and the exterior area is located in the $(\alpha R, R)$ region.

[0088] In LTE systems, eNB distinguishes between the interior and exterior users based on their corresponding uplink power received at the central DRU. To implement this technique, we propose a threshold T_p as a parameter in eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa.

[0089] Note that

$$N_{\text{int}erior} = \alpha^2 N_{users},$$
$$N_{exterior} = \left(1-\alpha^2\right) N_{users}, \quad (15)$$

where $N_{\text{int}erior}$ represents the number of interior users, $N_{exterior}$ represents the number of exterior users, and N_{users} represents the total number of users. We will consider the 3 different resource allocation scenarios mentioned above, where the number of RBs per users assigned in the different regions (interior or exterior) for different Scenarios can be expressed as in TABLE 1, where $N_{RB^{(F_i)}}, i=1,2,3$ represents the number of RBs for given frequency part F_i and $N_{RB^{(F_i)}}^{tech}$ represent the number of RBs for given F_i for the different techniques.

[0090] Note that in all 3 scenarios we have applied the Round Robin scheduling technique.

[0091] If we consider the number of RBs which are assigned to the different regional users under the different scenarios, the capacity metric of the total system can be obtained by,

$$C_{metric}^{total,\,tech} = C_{metric}^{(tech,\,F_1)} + C_{metric}^{(tech,\,F_2)} + C_{metric}^{(tech,\,F_3)} \quad (16)$$

where

$$C_{metric}^{(tech,\,F_i)} = N_{RB^{(F_i)}}^{tech}.C^{(F_i)} \quad , i=1,2,3,$$
$$tech \in \begin{Bmatrix} DAS-SFR-SC1, DAS-SFR-SC2, DAS-SFR-SC3, \\ DAS-HFR3, Con-HFR3, DAS-HFR1, Con-HFR1 \end{Bmatrix}.$$

[0092] In FIG. 5, the capacity metric is provided considering a uniform distribution of users and a Round Robin Scheduler. In this example, which illustrates the capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area, we

assume α is 0.5. The achieved capacity of the DAS-SFR architecture with Scenario2 and Scenario3 is higher than that of DAS-SFR system with Scenario1, especially near the central DRU. This is due to the fact that the F_2 and F_3 RBs are not assigned to the exterior users which have very low SINR and all F_2 and F_3 RBs assigned to interior users.

[0093] Comparing Scenario2 with Scenario3, we observe that the achievable capacity for interior users in DAS-SFR architecture with Scenario2 is slightly higher than that of scenario3 due to the full frequency reuse for the interior users in Scenario2. However, in Scenario3, only the F_2 and F_3 frequency bands are used by the interior users. Conversely, the achieved capacity for exterior users in a DAS-SFR architecture with Scenario3 is slightly higher than that of Scenario 2, due to the fact that all F_1 RBs are used by the exterior users, whereas in Scenario2 the F_1 RBs are partially used by the exterior users.

[0094] Note that FIG. 5 illustrates that the DAS-HFR1 technique outperforms other techniques in terms of the achieved throughput by majority of the interior users; nevertheless, SFR technique significantly improves the system performance by making up for the dead spots which appear at the cell edges. Note that there is a significant amount of interference happening in the ($0.8R, R$) region, causing the dead spots in DAS-HFR1 technique.

[0095] In the established system environment, we evaluate the total system capacity for several cases for non-edge users (inside $(0, 0.8R)$ region) and edge users (inside $(0.8R, R)$). We assume α sweeps from 0.2 to 0.8. Remember that α manages the portion of resources allocated in Scenario2 and Scenario3.

[0096] FIG. 6 illustrates the analytical results for the non-edge users and edge users, where α varies between 0.2 and 0.8, that is, the analytical ergodic capacity for edge cell and non-edge cell users versus the parameter α.

[0097] Note that as α changes, the number of RBs assigned to the users in Scenario2 and Scenario3 changes accordingly. However, in other techniques, with changing α, number of assigned RBs to the users remains unaltered. As α increases, the edge user's throughput increases in Scenario3, due to the fact that more RBs are assigned to those users. Specifically, as α increases, less users need to use F_1 RBs in Scenario3. However, in other techniques, edge

users experience a constant throughput, due to the fact that the number of RBs allocated to the edge users remains constant as α changes. Specifically, regardless of the changes in α, all F_1 RBs are assigned to all users.

[0098] As α increases, non-edge users' throughput decreases, due to the fact that the total constant number of F_2 and F_3 RBs should be assigned to more number of users accordingly. Note that the rate of decrease in user throughput for non-edge users for Scenario3 is more than that of Scenario2, as α increases. The reason behind this is that the rate of decrease in number of RBs assigned to the non-edge users in Scenario3 is more than that of Scenario2. Specifically, as was previously mentioned, since no F_1 RBs are assigned to the non-edge users in Scenario3, non-edge users' throughput in Scenario3 is less than that of Scenario2.

[0099] The capacity of the above mentioned architectures is investigated through the system level simulation. We consider the two-ring hexagonal cellular system with nineteen eNBs, such that each cell has 7 DRUs, as in FIG. 2, where the eNBs distance is 500 meters. The 10 UEs are located in each DRU area, following a uniform distribution. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in TABLE 2.

[0100] At a TTI of simulation, the eNB in a cell gathers the CQI information of UEs and allocates the RBs to each UE using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB^{(f)}} \log\left(1 + SINR_m^{(f)}\right), \quad f = F_1, F_2, F_3 \tag{16}$$

where, $W_{RB^{(f)}}$ is the bandwidth of RBs assigned to a UE and $SINR_m^{(f)}$ is the SINR of a UE_m. The cell capacity in each region is total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^{3} \sum_{m=1}^{M} C_m^{(F_i)} \tag{17}$$

where M is the number of UEs in a group.

[0101] FIG. 7 illustrates the simulation results for the non-edge users and edge users (i.e., the simulated capacity for edge cell and non-edge cell users versus the parameter α, where α varies between 0.2 and 0.8. The results obtained through simulation corroborate the results provided by analytical methods.

[0102] The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique, since the interference signal from neighbor cells is lower than that when we use HFR1 technique. In an embodiment using Scenario3 as a resource allocation strategy, the exterior user's throughput is increased.

[0103] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention. The method 800 includes transmitting and receiving data in a first geographical area and a first frequency band (810). The method also includes transmitting and receiving data in a second geographical area and a second frequency band (812). In an embodiment, the first geographical area is a central area of a cell including multiple DRUs and the second geographical area is a peripheral area of the cell. In another embodiment, the second geographical area includes and extends to an area larger than the first geographical area (e.g., an area surrounding the first geographical area). The method further includes transmitting and receiving data in a third geographical area and at least a portion of the first frequency band (814). At least a portion of the frequency band used for the third geographical area is thus reused in relation to the first geographical area. The method also includes transmitting and receiving data in a fourth geographical area and a third frequency band (816). In an embodiment, the third geographical area is a central area of a cell including multiple DRUs and the fourth geographical area is a peripheral area of the cell. In another embodiment, the fourth geographical area includes and surrounds the third geographical area. The third frequency band may overlap with part of the first frequency band. Accordingly, multiple cells reuse the portions of the first frequency band, which may include multiple sub-bands that are contiguous or separated in frequency domain, in multiple adjacent cells.

[0104] It should be appreciated that the specific steps illustrated in FIG. 8 provide a particular method of implementing soft frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative

embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 8 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0105] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention. The method 900 includes transmitting and receiving data in a first geographical area and a first frequency band (910) and transmitting and receiving data in a second geographical area and a second frequency band (912). In an embodiment, the second geographical area surrounds the first geographical area. As an example, the first geographical area can be a central portion of a cell that is covered by a central DRU and the second geographical area can be a peripheral portion of the cell that is covered by a plurality of peripheral DRUs.

[0106] The method further includes transmitting and receiving data in a third geographical area and the first frequency band (914) and transmitting and receiving data in a fourth geographical area and a third frequency band (916). In an embodiment, the third geographical area surrounds the fourth geographical area. As an example, the third geographical area can be a central portion of another cell that is covered by a central DRU and the fourth geographical area can be a peripheral portion of the another cell that is covered by a plurality of peripheral DRUs. Thus, the frequency band used at the central portion of the first cell is reused at the central portion of the second cell. In embodiments, the frequency bands are not limited to contiguous blocks of frequencies, but can include sub-bands each including one or more frequency. The third frequency band can be different from the second frequency band, providing differing frequencies for the differing cells at adjacent geographical areas.

[0107] It should be appreciated that the specific steps illustrated in FIG. 9 provide a particular method of implementing fractional frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 9 may include multiple sub-steps that may be performed in various sequences as appropriate to the

individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0108] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

TABLE 1. Number of RBs per user

	Interior region			Exterior region		
	F_1	F_2	F_3	F_1	F_2	F_3
$N_{RB^{(F)}}^{DAS-SFR-SC1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$
$N_{RB^{(F)}}^{DAS-SFR-SC2}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-SFR-SC3}$	0	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{\left(1-\alpha^2\right) N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR3}, N_{RB^{(F)}}^{Con-HFR3}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR1}, N_{RB^{(F)}}^{Con-HFR1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$

TABLE 2. Simulation Parameters

Parameters	Value
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1+37.6 \log_{10}(R(km))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms

WHAT IS CLAIMED IS:

1. A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. The method of claim 1 wherein the DRUs comprise remote radio units.

3. The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical

footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

ABSTRACT OF THE DISCLOSURE

A method for routing and switching operator RF signals includes providing one or more Digital Remote Units (DRUs) and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

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PATENT APPLICATION

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

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METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/649,143, filed on May 18, 2012, entitled "Method and System for Soft Frequency Reuse in a Distributed Antenna System," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] Wireless communication systems employing Distributed Antenna Systems (DAS) are available. A DAS typically includes one or more host units, optical fiber cable or other suitable transport infrastructure, and multiple remote antenna units. A radio base station is often employed at the host unit location commonly known as a base station hotel, and the DAS provides a means for distribution of the base station's downlink and uplink signals among multiple remote antenna units. The DAS architecture with routing of signals to and from remote antenna units can be either fixed or reconfigurable.

[0003] A DAS is advantageous from a signal strength and throughput perspective because its remote antenna units are physically close to wireless subscribers. The benefits of a DAS include reducing average downlink transmit power and reducing average uplink transmit power, as well as enhancing quality of service and data throughput.

[0004] Despite the progress made in wireless communications systems, a need exists for improved methods and systems related to wireless communications.

SUMMARY OF THE INVENTION

[0005] The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS) as part of a distributed wireless network. More specifically, the present invention relates to a DAS utilizing Soft Frequency Reuse or Fractional Frequency Reuse techniques. In a particular embodiment, the present invention has been applied to the

reuse of communications frequencies in central portions of adjacent DAS cells, improving system data rates and performance. The methods and systems described herein are applicable to a variety of communications systems including systems utilizing various communications standards.

[0006] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies, and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU in a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU in a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

[0007] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

[0008] According to a specific embodiment of the present invention, a communications system is provided. The communications system includes a host unit and a first communications unit

coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint. The communications system also includes a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

[0009] According to an embodiment of the present invention, a method for routing and switching operator RF signals is provided. The method includes providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU of a first cell is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a plurality of additional DRUs of the first cell are operable to communicate using a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint surrounding the first geographic footprint. A first DRU of a second cell is operable to communicate using the first set of frequencies over a third geographical footprint and a plurality of additional DRUs of the second cell are operable to communication using a third set of frequencies characterized by a third frequency band different from the first frequency band over a fourth geographic range surrounding the third geographic range.

[0010] The DRUs can comprise remote radio units. The method may also include communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU. One or more of the plurality of BTSs can be coupled to the DAU using a plurality of BTS sector RF connections. The method may further include transporting signals between one or more DRUs and the at least one DAU.

[0011] According to another embodiment of the present invention, a method of distributing communications frequencies is provided. The method includes providing a set of communications units in an array configuration and transmitting and receiving, from a first communications unit of the set of communications units, a first set of frequencies characterized

by a first frequency band and a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic range surrounding the first geographic footprint. The method also includes transmitting, and receiving, from a second communications unit of the set of communications units, a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint and a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint surrounding the third geographical footprint.

[0012] In an embodiment, the set of communications units include a plurality of remote units in communication with a host unit. The first geographic footprint can be centered on the first communications unit. The second geographic footprint can be a peripheral footprint centered on the first communications unit. The third geographical footprint can be centered on the second communications unit. The fourth geographical footprint can be a peripheral footprint centered on the second communications unit. The second geographical footprint can abut the fourth geographical footprint. The method can also include transmitting, and receiving, from a third communications unit of the set of communications units, a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint surrounding the fifth geographical footprint.

[0013] According to yet another embodiment, a communications system is provided. The communications system includes a first communications unit operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint and a second communications unit operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and one or more of the second set of frequencies in a region associated with a fourth geographical footprint.

[0014] The first communications unit can include a central DRU and a plurality of peripheral DRUs disposed adjacent the central DRU. The system can also include a DAU communicatively coupled to the central DRU and the plurality of peripheral DRUs. In an embodiment, the system includes a DAU communicatively coupled to the central DRU. Additionally, a second DAU can

be communicatively coupled to the plurality of peripheral DRUs. In an embodiment, the second geographical footprint at least partially surrounds the first geographical footprint. In another embodiment, the fourth geographical footprint at least partially surrounds the third geographical footprint or the second geographical footprint at least partially overlaps the fourth geographical footprint.

[0015] According to a specific embodiment, a frequency sharing system for a distributed antenna system is provided. The frequency sharing system includes a first frequency band characterized by a first frequency range and associated with a first geographic area associated with a first communications unit and a second frequency band characterized by a second frequency range different from the first frequency range and associated with a second geographic area at least partially surrounding the first geographic area. The frequency sharing system also includes a third frequency band overlapping at least a portion of the second frequency band and associated with a third geographic area associated with a second communications unit and a fourth frequency band overlapping at least a portion of the first frequency band and associated with a fourth geographic area at least partially surrounding the third geographic area.

[0016] The first geographic area can be characterized by a first border and the second geographic area can be characterized by a second border, wherein a predetermined distance separates the first border and the second border. The first frequency band and the second frequency band can be contiguous frequency bands. In an embodiment, the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent the first frequency band.

[0017] According to another specific embodiment, a communications system is provided and includes a first communications unit operable to transmit and receive communications using a first set of frequencies over a first predetermined area and a second communications unit operable to transmit and receive communications using a second set of frequencies over a second predetermined area. The first communications unit is operable to transmit and receive communications using a third set of frequencies over a third predetermined area and the second communications unit is operable to transmit and receive communications using at least a portion of the third set of frequencies over a fourth predetermined area.

[0018] The first communications unit can include a plurality of DRUs, at least one of the plurality of DRUs being coupled to a DAU. The third predetermined area can be at least

partially surrounded by the first predetermined area and the fourth predetermined area can be at least partially surrounded by the second predetermined area. In an embodiment, the first set of frequencies, the second set of frequencies, and the third set of frequencies are distinct frequencies. The first communications unit and the second communications unit can be disposed in an array configuration. The first predetermined area overlaps at least a portion of the second predetermined area in some implementations and the third predetermined area includes a location of the first communications unit and the fourth predetermined area includes a location of the second communications unit. The first communications unit can include a first plurality of digital remote units and the second communications unit comprises a second plurality of digital remote units. The first set of frequencies can be associated with a first number of the first plurality of digital remote units and the third set of frequencies can be associated with another of the first plurality of digital remote units. The second set of frequencies can be associated with a first number of the second plurality of digital remote units and the third set of frequencies can be associated with another of the second plurality of digital remote units.

[0019] Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIGS. 1A - 1C illustrate different frequency reuse techniques according to embodiments of the present invention;

[0020.A] FIG. 1D illustrates, for the Hard Frequency Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0020.B] FIG. 1E illustrates, for the Fractional Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0020.C] FIG. 1F illustrates, for the Soft Frequency Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

[0021] FIG. 2 illustrates the structure of a Distributed Antenna System (DAS) according to an embodiment of the present invention;

[0022] FIG. 3 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to an embodiment of the present invention;

[0023] FIG. 4 is a plot illustrating ergodic capacity versus the normalized distance from the DRU0 according to another embodiment of the present invention;

[0024] FIG. 5 illustrates a capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area according to an embodiment of the present invention;

[0025] FIG. 6 is a plot illustrating analytical ergodic capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention; and

[0026] FIG. 7 is a plot illustrating simulation capacity for edge cell and non-edge cell users versus α according to an embodiment of the present invention.

[0027] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention; and

[0028] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0029] Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency.

[0030] Orthogonal Frequency Division Multiple Access (OFDMA) has been adopted as the transmission scheme for the next generation wireless communication systems. However, the downlink performance of cellular networks is known to be strongly limited by inter-cell interference in OFDMA based systems. In order to mitigate this interference, a number of techniques have recently been proposed, e.g. the Soft Frequency Reuse (SFR) scheme and Distributed Antenna System (DAS). According to embodiments of the present invention, these two techniques are combined in a unique cell architecture, which can be referred to as DAS-SFR. In an implementation of this architecture, which is described herein, the antennas are distributed

in a hexagonal cell such that the central antenna is responsible for serving a special area using multiple frequency bands (e.g., all of the frequency bands) while the remaining antennas utilize only a subset of the frequency bands based on a frequency reuse factor. The inventors have analytically quantified the performance of the downlink multi-cell DAS-SFR in terms of the individual user's throughput under three different resource allocation scenarios. The results show that DAS-SFR reduces inter-cell interference in a multi-cell environment for users near the cell boundaries as compared to a Hard Frequency Reuse (HFR) scheme with a frequency reuse factor of 1. The results also show that DAS-SFR significantly increases the system capacity as compared to the HFR scheme with a frequency reuse factor of 3.

[0031] In DAS-SFR, by controlling the amount of resources allocated to users located in different areas, embodiments of the present invention increase the frequency efficiency and also improve the data rate for cell edge users. If the throughput requirement for the interior users is small, more resources can be assigned to the exterior users.

[0032] In the next generation wireless communication systems that use the 3GPP LTE (Long Term Evolution) standard, there is tremendous pressure to support a high data rate transmission. These systems are based on Orthogonal Frequency Division Multiple Access (OFDMA) to support the high data rate service and improve the Quality of Service (QoS), even for cell edge users as the main targets in the downlink.

[0033] The system bandwidth is divided into a number of sub-carriers in an OFDMA-based system such that each user utilizes a bandwidth smaller than the systems coherence bandwidth. Data from different users is transmitted in parallel on different sub-carriers. The orthogonality amongst the sub-carriers mitigates inter-carrier interference (ICI) while the resulting large OFDM symbol time and the narrow sub-carrier bandwidth reduces the effect of inter-symbol interference (ISI). Users located at the cell edge largely suffer from co-channel interference (CCI) or inter-cell interference from base stations (BS) of neighboring cells. Mobile 3GPP LTE adopts a frequency reuse factor of one, in which each cell serves users using the entire system bandwidth.

[0034] In order to reduce interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are three potential ways to reduce interference in cellular systems but these require a

more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes(CLMD) and Beamforming are three other techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beamforming sacrifice spatial dimensions and require channel state knowledge.

[0035] One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a distributed antenna systems (DAS), which also has the additional advantage of improving capacity and coverage.

[0036] Other possible strategies include Frequency Reuse techniques, which effectively reduce inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

[0037] Distributed Antenna System (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems. As opposed to a conventional cellular system, where the antenna is centrally located, a DAS network consists of antenna modules that are geographically distributed to reduce access distance. These distributed antennas are connected to an eNodeB (eNB) LTE system by dedicated wires, fiber optics, or via a radio frequency link.

[0038] DAS has advantages including throughput improvement, coverage improvement, increased cellphone battery life, and a reduction in transmitter power. Recent research has shown benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is a Virtual DAS, wherein each remote has the added flexibility of independently transmitting preselected carriers.

[0039] Frequency reuse techniques are utilized herein to reduce inter-cell interference in cellular systems. This benefits users near the cell edges owing to simplicity and practicality. There are three major frequency reuse patterns illustrated in FIGS. 1A-1E for mitigating inter-cell interference: Hard Frequency Reuse, Fractional Frequency Reuse and Soft Frequency Reuse.

[0040] Hard Frequency Reuse (HFR) splits the system bandwidth into a number of distinct sub-bands according to a chosen reuse factor and lets neighboring cells transmit on different sub-bands. This inter-cell interference mitigation method is typically seen in GSM networks, when it

comes to distribution of frequencies among the cells. When applied to LTE, the Resource Blocks (a group of sub-carriers) are divided into 3, 4 or 7 disjoint sets. These sets of Resource Blocks (RBs) are assigned to the individual eNBs in such a way that neighboring cells don't use the same set of frequencies, as illustrated in FIG. 1A. FIGS. 1D, 1E, and 1F show, for each case (Hard Frequency Reuse (FIG. 1A and FIG. 1D), Fractional Frequency Reuse (FIG. 1B and FIG. 1E), and Soft Frequency Reuse (FIG. 1C and FIG. 1F)), the transmit/receive power as a function of frequency. This reduces the interference at the cell edge of any pair of cells significantly and can be considered the opposite extreme to Full Frequency Reuse in matters of frequency partitioning techniques. While user interference at the cell edge is maximally reduced, the spectrum efficiency drops by a factor equal to the reuse factor. The inter-cell interference can be reduced with a frequency reuse factor of more than one, however, it may reduce the system capacity.

[0041] Fractional Frequency Reuse (FFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. OFDMA provides the ability for each eNB to selectively allocate frequency sub-bands, data rates and power to the users depending on their location in the cell, according to some predefined frequency reuse pattern which may lead to significant capacity gains for the overall network. FFR splits the given bandwidth into an inner and an outer region as illustrated in FIG. 1B. The spectrum allocated to the inner region is assigned to the nearby users (located close to the eNB in terms of path loss) applying a frequency reuse factor of one (i.e. the inner part is completely reused by all eNBs). While the spectrum allocated to the outer region, for users close to the cell edge (far users), is divided among the different eNBs as in hard frequency reuse techniques. This scheme is particularly useful to mitigate the inter-cell interference in the uplink, where severe interference situations can occur when the user is located close to a strong interferer from a neighbor cell.

[0042] Soft Frequency Reuse (SFR) is an inter-cell interference mitigation technique in OFDMA based wireless networks. SFR shares the overall bandwidth by all eNBs (i.e. a reuse factor of one is applied), but for transmission on each group of RBs, the eNBs are restricted to a certain power bound. FIG. 1C illustrates the power and frequency assignments in the different cells of a system with SFR for a reuse factor of 3. It can be noticed in the frequency spectrum of FIG. 1F associated with Soft Frequency Reuse (i.e., FIG. 1C), that there is a region of high-power transmissions and some regions of low-power transmissions. Using a similar strategy extending Fractional Frequency Reuse, resources in the high-power region are preferably

assigned to User Equipment (UEs) located at the cell edge, while cell-center UEs are typically assigned resources in the low-power regions. SFR can utilize the entire frequency spectrum that has been allocated, increasing the system data rate and/or capacity.

[0043] Referring to FIGS. 1C-1F, frequencies in the grey frequency band (~ upper 2/3 of the available frequencies) are transmitted/received by a DRU at a first power level in Cell 1, providing coverage for the central portion of Cell 1. Frequencies in the horizontal stripes band are transmitted/received by the DRU at a second power level higher than the first power level, providing coverage over both the central portion of Cell 1 as well as the peripheral portions of Cell 1 since the higher power level results in a larger coverage area. In this example, each cell utilizes a single DRU, although other embodiments can utilize multiple DRUs per cell as described more fully herein. DRUs in the other cells also transmit/receive at both high power for a subset of the frequencies and low power for remaining frequencies as shown in FIG. 1D, producing the coverage maps illustrated in FIG. 1C, with low power frequencies providing centralized coverage and higher power frequencies providing a large coverage area extending to the peripheral regions of the cells. Although all three cells are transmitting/receiving using overlapping (or the same) frequencies at low power, the corresponding propagation distances for these frequencies are smaller, preventing geographic overlap between the central grey regions.

[0044] In order to reduce interference in areas where cells are adjacent, the frequencies associated with higher power are grouped into subbands, with little or no overlap between the subbands. Referring to FIG. IF, in the SFR implementation, Cell 1 uses high power for the horizontal stripes band in approximately the first third of the frequency bandwidth, Cell 2 uses high power for the dotted band in approximately the second third of the frequency bandwidth, and Cell 3 uses high power for the vertical stripes band in approximately the last third of the frequency bandwidth. Thus, at the intersections between cells, since different portions of the available frequency band are being utilized, interference is reduced. Thus, in some embodiments, different frequency bands are utilized in adjacent cells, which is illustrated by the high power frequency bands for SFR in FIG. IF: the first frequency band in Cell 1, the second frequency band different from the first frequency band in Cell 2, and the third frequency band different from the first frequency band and the second frequency band in Cell 3. For an additional number of cells, the subdivision of the available bandwidth can be increased as appropriate to the particular number of adjacent cells in the implementation. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0045] HFR, though simple in implementation, suffers from a reduced spectral efficiency. On the other hand, both SFR and FFR have increased (e.g., full) spectral efficiency and are a strong mechanism for inter-cell interference mitigation. A coordinated resource allocation system can be impractical in realistic settings involving a large number of eNBs, random traffic and realistic path-loss models. However, an encouraging result is that by using even limited (yet practical) levels of coordination, significant performance benefits can still be obtained over a conventional cellular architecture. Most of the recent publications have focused on investigating SINR advantages of DAS and analyzing its performance. On the other hand, there are no studies that combine DAS with SFR in order to reduce inter-cell interference. Some publications on DAS have focused on analyzing the uplink performance because of its analytical simplicity and there are few studies on the downlink performance of DAS although the demand for high-speed data rate will be dominant in the downlink path. There are also very few publications that consider the advantages of DAS in a multi-cell context. Recent research on FFR and SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional works on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

[0046] According to embodiments of the present invention, a new architecture is provided to suppress inter-cell interference. The architecture described herein combines DAS and SFR for an OFDMA system (e.g., LTE). Embodiments of the present invention provide benefits by using DAS-SFR in a multi-cell environment. The downlink advantages of DAS-SFR are described in terms of achievable ergodic capacity for three different frequency resource allocation scenarios. The results shows that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture and achieves a non-trivial capacity increase over a HFR cellular architecture with a frequency reuse factor of 3. Other reuse factors are included within the scope of the present invention, for example, up to or more than 7 as suitable for the DAS architecture illustrated in FIG. 2.

[0047] As described herein, an analytical framework has been developed to evaluate the ergodic capacity in a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service, regardless of their geographic

location, instead of simply a minimum user throughput which may be acceptable for applications like voice traffic. We present a strategy for optimally allocating frequency RBs to edge users for a DAS-SFR architecture, based on a chosen performance threshold T_p, which can be related to network traffic load. Finally we prepare a simulation scenario to compare the analytical results with the simulation results.

[0048] Referring to the spectral plots illustrated in FIG. 1D, in the HFR system, the horizontal stripes, shaded, and vertical stripes frequency bands occupy different frequency ranges and, in combination, fill the entire spectrum. In HFR (FIG. 1A), cell 1 uses the lower frequencies (horizontal stripes), cell 2 uses the middle frequencies (shaded), and cell 3 uses the higher frequencies (vertical stripes).

[0049] Referring to FIG. 2, the DAS includes a central cell referenced as eNB0, which includes DRU0 through DRU6 that are communicating through one base station at eNB0 through a DAU. DRU0 can be considered to be Cell 1 in FIGS. 1A - 1C, DRU1 can be considered to be Cell 2 in FIGS. 1A - 1C, and DRU2 can be considered to be Cell 3 in FIGS. 1A-1C. In other embodiments, eNB0 is considered to be Cell 1 in FIGS. 1A - 1C and eBN1, including a different set of DRUs, DRU0 through DRU6, can be considered to be Cell 2 in FIGS. 1A - 1C, etc. In FIG. 1A, Cell 1 (e.g., DRU0 of eNB0) utilizes the horizontal stripes frequency band and the other cells use different frequency bands as illustrated. In the embodiment illustrated in FIG. 2, seven different frequency bands could be utilized for high power transmission by the seven DRUs connected to each base station. For cells geographically separated from Cell 1, for example, cells in eNB7 could reuse the same frequencies (horizontal stripes) used in Cell 1 (e.g., eNB0).

[0050] Referring once again to FIG. 1B, a set of frequencies operating at reduced power compared to the frequencies discussed in relation to HFR and represented by the grey frequency bands in the FFR and SFR portion of FIGS. 1E and 1F, respectively, are reused in each of the cells (i.e., Cell 1, Cell 2, and Cell 3). Because this frequency band does not geographically overlap with adjacent cells (i.e., it is used at the central portion of the cell as a result of the lower power), overlap between adjacent cells is prevented and this frequency band can be reused in adjacent cells.

[0051] For fractional frequencies, because there is a spatial separation between the grey areas in the spectra in Cell 1 and Cell 2 and Cell 3, as long as the spatial separation is significant enough, there will not be significant interference between the cells although the central portions of the cells are transmitting on the same (e.g., exact same) frequencies. By keeping a separation and allocating the horizontal stripes frequency band in Cell 1 to specific frequencies, the shaded frequency band in Cell 2 to other specific frequencies, the vertical stripes frequency band in Cell 3 to still other specific frequencies, and the like for additional cells, embodiments of the present invention make efficient use of the given spectrum. Comparing the Fractional Frequency Reuse spectrum to the Hard Frequency Reuse spectrum, it is evident that FFR uses more of the available spectrum, which enables support for more users, operation at a higher data rate, combinations thereof, or the like. In the illustrated example, the fraction of the spectrum used in each cell has increased from about a third of the spectrum (HFR) to about half of the spectrum (FFR). Other implementations can utilized different fractions of the spectrum and the present invention is not limited to the particular example illustrated in FIG. 1B and FIG. 1E.

[0052] In one embodiment, to implement the fractional frequency reuse technique illustrated in FIG. 1B using the architecture illustrated in FIG. 2, DRUs 1, 2, 3, 4, 5 and 6 of eNB0 would transmit and receive data using frequencies in the horizontal stripe frequency band and DRU0 of eNB0 would transmit and receive data using the grey frequencies. In an embodiment, the size of the area covered by DRU0 can be increased by increasing the transmit power associated with the central DRU (i.e., DRU0). In another embodiment, each DRU in eNB0 transmits and receives data at a first power level using frequencies in the grey frequency bands and at a second, higher power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands. In this embodiment, three of the seven DRUs illustrated in an eNB are illustrated by Cells 1-3.

[0053] Referring to FIG. 1C, an architecture implementing Soft Frequency Reuse is illustrated and the matching spectrum in FIG. 1F illustrates the full use the spectrum by each of the adjacent cells. In an embodiment in which multiple DRUs are utilized per cell, the horizontal stripe geographical area in Cell 1 is associated with the outer DRUs in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRUs 1-6) and the grey geographical area in Cell 1 is associated with the central DRU in the communications unit illustrated as eNB0 in FIG. 2 (i.e., DRU0). As discussed above, the size of the grey circle can be increased/decreased by increasing/decreasing the power of utilized in conjunction with DRU0. As shown in the SFR

spectrum for Cell 1, data is transmitted and received over the entire allocated spectrum, including portions of the spectrum that were unused for Cell 1 in the HFR example. The increase in spectrum provides increased data rate, increased capacity, combinations thereof, or the like. In other embodiments, a single DRU in Cell 1 broadcasts at low power over the grey band and at a higher power over the horizontal stripe spectrum. Other cells demonstrate similar behavior. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0054] Comparing FFR (FIG. 1B) and SFR (FIG. 1C), the frequency bandwidth available for the peripheral DRUs or for the higher power broadcast from a DRU in the cell (i.e., horizontal stripe, dotted, or vertical stripe spectra) is increased for SFR in comparison to FFR. Additionally, the frequency bandwidth available for the central DRU or for the lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

[0055] In an embodiment, fractional frequency reuse is implemented in a DAS system with a plurality of adjacent cells, each of the cells including a plurality of remote units. A first cell utilizes a first frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and a second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs). A second cell utilizes a third frequency bandwidth at a central portion of the cell (i.e., a central geographical area associated with a central DRU) and the second frequency bandwidth at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs).

[0056] In another embodiment, soft frequency reuse is implemented in a DAS system with a plurality of adjacent cells. A first cell utilizes a first frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a second frequency band (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). A second cell utilizes a third frequency band at peripheral portions of the cell (i.e., a peripheral geographical area associated with peripheral DRUs) and a fourth frequency band, which may include multiple sub-bands (e.g., the remaining bandwidth) at a central portion of the cell (i.e., a central geographical area associated with a central DRU). The third frequency band may include frequencies in the second frequency band and the multiple sub-bands of the fourth frequency band may include frequencies in the first frequency band as illustrated in FIG. 1C.

[0057] As will be appreciated by one of skill in the art, operators utilize different spectrums and, in the examples illustrated in FIGS. 1D-1F, they are contiguous. However, it should be noted that although contiguous spectra are illustrated in FIGS. 1D-1F, this is not required by embodiments of the present invention and non-contiguous spectrums may be utilized in other embodiments. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0058] Although the embodiments illustrated in FIGS. 1D-1F utilize three frequencies, embodiments of the present invention are not limited to this particular number and additional frequencies and frequency bands can be utilized, for example, additional frequency bands used in conjunction with additional cells. In a particular embodiment, seven frequency bands, twelve frequency bands, or the like can be utilized. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0059] System Architecture (DAS-SFR)

[0060] The general architecture of a Virtualized DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRUs) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized such that each DRU allocated to a given eNB sector is simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. The DAUs assign the RBs of the various sectors to the independent DRUs. In contrast, the same area (7 DRUs) is covered by only a high-power eNB in traditional cellular system. The proposed architecture divides the entire spectral bandwidth *F* into 3 parts (F_1, F_2, F_3). The idea is that the eNB assigns the full-reused frequency (all 3 parts) to the central DRU and the other 6 edge DRUs work on just 1 part based on a reuse factor of Δ in such a way that neighbor cell edge DRUs don't use the same frequency part.

[0061] The total transmit power of the *n*-th DRU of *i*-th cell in *f*-th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by *n* = 0. Throughout this application, we assume that $P_n^{(i,f)} = P$.

[0062] We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

[0063] Resource Allocation Scenarios:

[0064] In cellular DAS-SFR with multi users, there are several possible resource allocation scenarios using multiple DRUs. Much of the research on SFR system design has focused on how to determine the size of the frequency partition, for example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users per each frequency part($F_i, i=1,2,3$).

[0065] For a typical central cell, let's assume the center DRU is assigned the full-reused frequency and the other six edge DRUs are assigned to F_1. Now, we consider three resource allocation scenarios:

[0066] - **Scenario 1:** All F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

[0067] - **Scenario 2:** F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

[0068] - **Scenario 3:** F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

[0069] We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario we investigate both the analytical and simulation results in order to verify the system's capacity improvement.

[0070] Channel Model and Received Signal

[0071] The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise. The received signal vector of the user in the 0th cell at frequency f can be expressed as:

$$\begin{aligned} y^{(0,f)} &= signal + interference + noise \\ &= \mathbf{H}^{(0,f)}\mathbf{x}^{(0,f)} + \sum_{i=1}^{18}\mathbf{H}^{(i,f)}\mathbf{x}^{(i,f)} + \mathbf{n} \end{aligned} \quad (1)$$

where $\mathbf{H}^{(i,f)} \in C^{1\times 7}$, $i = 0, 1, \ldots, 18$, denotes the channel matrix between the DRUs in the i-th cell and the user in the central (0th) cell, $x^{(i,f)} = \left[x_0^{(i,f)}, x_1^{(i,f)}, \ldots, x_6^{(i,f)}\right]^T \in C^{7x1}, i - 0,1, \ldots,18$ is the transmitted signal vector of the DRUs in the i-th cell, $n^{(f)} \in C^{1x1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma_{n^{(f)}}^2 \mathbf{I}_1)$.

[0072] The distributed antenna power constraint is considered, we have

$$\mathbf{E}\left[\left|x_n^{(i,f)}\right|^2\right] \le P_n^{(i,f)}, n = 0,1,\ldots,6, \quad i = 0,1,\ldots,18, \quad (2)$$

where in DAS-SFR,

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)} = 0, P_n^{(i,F_1)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 1,2,\ldots,7,9,11,13,15,17),$$
$$x_n^{(i,F_2)} = 0, P_n^{(i,F_2)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,2,4,6,7,8,10,11,12,14,15,16,18),$$
$$x_n^{(i,F_3)} = 0, P_n^{(i,F_3)} = 0 \quad when \quad (n = 1,2,\ldots,6 \quad and \quad i = 0,1,3,5,8,9,10,12,13,14,16,17,18),$$

in DAS-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)} \neq 0, P_n^{(i,f)} \neq 0 \quad when \quad (n = 0,1,\ldots,6 \quad and \quad i = 0,1,\ldots,18 \quad , f = F_1, F_2, F_3),$$

in Conventional Cellular-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0 \quad when \quad (n=0,1,...,6 \quad and \quad i=1,2,...,7,9,11,13,15,17) \; or$$
$$(n=1,2,...,6 \quad and \quad i=0,8,10,12,14,16,18),$$
$$x_n^{(i,F_2)}=0, P_n^{(i,F_2)}=0 \quad when \quad (n=0,1,...,6 \quad and \quad i=0,2,4,6,7,8,10,11,12,14,15,16,18) \; or$$
$$(n=1,2,...,6 \quad and \quad i=1,3,5,9,13,17),$$
$$x_n^{(i,F_3)}=0, P_n^{(i,F_3)}=0 \quad when \quad (n=0,1,...,6 \quad and \quad i=0,1,3,5,8,9,10,12,13,14,16,17,18) \; or$$
$$(n=1,2,...,6 \quad and \quad i=2,4,6,7,11,15),$$

and in Conventional cellular-HFR1 (frequency reuse factor 1),

$$x_n^{(i,f)}=0, P_n^{(i,f)}=0 \quad when \quad (n=1,...,6 \quad and \quad i=0,1,...,18 \quad and \quad f=F_1,F_2,F_3),$$

where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell.

[0073] The composite fading channel matrix $\mathbf{H}^{(i,f)}, i=0,1,...,18$, encompasses not only small-scale fading but also large-scale fading, which is modeled as

$$\begin{aligned}\mathbf{H}^{(i,f)} &= \mathbf{H}_w^{(i,f)}\mathbf{L}^{(i,f)} \\ &= \left[h_0^{(i,f)}, h_1^{(i,f)}, ..., h_6^{(i,f)}\right].diag\left\{l_0^{(i,f)}, l_1^{(i,f)}, ..., l_6^{(i,f)}\right\}\end{aligned} \tag{3}$$

where $\mathbf{H}_w^{(i,f)}$ and $\mathbf{L}^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the 0th cell, respectively. $\left\{h_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are independent and identically distribute (*i.i.d*) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\left\{l_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{\left[D_n^{(i)}\right]^{-\gamma} \chi_n^{(i,f)}}, \quad n=0,1,...,6, \quad i=0,1,...,18 \tag{4}$$

where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the 0th cell and the nth DRU in the i-th cell, respectively, γ denotes the path loss exponent. $\left\{\chi_j^{(i,f)} \middle| j=0,1,...,6; i=0,1,...,18; f=F_1,F_2,F_3\right\}$ are *i.i.d* random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi}\lambda\sigma_\chi\chi}\exp\left(-\frac{(\ln\chi)^2}{2\lambda^2\sigma_\chi^2}\right), \quad \chi>0, \tag{5}$$

where σ_χ is the shadowing standard deviation and $\lambda=\frac{\ln 10}{10}$.

[0074] Since the number of interfering source is sufficiently large and interfering source are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18} \mathbf{H}^{(i,f)} \mathbf{x}^{(i,f)} + \mathbf{n}^{(f)} \tag{6}$$

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned} Var(N^{(f)}) &= \left[\sum_{i=1}^{18} \sum_{n=0}^{6} \left[l_n^{(i,f)} \right]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2 \right] \mathbf{I}_1 \\ &= \left[\sigma^{(f)} \right]^2 \mathbf{I}_1 \end{aligned} \tag{7}$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$\mathbf{y}^{(0)} = \mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)} \mathbf{x}^{(0,f)} + N^{(f)} \tag{8}$$

[0075] Achievable capacity of distributed antenna network

[0076] If we assume the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station can be calculated by

$$C^{(f)} = \mathbf{E}_{\mathbf{H}_w^{(0,f)}} \left[\log_2 \det(\mathbf{I}_1 + \frac{1}{\left[\sigma^{(f)} \right]^2} (\mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)}) \mathbf{P}^{(0,f)} (\mathbf{H}_w^{(0,f)} \mathbf{L}^{(0,f)})^H) \right] \tag{9}$$

where $\mathbf{P}^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $diag\left\{ P_0^{(0,f)}, P_1^{(0,f)}, ..., P_6^{(0,f)} \right\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$\begin{aligned} C^{(f)} &= \mathbf{E}_{\mathbf{H}_w^{(0,f)}} \left[\log_2 (1 + \frac{1}{\left[\sigma^{(f)} \right]^2} \sum_{i=0}^{6} \left| h_i^{(0,f)} \right|^2 \left[l_i^{(0,f)} \right]^2 P_i^{(0,f)}) \right] \\ &= \int_{\gamma_f=0}^{\infty} \log_2 (1 + \gamma_f) f_{\gamma_f}(\gamma_f) d\gamma_f \end{aligned} \tag{10}$$

where $\gamma_f = \frac{1}{\left[\sigma^{(f)} \right]^2} \sum_{i=0}^{6} \left| h_i^{(0,f)} \right|^2 \left[l_i^{(0,f)} \right]^2 P_i^{(0,f)}$ is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f)=\sum_{i=0}^{6}\frac{\left[\sigma^{(f)}\right]^2\pi_i}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2\gamma_f}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right), \tag{11}$$

where

$$\pi_i=\prod_{k=0,k\neq i}^{6}\frac{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}-\left[l_i^{(0,f)}\right]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$C^{(f)}=-\frac{1}{\ln 2}\sum_{i=0}^{6}\pi_i\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right)Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right),\ f=F_1,F_2,F_3 \tag{12}$$

where $Ei(t)$ is the exponential integral function ($Ei(t)=-\int_{-x}^{\infty}e^{-t}/t\,dt$) and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

[0077] Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$C^{(f)}=-\frac{1}{\ln 2}\exp\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right)Ei\left(-\frac{\left[\sigma^{(f)}\right]^2}{\left[l_i^{(0,f)}\right]^2 P_i^{(0,f)}}\right),\ f=F_1,F_2,F_3 \tag{13}$$

[0078] Thus, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total}=C^{(F_1)}+C^{(F_2)}+C^{(F_3)} \tag{14}$$

[0079] Analytical and Simulation Results

[0080] FIG. 3 and FIG. 4 represents the ergodic capacity of cellular DAS for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position *X* when the path loss exponent is 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}, C^{(F_2)}, C^{(F_3)}$, and also for the total capacity C_{total}.

[0081] The transmit power of each distributed antenna module is *P* whereas the transmit power of eNB in the conventional cellular system is 7*P*. These figures show an interesting non-

monotonic relationship between capacity and the normalized distance from the base station. This is because the signal from a distributed antenna module becomes dominant around 0.6R.

[0082] FIG. 3 compares the capacity performance of the two frequency reuse techniques, SFR and HFR3, for a particular central cell. Note that in the SFR technique, all 3 frequency bands are assigned, whereas, in the HFR3 method, only the F_1 band is used. The results show that the SFR method achieves the highest throughput, owing to use of more frequency bandwidth. More specifically, the total capacity achieved using the SFR method is the highest inside the normalized distance 0.5.

[0083] A non-significant throughput reduction in the SFR technique is observed happening beyond a normalized distance 0.5, due to the interference introduced from the neighboring central DRU cells. Note that there is no interference introduced from the DRU neighboring cells when the HFR3 method is applied. It is worth mentioning that the achieved throughput of the DAS-HFR3 is slightly lower than that of a conventional cellular (Con-HFR3) system near the eNB0 DRU0, due to the reduced transmit power.

[0084] FIG. 4 compares the capacity performance of the two frequency reuse techniques, SFR and HFR1, for a particular central cell. Note that in both SFR and HFR1 techniques, all 3 frequency bands are assigned. The achieved throughputs of the DAS-HFR1 and DAS-SFR are slightly lower than that of a conventional cellular (Con-HFR1) system near the eNB0 (DRU0), due to the reduced transmit power.

[0085] FIG. 4 illustrates that the HFR1 technique outperforms the SFR technique in terms of the achieved throughput inside the $(0,\ 0.5R)$ region, nevertheless, the SFR technique significantly improves the system performance by making up for the dead spots happening at the cell edges. Note that there is a significant amount of interference happening in the $(0.8R, R)$ region, creating dead-spots in the HFR1 technique.

[0086] Note that 80% of the users are located inside the $(0.5R, R)$ region, assuming a uniform distribution, while the other 20% are farther from the interfering cells. Therefore, it is more important to improve the system capacity inside the $(0.5R, R)$ region.

[0087] In multiuser systems, where all users are uniformly distributed in the cell, we need to consider different resource allocation scenarios which were defined above. Assuming that each

cell has radius R, we define parameter α ($0<\alpha<1$) such that the interior area is located in the $(0, \alpha R)$ region and the exterior area is located in the $(\alpha R, R)$ region.

[0088] In LTE systems, eNB distinguishes between the interior and exterior users based on their corresponding uplink power received at the central DRU. To implement this technique, we propose a threshold T_p as a parameter in eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa.

[0089] Note that

$$N_{interior} = \alpha^2 N_{users},$$
$$N_{exterior} = \left(1-\alpha^2\right) N_{users}, \quad (15)$$

where $N_{interior}$ represents the number of interior users, $N_{exterior}$ represents the number of exterior users, and N_{users} represents the total number of users. We will consider the 3 different resource allocation scenarios mentioned above, where the number of RBs per users assigned in the different regions (interior or exterior) for different Scenarios can be expressed as in TABLE 1, where $N_{RB^{(F_i)}}, i=1,2,3$ represents the number of RBs for given frequency part F_i and $N_{RB^{(F_i)}}^{tech}$ represent the number of RBs for given F_i for the different techniques.

[0090] Note that in all 3 scenarios we have applied the Round Robin scheduling technique.

[0091] If we consider the number of RBs which are assigned to the different regional users under the different scenarios, the capacity metric of the total system can be obtained by,

$$C_{metric}^{total,tech} = C_{metric}^{(tech,F_1)} + C_{metric}^{(tech,F_2)} + C_{metric}^{(tech,F_3)} \quad (16)$$

where

$$C_{metric}^{(tech,F_i)} = N_{RB^{(F_i)}}^{tech} . C^{(F_i)} \quad , i=1,2,3,$$
$$tech \in \begin{Bmatrix} DAS-SFR-SC1, DAS-SFR-SC2, DAS-SFR-SC3, \\ DAS-HFR3, Con-HFR3, DAS-HFR1, Con-HFR1 \end{Bmatrix}.$$

[0092] In FIG. 5, the capacity metric is provided considering a uniform distribution of users and a Round Robin Scheduler. In this example, which illustrates the capacity metric for a multiuser case versus the normalized distance from the DRU0 in eNB0(central cell) area, we assume α is 0.5. The achieved capacity of the DAS-SFR architecture with Scenario2 and

Scenario3 is higher than that of DAS-SFR system with Scenario1, especially near the central DRU. This is due to the fact that the F_2 and F_3 RBs are not assigned to the exterior users which have very low SINR and all F_2 and F_3 RBs assigned to interior users.

[0093] Comparing Scenario2 with Scenario3, we observe that the achievable capacity for interior users in DAS-SFR architecture with Scenario2 is slightly higher than that of scenario3 due to the full frequency reuse for the interior users in Scenario2. However, in Scenario3, only the F_2 and F_3 frequency bands are used by the interior users. Conversely, the achieved capacity for exterior users in a DAS-SFR architecture with Scenario3 is slightly higher than that of Scenario 2, due to the fact that all F_1 RBs are used by the exterior users, whereas in Scenario2 the F_1 RBs are partially used by the exterior users.

[0094] Note that FIG. 5 illustrates that the DAS-HFR1 technique outperforms other techniques in terms of the achieved throughput by majority of the interior users; nevertheless, SFR technique significantly improves the system performance by making up for the dead spots which appear at the cell edges. Note that there is a significant amount of interference happening in the ($0.8R, R$) region, causing the dead spots in DAS-HFR1 technique.

[0095] In the established system environment, we evaluate the total system capacity for several cases for non-edge users (inside $(0, 0.8R)$ region) and edge users (inside ($0.8R, R$)). We assume α sweeps from 0.2 to 0.8. Remember that α manages the portion of resources allocated in Scenario2 and Scenario3.

[0096] FIG. 6 illustrates the analytical results for the non-edge users and edge users, where α varies between 0.2 and 0.8, that is, the analytical ergodic capacity for edge cell and non-edge cell users versus the parameter α.

[0097] Note that as α changes, the number of RBs assigned to the users in Scenario2 and Scenario3 changes accordingly. However, in other techniques, with changing α, number of assigned RBs to the users remains unaltered. As α increases, the edge user's throughput increases in Scenario3, due to the fact that more RBs are assigned to those users. Specifically, as α increases, less users need to use F_1 RBs in Scenario3. However, in other techniques, edge users experience a constant throughput, due to the fact that the number of RBs allocated to the

edge users remains constant as α changes. Specifically, regardless of the changes in α, all F_1 RBs are assigned to all users.

[0098] As α increases, non-edge users' throughput decreases, due to the fact that the total constant number of F_2 and F_3 RBs should be assigned to more number of users accordingly. Note that the rate of decrease in user throughput for non-edge users for Scenario3 is more than that of Scenario2, as α increases. The reason behind this is that the rate of decrease in number of RBs assigned to the non-edge users in Scenario3 is more than that of Scenario2. Specifically, as was previously mentioned, since no F_1 RBs are assigned to the non-edge users in Scenario3, non-edge users' throughput in Scenario3 is less than that of Scenario2.

[0099] The capacity of the above mentioned architectures is investigated through the system level simulation. We consider the two-ring hexagonal cellular system with nineteen eNBs, such that each cell has 7 DRUs, as in FIG. 2, where the eNBs distance is 500 meters. The 10 UEs are located in each DRU area, following a uniform distribution. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in TABLE 2.

[0100] At a TTI of simulation, the eNB in a cell gathers the CQI information of UEs and allocates the RBs to each UE using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB^{(f)}} \log\left(1 + SINR_m^{(f)}\right), \quad f = F_1, F_2, F_3 \tag{16}$$

where, $W_{RB^{(f)}}$ is the bandwidth of RBs assigned to a UE and $SINR_m^{(f)}$ is the SINR of a UE_m. The cell capacity in each region is total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^{3} \sum_{m=1}^{M} C_m^{(F_i)} \tag{17}$$

where M is the number of UEs in a group.

[0101] FIG. 7 illustrates the simulation results for the non-edge users and edge users (i.e., the simulated capacity for edge cell and non-edge cell users versus the parameter α, where α varies

between 0.2 and 0.8. The results obtained through simulation corroborate the results provided by analytical methods.

[0102] The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique, since the interference signal from neighbor cells is lower than that when we use HFR1 technique. In an embodiment using Scenario3 as a resource allocation strategy, the exterior user's throughput is increased.

[0103] FIG. 8 is a simplified flowchart illustrating a method of implementing soft frequency reuse according to an embodiment of the present invention. The method 800 includes transmitting and receiving data in a first geographical area and a first frequency band (810). The method also includes transmitting and receiving data in a second geographical area and a second frequency band (812). In an embodiment, the first geographical area is a central area of a cell including multiple DRUs and the second geographical area is a peripheral area of the cell. In another embodiment, the second geographical area includes and extends to an area larger than the first geographical area (e.g., an area surrounding the first geographical area). The method further includes transmitting and receiving data in a third geographical area and at least a portion of the first frequency band (814). At least a portion of the frequency band used for the third geographical area is thus reused in relation to the first geographical area. The method also includes transmitting and receiving data in a fourth geographical area and a third frequency band (816). In an embodiment, the third geographical area is a central area of a cell including multiple DRUs and the fourth geographical area is a peripheral area of the cell. In another embodiment, the fourth geographical area includes and surrounds the third geographical area. The third frequency band may overlap with part of the first frequency band. Accordingly, multiple cells reuse the portions of the first frequency band, which may include multiple sub-bands that are contiguous or separated in frequency domain, in multiple adjacent cells.

[0104] It should be appreciated that the specific steps illustrated in FIG. 8 provide a particular method of implementing soft frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 8

may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0105] FIG. 9 is a simplified flowchart illustrating a method of implementing fractional frequency reuse according to an embodiment of the present invention. The method 900 includes transmitting and receiving data in a first geographical area and a first frequency band (910) and transmitting and receiving data in a second geographical area and a second frequency band (912). In an embodiment, the second geographical area surrounds the first geographical area. As an example, the first geographical area can be a central portion of a cell that is covered by a central DRU and the second geographical area can be a peripheral portion of the cell that is covered by a plurality of peripheral DRUs.

[0106] The method further includes transmitting and receiving data in a third geographical area and the first frequency band (914) and transmitting and receiving data in a fourth geographical area and a third frequency band (916). In an embodiment, the third geographical area surrounds the fourth geographical area. As an example, the third geographical area can be a central portion of another cell that is covered by a central DRU and the fourth geographical area can be a peripheral portion of the another cell that is covered by a plurality of peripheral DRUs. Thus, the frequency band used at the central portion of the first cell is reused at the central portion of the second cell. In embodiments, the frequency bands are not limited to contiguous blocks of frequencies, but can include sub-bands each including one or more frequency. The third frequency band can be different from the second frequency band, providing differing frequencies for the differing cells at adjacent geographical areas.

[0107] It should be appreciated that the specific steps illustrated in FIG. 9 provide a particular method of implementing fractional frequency reuse according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 9 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the

particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

[0108] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

TABLE 1. Number of RBs per user

	Interior region			Exterior region		
	F_1	F_2	F_3	F_1	F_2	F_3
$N_{RB^{(F)}}^{DAS-SFR-SC1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$
$N_{RB^{(F)}}^{DAS-SFR-SC2}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-SFR-SC3}$	0	$\frac{N_{RB^{(F_2)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_3)}}}{\alpha^2 N_{users}}$	$\frac{N_{RB^{(F_1)}}}{\left(1-\alpha^2\right) N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR3}, N_{RB^{(F)}}^{Con-HFR3}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	0	0
$N_{RB^{(F)}}^{DAS-HFR1}, N_{RB^{(F)}}^{Con-HFR1}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$	$\frac{N_{RB^{(F_1)}}}{N_{users}}$	$\frac{N_{RB^{(F_2)}}}{N_{users}}$	$\frac{N_{RB^{(F_3)}}}{N_{users}}$

TABLE 2. Simulation Parameters

Parameters	Value
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1+37.6 \log_{10}(R(km))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms

CommScope Ex. 1002

WHAT IS CLAIMED IS:

1. A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. The method of claim 1 wherein the DRUs comprise remote radio units.

3. The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical

footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

ABSTRACT OF THE DISCLOSURE

A method for routing and switching operator RF signals includes providing one or more Digital Remote Units (DRUs) and providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs. A first DRU is operable to communicate using a first set of frequencies characterized by a first frequency band over a first geographic footprint and a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint. A second DRU is operable to communicate using the first set of frequencies over a third geographical footprint and a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

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SCORE Placeholder Sheet for IFW Content

Application Number: 13894309 Document Date: 05/07/2014

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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/894,309

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	70		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	300		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	360		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	21 minus 20 =	* 1	x 40 =	40	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 210 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	770		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)	OR	RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/894,309	05/14/2013	2649	840	91172-866895(103600US)	21	3

CONFIRMATION NO. 4407

UPDATED FILING RECEIPT

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Date Mailed: 05/13/2014

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

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Assignment For Published Patent Application

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Power of Attorney: The patent practitioners associated with Customer Number 20350

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/649,143 05/18/2012

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

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The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/894,309**
Projected Publication Date: 08/21/2014
Non-Publication Request: No

Early Publication Request: No
** **SMALL ENTITY** **
Title

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

Preliminary Class

455

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

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No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

PUBLICATION NOTICE

OC000000070318466

Title:METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

Publication No.US-2014-0233468-A1
Publication Date:08/21/2014

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PLUS Search Results for S/N 13894309, Searched Tue Dec 02 11:16:37 EST 2014

The Patent Linguistics Utility System (PLUS) is a USPTO automated search system for U.S. Patents from 1971 to the present PLUS is a query-by-example search system which produces a list of patents that are most closely related linguistically to the application searched. This search was prepared by the staff of the Scientific and Technical Information Center, SIRA.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)	4407

20350 7590 12/31/2014

KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

EXAMINER	
CHERY, DADY	

ART UNIT	PAPER NUMBER
2461	

NOTIFICATION DATE	DELIVERY MODE
12/31/2014	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

ipefiling@kilpatricktownsend.com
jlhice@kilpatrick.foundationip.com

Office Action Summary	Application No. 13/894,309	Applicant(s) HEJAZI ET AL.	
	Examiner DADY CHERY	Art Unit 2461	AIA (First Inventor to File) Status No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE *3* MONTHS FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *05/14/2013*.

☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims*

5)☒ Claim(s) *1-21* is/are pending in the application.

5a) Of the above claim(s) _____ is/are withdrawn from consideration.

6)☐ Claim(s) _____ is/are allowed.

7)☒ Claim(s) *1-21* is/are rejected.

8)☐ Claim(s) _____ is/are objected to.

9)☐ Claim(s) _____ are subject to restriction and/or election requirement.

* If any claims have been determined allowable, you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov.

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

a)☐ All b)☐ Some** c)☐ None of the:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

** See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Information Disclosure Statement(s) (PTO/SB/08a and/or PTO/SB/08b) Paper No(s)/Mail Date _____.

3) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .

4) ☐ Other: _____.

1. The present application is being examined under the pre-AIA first to invent provisions.

DETAILED ACTION

Claim Rejections - 35 USC § 102

2. The following is a quotation of the appropriate paragraphs of pre-AIA 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

3. Claims 1-21 are rejected under pre-AIA 35 U.S.C. 102b as being anticipated by Karabinis (US Application 2005/0239403, hereinafter Karabinis).

Regarding claim 1, Karabinis discloses method **(Fig. 1-Fig. 3)** for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs)**(120, 220a,220b, 220c),** each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies**([0004], and [0013]-[0017], which recites downlink and uplink communication radio frequencies);** providing at least one Digital Access Unit (DAU) **(130)** configured to communicate with at least one of the one or more DRUs**([0013], and [0030]-[0035], which recites the communication of between item 130 considered as a DAU and at least 120 considered as DRU);**

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint **([0013], and [0030]-[0035], which recites a first set frequencies F1)**; and a

second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint **([0013], and [0030]-[0035], which recites a second set frequencies F2 different from F1)**;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint**([0013], and [0030]-[0035], which recites a first set frequencies F1)**; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint**([0013], and [0030]-[0035], which recites a third set frequencies F1')**.

Regarding claim 7, Karabinis discloses a method **(Fig. 1-Fig. 3)** of distributing communications frequencies, the method providing:

providing a set of communications units**(120, 220a,220b, 220c)**;

transmitting and receiving, from a first communications unit of the set of communications units**([0013], and [0030]-[0035], which recites the communication of between communication units)**:

a first set of frequencies characterized by a first frequency band and a first geographic footprint**([0013], and [0030]-[0035], which recites a first set frequencies F1)**; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least

partially surrounding the first geographic footprint**([0013], and [0030]-[0035], which recites a second set frequencies F2 different from F1)**; and

transmitting, and receiving, from a second communications unit of the set of communications units**([0013], and [0030]-[0035], which recites the communication of between communication units)**:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint**([0013], and [0030]-[0035], which recites a third set frequencies F1')**. and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint**([0013], and [0030]-[0035], which recites a fourth set frequencies F2')**.

Regarding claim 15, Karabinis discloses a communications system **(Fig. 1-Fig. 3)** comprising:

a host unit**(120, 220a,220b, 220c)**;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint **([0013], and [0030]-[0035], which first and second frequencies band where the S-Band is larger than the L-Band)**; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint **([0013], and [0030]-[0035], which third and fourth frequencies band where the S-Band is larger than the L-Band)**.

Regarding claim 2, Karabinis discloses the method of claim 1 wherein the DRUs comprise remote radio units **([0013], and [0030]-[0035])**.

Regarding claim 3, Karabinis discloses the method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 4, Karabinis discloses the method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections **([0013], and [0030]-[0035])**.

Regarding claim 5, Karabinis discloses the method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU **([0013], and [0030]-[0035])**.

Regarding claim 6, Karabinis discloses the method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies**([0013], and [0030]-[0035])**.

Regarding claim 8, Karabinis discloses the method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 9, Karabinis discloses the method of claim 7 wherein the first geographic footprint includes a location of the first communications unit **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 10, Karabinis discloses the method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 11, Karabinis discloses the method of claim 7 wherein the third geographical footprint includes a location of the second communications unit **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 12, Karabinis discloses the method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 13, Karabinis discloses the method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 14, Karabinis discloses the method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of

communications units: a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 16, Karabinis discloses the communications system of claim 15 wherein the host unit comprises a DAU the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 17, Karabinis discloses the communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 18, Karabinis discloses the communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 19, Karabinis discloses the communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the

second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 20, Karabinis discloses the communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands **(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Regarding claim 21, Karabinis discloses the communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies**(Fig. 1-Fig.3**, **[0013], and [0030]-[0035])**.

Conclusion

4. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure. King et al. (US patent 7,403,500).

5. Karabinis (US Application 2005/0064813).

6. Karabinis (US Application 2003/0054762).

Any inquiry concerning this communication or earlier communications from the examiner should be directed to DADY CHERY whose telephone number is (571)270-1207. The examiner can normally be reached on Monday - Thursday 8 am - 4 pm ESt.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Huy D. VU can be reached on 571-272-3155. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/DADY CHERY/
Primary Examiner, Art Unit 2461

Notice of References Cited	Application/Control No. 13/894,309	Applicant(s)/Patent Under Reexamination HEJAZI ET AL.	
	Examiner DADY CHERY	Art Unit 2461	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2005/0239403	10-2005	Karabinis, Peter D.	455/012.1
*	B	US-7,403,500	07-2008	King et al.	370/328
*	C	US-2005/0064813	03-2005	Karabinis, Peter D.	455/013.2
*	D	US-2003/0054762	03-2003	Karabinis, Peter D.	455/12.1
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
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FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
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	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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BIB DATA SHEET

CONFIRMATION NO. 4407

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
13/894,309	05/14/2013 **RULE**	370	2461	91172-866895(103600US)

APPLICANTS
DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS

INVENTORS
Seyed Amin Hejazi, Burnaby, CANADA;
Shawn Patrick Stapleton, Burnaby, CANADA;

** **CONTINUING DATA** **************************
This appln claims benefit of 61/649,143 05/18/2012

** **FOREIGN APPLICATIONS** **************************

** **IF REQUIRED, FOREIGN FILING LICENSE GRANTED** ** ** SMALL ENTITY **
06/13/2013

Foreign Priority claimed / 35 USC 119(a-d) conditions met / Verified and Acknowledged	Met after Allowance	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed ☐ Yes ☑ No 35 USC 119(a-d) conditions met ☐ Yes ☑ No Verified and Acknowledged /DADY CHERY/ Examiner's Signature	☐ Met after Allowance Initials	CANADA	9	21	3

ADDRESS

KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834
UNITED STATES

TITLE

METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

FILING FEE RECEIVED		
840	FEES: Authority has been given in Paper No.____________ to charge/credit DEPOSIT ACCOUNT No.____________ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other ________________ ☐ Credit

BIB (Rev. 05/07).

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	**Art Unit**
	DADY CHERY	2461

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIM		DATE								
Final	Original	12/23/2014								
	1	✓								
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	20	✓								
	21	✓								

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L2	53689	(370/329,330,335,336,338,341-347).ccls.	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:02
L3	19646	(455/403,429,427,430,446,447,450,452.1,509,517).ccls.	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:03
L4	4834	l2 and l3	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:03
L5	860	frequenc$3 same band same footprint	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:03
L6	7	l4 and l5	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:04
L7	149	l3 and l5	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:04
L8	28	l2 and l5	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:04
L9	5	(hejazi near2 amin).in.	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:05
L12	90	(stapleton near2 patrick).in.	US-PGPUB; USPAT	OR	OFF	2014/12/23 10:06

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L10	0	(hejazi near2 amin).in.	USPAT; UPAD	OR	OFF	2014/12/23 10:05
L11	34	(stapleton near2 patrick).in.	USPAT; UPAD	OR	OFF	2014/12/23 10:06

12/23/2014 10:10:13 AM
C:\Users\dchery\Documents\EAST\Workspaces\13894309.wsp

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	Art Unit
	DADY CHERY	2461

CPC- SEARCHED		
Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner
370	329,330,335,336,338,341-347	12/02/2014	DC
455	403,429,427,430,446,447,450,452.1,509,517	12/02/2014	DC

SEARCH NOTES		
Search Notes	Date	Examiner
Inventorship, NPL, and Plus search	12/02/2014	DC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on May 27, 2015.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /Kristina Alvarez/
Kristina Alvarez

PATENT
Attorney Docket No.: 91172-866895-103600US
Client Ref. No.: DW-1036

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 4407
Seyed Amin Hejazi et al.	Examiner: Dady Chery
Application No.: 13/894,309	Technology Center/Art Unit: 2461
Filed: May 14, 2013	
For: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	AMENDMENT
Customer No.: 20350	

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

In response to the Office Action mailed December 31, 2014, please enter the following remarks:

A Listing of the Claims begins on page 2 of this paper.

Remarks/Arguments begin on page 6 of this paper.

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings of claims in the application:

Listing of Claims:

1. (Original) A method for routing and switching operator RF signals, the method comprising:

providing one or more Digital Remote Units (DRUs), each configured to receive one or more downlink radio frequencies and to transmit one or more uplink radio frequencies;

providing at least one Digital Access Unit (DAU) configured to communicate with at least one of the one or more DRUs;

wherein a first DRU in a first cell is operable to communicate using:

a first set of frequencies characterized by a first frequency band over a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band over a second geographic footprint including and surrounding the first geographic footprint;

wherein a second DRU in a second cell is operable to communicate using:

the first set of frequencies over a third geographical footprint; and

a third set of frequencies characterized by a third frequency band different from the first frequency band and the second frequency band over a fourth geographic footprint including and surrounding the third geographic footprint.

2. (Original) The method of claim 1 wherein the DRUs comprise remote radio units.

3. (Original) The method of claim 1 further comprising communicating between a plurality of Base Transceiver Stations (BTS) coupled to the at least one DAU.

4. (Original) The method of claim 3 wherein one or more of the plurality of BTSs are coupled to the at least one DAU using BTS sector RF connections.

5. (Original) The method of claim 1 further comprising transporting signals between the one or more DRUs and the at least one DAU.

6. (Original) The method of claim 1 wherein a power level associated with the first set of frequencies is less than power levels associated with the second set of frequencies and the third set of frequencies.

7. (Original) A method of distributing communications frequencies, the method providing:

providing a set of communications units;

transmitting and receiving, from a first communications unit of the set of communications units:

a first set of frequencies characterized by a first frequency band and a first geographic footprint; and

a second set of frequencies characterized by a second frequency band different from the first frequency band and a second geographic footprint larger than and at least partially surrounding the first geographic footprint; and

transmitting, and receiving, from a second communications unit of the set of communications units:

a third set of frequencies including one or more frequencies in the first frequency band and a third geographical footprint; and

a fourth set of frequencies including one or more frequencies in a third frequency band and a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint.

8. (Original) The method of claim 7 wherein the set of communications units includes a plurality of remote units in communication with a host unit.

9. (Original) The method of claim 7 wherein the first geographic footprint includes a location of the first communications unit.

10. (Original) The method of claim 9 wherein the second geographic footprint covers the first geographic footprint and further extends over a peripheral footprint adjacent the first geographical footprint.

11. (Original) The method of claim 7 wherein the third geographical footprint includes a location of the second communications unit.

12. (Original) The method of claim 11 wherein the fourth geographical footprint covers the third geographical footprint and extends over a peripheral footprint adjacent the third geographical footprint.

13. (Original) The method of claim 7 wherein the second geographical footprint abuts the fourth geographical footprint.

14. (Original) The method of claim 7 further comprising transmitting, and receiving, from a third communications unit of the set of communications units:

a fifth set of frequencies including one or more frequencies in the first frequency band and a fifth geographical footprint; and

a sixth set of frequencies in a fourth frequency band and a sixth geographical footprint larger than and at least partially surrounding the fifth geographical footprint.

15. (Original) A communications system comprising:

a host unit;

a first communications unit coupled to the host unit and operable to transmit and receive communications using a first set of frequencies in a first frequency range and associated with a first geographical footprint and a second set of frequencies in a second frequency range and associated with a second geographical footprint larger than the first geographical footprint; and

a second communications unit coupled to the host unit and operable to transmit and receive communications using one or more of the first set of frequencies in a region associated with a third geographical footprint and a third set of frequencies in a third frequency range and associated with a fourth geographical footprint larger than the third geographical footprint.

16. (Original) The communications system of claim 15 wherein the host unit comprises a DAU, the first communications unit comprises a first DRU, and the second communication unit comprises a second DRU.

17. (Original) The communications system of claim 15 wherein the communications using the first set of frequencies in the first frequency range are associated with a first power level and the communications using the second set of frequencies in the second frequency range are associated with a second power level greater than the first power level.

18. (Original) The communications system of claim 15 wherein the communications using one or more of the first set of frequencies in the region associated with a third geographical footprint are associated with a first power level and the communications using the third set of frequencies in the third frequency range are associated with a second power level greater than the first power level.

19. (Original) The communications system of claim 15 wherein the first geographic footprint is characterized by a first border and the second geographic footprint is characterized by a second border, wherein a predetermined distance separates the first border and the second border.

20. (Original) The communications system of claim 15 wherein the first frequency band and the second frequency band are contiguous frequency bands.

21. (Original) The communications system of claim 15 wherein the first frequency range, the second frequency range, and the third frequency range include distinct frequencies.

REMARKS/ARGUMENTS

Upon entry of the present response, claims 1-21 will be pending in this application. No claims have been amended, canceled, or added. No new matter is added by this amendment. Based on the following remarks, Applicants respectfully request reconsideration and allowance of the pending claims.

Claim Rejections Under 35 U.S.C. § 102(b)

Claims 1-21 stand rejected under pre-AIA § 102(b) as being anticipated by Karabinis (2005/0239403). Applicants respectfully disagree, and submit that Karabinis fails to disclose or suggest each and every element recited by independent claims 1, 7 and 15, as is required for a proper rejection under 35 U.S.C. § 102.

For example, in the Office Action, the Examiner asserts that Karabinis discloses, *inter alia*, "a third set of frequencies characterized by a third frequency band *different from the first frequency band and the second frequency band* […]", as is recited in independent claim 1. *Emphasis added*. The Examiner compares F1 of Karabinis to the claimed first frequency band and F1' of Karabinis to the claimed third frequency band. However, paragraph [0032] of Karabinis discloses that "the radioterminals 120 transmit communications to one or more ATCs 130 using […] *substantially the same forward link frequencies in the first satellite band (F1')*". *Emphasis added*. Thus, the asserted third frequency band of Karabinis is substantially the same as the asserted first frequency band, contradicting the recitation of independent claim 1.

The Examiner further generally asserts that Karabinis discloses "a second geographic footprint including and surrounding the first geographic footprint" and "a fourth geographic footprint including and surrounding the third geographic footprint", as is recited in independent claim 1. *See, for example, FIG. 1B of the originally filed drawings*. However, FIGS. 1-3 and paragraphs [0030]-[0035] of Karabinis fail to illustrate or describe any geographic footprint associated with a set of frequencies including and surrounding another geographic footprint associated with another set of frequencies.

Independent claim 7 recites "a second geographic footprint larger than and at least partially surrounding the first geographic footprint" and "a fourth geographical footprint larger than and at least partially surrounding the third geographical footprint". Independent claim 15

recites "a second geographical footprint larger than the first geographical footprint" and "a fourth geographical footprint larger than the third geographical footprint". These features are similarly not disclosed by Karabinis. *See, for example, FIGS. 1-3 of Karabinis*.

Karabinis therefore fails to disclose each and every element of independent claims 1, 7 and 15. Thus, Applicants respectfully request withdrawal of the rejection of independent claims 1, 7 and 15 and the issuance of a new Non-Final Office Action.

The rejection of claims 2-6, 8-14 and 16-21 is also improper at least by virtue of their dependence on claims 1, 7 or 15, respectively, as well as for the additional elements they recite.

CONCLUSION

In view of the foregoing, Applicants believe all claims now pending in this Application are in condition for allowance. The issuance of a formal Notice of Allowance at an early date is respectfully requested.

Except for the issue fees payable under 37 C.F.R. § 1.18, the Director is authorized to charge any additional fees during pendency of this application, including any required extension of time fees, or credit any overpayment to Deposit Account Number 20-1430. This paragraph is intended to be a constructive petition for extension of time in accordance with 37 C.F.R. § 1.136(a)(3).

If the Examiner believes a telephone conference would expedite prosecution of this application, please contact the undersigned at (650) 326-2400.

Respectfully submitted,

/Craig C. Largent/
Craig C. Largent
Registration No. 56,400

KILPATRICK TOWNSEND & STOCKTON, LLP
CCL/AYB/lb/ka
66843815V.1

Electronic Patent Application Fee Transmittal					
Application Number:	13894309				
Filing Date:	14-May-2013				
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM				
First Named Inventor/Applicant Name:	Seyed Amin Hejazi				
Filer:	Craig Cody Largent/Kristina Alvarez				
Attorney Docket Number:	91172-866895(103600US)				
Filed as Small Entity					
Filing Fees for	**Utility under 35 USC 111(a)**				
Description		**Fee Code**	**Quantity**	**Amount**	**Sub-Total in USD($)**
Basic Filing:					
Pages:					
Claims:					
Miscellaneous-Filing:					
Petition:					
Patent-Appeals-and-Interference:					
Post-Allowance-and-Post-Issuance:					
Extension-of-Time:					

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension - 2 months with $0 paid	2252	1	300	300
Miscellaneous:				
		Total in USD ($)		**300**

Electronic Acknowledgement Receipt	
EFS ID:	22465790
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Craig Cody Largent/Kristina Alvarez
Filer Authorized By:	Craig Cody Largent
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	27-MAY-2015
Filing Date:	14-MAY-2013
Time Stamp:	22:01:14
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$300
RAM confirmation Number	9381
Deposit Account	201430
Authorized User	LARGENT, CRAIG C.
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees) Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)	

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Amendment_103600US.pdf	127383 a71faabc0104c5118d0e8cf440e0b30982ee57ab	yes	7

Multipart Description/PDF files in .zip description		
Document Description	**Start**	**End**
Amendment/Req. Reconsideration-After Non-Final Reject	1	1
Claims	2	5
Applicant Arguments/Remarks Made in an Amendment	6	7

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	30991 695dab17ad46ca6ba9836ecf3175601c913af50d	no	2

Warnings:

Information:

Total Files Size (in bytes):	158374

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

<u>New Applications Under 35 U.S.C. 111</u>
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

<u>National Stage of an International Application under 35 U.S.C. 371</u>
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

<u>New International Application Filed with the USPTO as a Receiving Office</u>
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 13/894,309	Filing Date 05/14/2013	☐ To be Mailed

ENTITY: ☐ LARGE ☒ SMALL ☐ MICRO

APPLICATION AS FILED – PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT **05/27/2015**

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	* 21	Minus	** 21	= 0	X $40 =	0
Independent (37 CFR 1.16(h))	* 3	Minus	***3	= 0	X $210 =	0
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	0

AMENDMENT

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =	
☐ Application Size Fee (37 CFR 1.16(s))						
☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))						
					TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

LIE
/VIOLA ROGERS/

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**
If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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UNITED STATES DEPARTMENT OF COMMERCE
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NOTICE OF ALLOWANCE AND FEE(S) DUE

20350 7590 07/17/2015

KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

EXAMINER
CHERY, DADY

ART UNIT	PAPER NUMBER
2461	

DATE MAILED: 07/17/2015

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)	4407

TITLE OF INVENTION: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	10/19/2015

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

20350 7590 07/17/2015
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission
I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)	4407

TITLE OF INVENTION: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	10/19/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHERY, DADY	2461	370-329000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
- ❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
- ❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.
1 _____
2 _____
3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE (B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

4a. The following fee(s) are submitted:
- ❑ Issue Fee
- ❑ Publication Fee (No small entity discount permitted)
- ❑ Advance Order - # of Copies _____

4b. Payment of Fee(s): (**Please first reapply any previously paid issue fee shown above**)
- ❑ A check is enclosed.
- ❑ Payment by credit card. Form PTO-2038 is attached.
- ❑ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ❑ Applicant certifying micro entity status. See 37 CFR 1.29
  NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
- ❑ Applicant asserting small entity status. See 37 CFR 1.27
  NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
- ❑ Applicant changing to regular undiscounted fee status.
  NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

PTOL-85 Part B (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)	4407

20350 7590 07/17/2015

KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

EXAMINER	
CHERY, DADY	

ART UNIT	PAPER NUMBER
2461	

DATE MAILED: 07/17/2015

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	Application No. 13/894,309	Applicant(s) HEJAZI ET AL.	
	Examiner DADY CHERY	Art Unit 2461	AIA (First Inventor to File) Status No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to *05/27/2015*.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on_____.
2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.
3. ☒ The allowed claim(s) is/are *1-21*. As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov .
4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some *c) ☐ None of the:
   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____.

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).
6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)
2. ☐ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date _____ .
5. ☐ Examiner's Amendment/Comment
6. ☐ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/DADY CHERY/
Primary Examiner, Art Unit 2461

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	3	(Provid$3 and digital and remote and units and frequenc$3 and footprint and band).clm.	US-PGPUB; USPAT	OR	OFF	2015/06/29 10:19
L3	10904	(h04l11/00, h04w28/06, h04w52/04, h04w72/04, h04j11/0023).cpc.	US-PGPUB; USPAT	OR	ON	2015/06/29 10:25
L4	58262	(370/329,330,335,336,338,341-347).ccls.	US-PGPUB; USPAT	OR	ON	2015/06/29 10:26
L5	4364	l3 and l4	US-PGPUB; USPAT	OR	ON	2015/06/29 10:26
L6	20606	(455/403,429,427,430,446,447,450,452,452.1,509,517).ccls.	US-PGPUB; USPAT	OR	ON	2015/06/29 10:27
L7	471	l5 and l6	US-PGPUB; USPAT	OR	ON	2015/06/29 10:27

6/ 29/ 2015 10:27:25 AM
C:\ Users\ dchery\ Documents\ EAST\ Workspaces\ 13894309.wsp

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	**Art Unit**
	DADY CHERY	2461

CPC						
Symbol					**Type**	**Version**
H04L		1	/	00	F	2013-01-01
H04W		28	/	06	A	2013-01-01
H04W		52	/	04	I	2013-01-01
H04W		72	/	04	A	2013-01-01
H04J		11	/	0023	A	2013-01-01
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			/			

CPC Combination Sets							
Symbol				**Type**	**Set**	**Ranking**	**Version**
			/				
			/				

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 21	
/DADY CHERY/ Primary Examiner.Art Unit 2461 (Primary Examiner)	06/29/2015 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 2

U.S. Patent and Trademark Office — Part of Paper No. 20150629

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	Art Unit
	DADY CHERY	2461

US ORIGINAL CLASSIFICATION		INTERNATIONAL CLASSIFICATION	
CLASS	SUBCLASS	CLAIMED	NON-CLAIMED
		H 0 4 L 1 / 00 (2006.01.01)	

CROSS REFERENCE(S)					
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				

NONE (Assistant Examiner)	(Date)	Total Claims Allowed: 21	
/DADY CHERY/ Primary Examiner.Art Unit 2461 (Primary Examiner)	06/29/2015 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 2

U.S. Patent and Trademark Office

Part of Paper No. 20150629

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	**Art Unit**
	DADY CHERY	2461

☒ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
	1		17												
	2		18												
	3		19												
	4		20												
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	13														
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	15														
	16														

NONE (Assistant Examiner)	(Date)	**Total Claims Allowed:** 21	
/DADY CHERY/ Primary Examiner.Art Unit 2461 (Primary Examiner)	06/29/2015 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 2

U.S. Patent and Trademark Office Part of Paper No. 20150629

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	13894309	HEJAZI ET AL.
	Examiner	Art Unit
	DADY CHERY	2461

CPC- SEARCHED		
Symbol	Date	Examiner
h04l11/00, h04w28/06, h04w52/04, h04w72/04, h04j11/0023	12/02/2014	DC

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner
370	329,330,335,336,338,341-347	12/02/2014	DC
455	403,429,427,430,446,447,450,452.1,509,517	12/02/2014	DC

SEARCH NOTES		
Search Notes	Date	Examiner
Inventorship, NPL, and Plus search	12/02/2014	DC
Updated search	06/29/2015	DC

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
	h04l11/00, h04w28/06, h04w52/04, h04w72/04, h04j11/0023	06/29/2015	DC

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	3	(Provid$3 and digital and remote and units and frequenc$3 and footprint and band).clm.	US-PGPUB; USPAT	OR	OFF	2015/06/29 10:19

6/29/2015 10:19:36 AM
C:\Users\dchery\Documents\EAST\Workspaces\13894309.wsp

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

20350 7590 07/17/2015
KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission
I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)	4407

TITLE OF INVENTION: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$480	$0	$0	$480	10/19/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
CHERY, DADY	2461	370-329000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Kilpatrick Townsend & Stockton LLP
2
3

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Dali Systems Co. Ltd.

(B) RESIDENCE: (CITY and STATE OR COUNTRY): George Town, Grand Cayman, Cayman Islands

Please check the appropriate assignee category or categories (will not be printed on the patent): ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. The following fee(s) are submitted:
☒ Issue Fee
☐ Publication Fee (No small entity discount permitted)
☐ Advance Order - # of Copies _____

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
☐ A check is enclosed.
☒ Payment by credit card. ~~Form PTO-2038 is attached.~~
☒ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number 20-1430 (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
☐ Applicant certifying micro entity status. See 37 CFR 1.29
NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
☐ Applicant asserting small entity status. See 37 CFR 1.27
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
☐ Applicant changing to regular undiscounted fee status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature /Craig C. Largent/ Date October 19, 2015
Typed or printed name Craig C. Largent Registration No. 56.400

PTOL-85 Part B (10-13) Approved for use through 10/31/2013. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Electronic Patent Application Fee Transmittal

Application Number:	13894309
Filing Date:	14-May-2013
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Filer:	Craig Cody Largent/Brian Kanter
Attorney Docket Number:	91172-866895(103600US)

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Utility Appl Issue Fee	2501	1	480	480

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**480**

Electronic Acknowledgement Receipt	
EFS ID:	23820617
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Craig Cody Largent/Brian Kanter
Filer Authorized By:	Craig Cody Largent
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	19-OCT-2015
Filing Date:	14-MAY-2013
Time Stamp:	13:58:45
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$480
RAM confirmation Number	387
Deposit Account	201430
Authorized User	LARGENT, CRAIG C.
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:	

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Issue Fee Payment (PTO-85B)	0866895.pdf	1613515 7498398bdab4817611af1e71f5f34aa4a708a287	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30766 578b424b3064c505a89a0c5fcea76ecd61e9e8c6	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	1644281		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
13/894,309	11/24/2015	9197358	91172-866895(103600US)	4407

20350 7590 11/04/2015

KILPATRICK TOWNSEND & STOCKTON LLP
TWO EMBARCADERO CENTER
EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 0 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

DALI SYSTEMS CO. LTD., George Town, CAYMAN ISLANDS
Seyed Amin Hejazi, Burnaby, CANADA;
Shawn Patrick Stapleton, Burnaby, CANADA;

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage and facilitate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82A (07-13)
Approved for use through 11/30/2014. OMB 0651-0051
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE REGISTERED PRACTITIONERS

NOTE: This form is to be submitted with the Power of Attorney by Applicant form (PTO/AIA/82B) to identify the application to which the Power of Attorney is directed, in accordance with 37 CFR 1.5, unless the application number and filing date are identified in the Power of Attorney by Applicant form. If neither form PTO/AIA/82A nor form PTO/AIA82B identifies the application to which the Power of Attorney is directed, the Power of Attorney will not be recognized in the application.

Application Number	13/894,309
Filing Date	05-14-2013
First Named Inventor	Seyed Amin Hejazi
Title	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
Art Unit	2461
Examiner Name	CHERY, DADY
Attorney Docket Number	91172-866895(103600US)

SIGNATURE of Applicant or Patent Practitioner

Signature	/Jennifer Spaith/	Date (Optional)	
Name	Jennifer Spaith	Registration Number	51,916
Title (if Applicant is a juristic entity)	Patent Practitioner		
Applicant Name (if Applicant is a juristic entity)	DALI SYSTEMS CO. LTD		

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.

☑ *Total of 1 forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Doc Code: PA..
Document Description: Power of Attorney

PTO/AIA/82B (07-13)
Approved for use through 11/30/2014. OMB 0651-0051
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number

POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

Application Number	Filing Date

(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☑ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above: 27076

OR

☐ I hereby appoint Practitioner(s) named in the attached list (form PTO/AIA/82C) as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above. (Note: Complete form PTO/AIA/82C.)

Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:

☑ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number:

OR

Firm or Individual Name					
Address					
City		State		Zip	
Country					
Telephone		Email			

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

DALI SYSTEMS CO. LTD

☐ Inventor or Joint Inventor (title not required below)

☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)

☑ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)

☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature		Date (Optional)	
Name	Albert Lee		
Title	CEO		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☑ Total of 1 forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Electronic Acknowledgement Receipt	
EFS ID:	36491318
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	20350
Filer:	Jennifer Lane Spaith/Angela Staschke
Filer Authorized By:	Jennifer Lane Spaith
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	03-JUL-2019
Filing Date:	14-MAY-2013
Time Stamp:	12:26:29
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Power of Attorney	POA_13894309_4407_P282738US02.pdf	642336 75a32077486942d5c792e8d12376b18a3cdcd236	no	2

Warnings:

The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing	
Information:	
Total Files Size (in bytes):	642336

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

27076
DORSEY & WHITNEY LLP - Seattle
INTELLECTUAL PROPERTY DEPARTMENT
Columbia Center
701 Fifth Avenue, Suite 6100
Seattle, WA 98104-7043

POA ACCEPTANCE LETTER

OC000000109461644

Date Mailed: 07/09/2019

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 07/03/2019.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/byemane/

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

20350
KILPATRICK TOWNSEND & STOCKTON LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, GA 30309

POWER OF ATTORNEY NOTICE

OC000000109461596

Date Mailed: 07/09/2019

NOTICE REGARDING CHANGE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 07/03/2019.

- The Power of Attorney to you in this application has been revoked by the applicant. Future correspondence will be mailed to the new address of record(37 CFR 1.33).

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/byemane/

PATENT ASSIGNMENT COVER SHEET

Electronic Version v1.1
Stylesheet Version v1.2

EPAS ID: PAT5633990

SUBMISSION TYPE:	NEW ASSIGNMENT
NATURE OF CONVEYANCE:	SECURITY INTEREST

CONVEYING PARTY DATA

Name	Execution Date
DALI WIRELESS, INC.	06/18/2019

RECEIVING PARTY DATA

Name:	DALI RESEARCH (NORTHWIND) LLC
Street Address:	156 WEST 56TH STREET
Internal Address:	9TH FLOOR
City:	NEW YORK
State/Country:	NEW YORK
Postal Code:	10019

PROPERTY NUMBERS Total: 143

Property Type	Number
Application Number:	15251293
Application Number:	13960346
Application Number:	15682431
Application Number:	16059434
Application Number:	10137556
Application Number:	11262079
Application Number:	11799239
Application Number:	11961969
Application Number:	12021241
Application Number:	13211243
Application Number:	13211247
Application Number:	13301224
Application Number:	13404679
Application Number:	13619538
Application Number:	13724157
Application Number:	13887133
Application Number:	13913207
Application Number:	14095891
Application Number:	14169719

Property Type	Number
Application Number:	14245190
Application Number:	14260145
Application Number:	14480285
Application Number:	14684678
Application Number:	14691152
Application Number:	14788567
Application Number:	14800515
Application Number:	14949405
Application Number:	14991264
Application Number:	15205820
Application Number:	15223819
Application Number:	14743789
Application Number:	14044668
Application Number:	13770113
Application Number:	14574071
Application Number:	14837850
Application Number:	15782309
Application Number:	15812018
Application Number:	15391408
Application Number:	16230750
Application Number:	16388680
Application Number:	11962025
Application Number:	16118329
Application Number:	12203064
Application Number:	12203076
Application Number:	15875936
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Application Number:	13481389
Application Number:	13776163
Application Number:	12767669
Application Number:	12603419
Application Number:	13553967
Application Number:	14087682
Application Number:	14885890

Property Type	Number
Application Number:	12928934
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Application Number:	13894987
Application Number:	14553828
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Application Number:	14248597
Application Number:	14754908
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Application Number:	16213103
Application Number:	12928931
Application Number:	14337004
Application Number:	15827794
Application Number:	12928943
Application Number:	14020425
Application Number:	14335647
Application Number:	14703579
Application Number:	13211236
Application Number:	14479875
Application Number:	15786396
Application Number:	16406252
Application Number:	16175520
Application Number:	16410860
Application Number:	13602818
Application Number:	14333277
Application Number:	14831626
Application Number:	13625760
Application Number:	14480267
Application Number:	14918371
Application Number:	16279535
Application Number:	13686036
Application Number:	14225673
Application Number:	14960177
Application Number:	13670162
Application Number:	13670290
Application Number:	15857356
Application Number:	13671203
Application Number:	13754702

Property Type	Number
Application Number:	14678779
Application Number:	15445467
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Application Number:	13753288
Application Number:	13777185
Application Number:	15383121
Application Number:	16054678
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Application Number:	15383431
Application Number:	15912859
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Application Number:	15154073
Application Number:	15676631
Application Number:	13945736
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Application Number:	13777194
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Application Number:	14987093
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Application Number:	16240433
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Application Number:	14199617
Application Number:	15917342
Application Number:	14257209
Application Number:	15819279

Property Type	Number
Application Number:	14590447
Application Number:	14580585
Application Number:	14621192
Application Number:	16360980
Application Number:	14639418
Application Number:	15090402
Application Number:	15820299
Application Number:	15203015
Application Number:	15358060
Application Number:	15594323

CORRESPONDENCE DATA

Fax Number: (212)586-5095

Correspondence will be sent to the e-mail address first; if that is unsuccessful, it will be sent using a fax number, if provided; if that is unsuccessful, it will be sent via US Mail.

Phone: 2125865800
Email: DFRIEDMAN@CTSWLAW.COM
Correspondent Name: DANIEL J. FRIEDMAN
Address Line 1: 420 LEXINGTON AVENUE
Address Line 2: SUITE 2400
Address Line 4: NEW YORK, NEW YORK 10170

NAME OF SUBMITTER:	DANIEL J. FRIEDMAN
SIGNATURE:	/Daniel J. Friedman/
DATE SIGNED:	07/24/2019
	This document serves as an Oath/Declaration (37 CFR 1.63).

Total Attachments: 42
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PATENT SECURITY AGREEMENT

This Patent Security Agreement, dated as of June 18, 2019 (this "Agreement"), made by Dali Wireless, Inc., a Delaware corporation ("Grantor"), in favor of Dali Research (Northwind) LLC, a Delaware limited liability company (together with its successors and assigns, "Grantee"). Reference is made to that certain Prepaid Forward Purchase Agreement between Buyer and Seller, dated as of the date hereof (as it may be amended from time to time, the "Purchase Agreement").

RECITALS

WHEREAS, the Grantor has an ownership interest in certain Patents set forth on Exhibit A hereto (the "Patents"); and

WHEREAS, the Grantor and Grantee are parties to that certain Security Agreement, of even date herewith (as from time to time amended or supplemented, the "Security Document"); and

WHEREAS, pursuant to the Security Document, Grantor has granted to Grantee a security interest in certain of its assets, including, without limitation, the Patents, to secure the performance of Grantor's obligations under the Security Document and related agreements; and

WHEREAS, it is a condition precedent to Grantee's entry into the Security Document and related agreements that the Grantor execute and deliver this Agreement to Grantee; and

WHEREAS, the Grantor and Grantee by this instrument seek to confirm and make a record of the grant of the security interest in the Patents and the assignment of the Patents upon the occurrence of an Event of Default (as defined below) in accordance with the terms of this Agreement; and

WHEREAS, capitalized terms used and not defined herein have the meanings given to them in the Security Document.

NOW, THEREFORE, for good and valuable consideration, the receipt and adequacy of which are hereby acknowledged, the Grantor hereby agrees, confirms and acknowledges as follows:

1. As collateral security for the payment and performance of the Obligations, Grantor hereby grants and conveys to Grantee a first priority continuing security interest in and lien upon all Patents now owned and hereafter acquired by Grantor and the Proceeds and products thereof. The Grantor does hereby acknowledge and confirm that the Patents, the goodwill associated therewith, and the Proceeds and products thereof constitute Collateral pledged by Grantor to Grantee pursuant to the Security Document.

2. The Grantor further acknowledges and confirms that the rights and remedies of Grantee with respect to the Patents are more fully set forth in the Security Document, the terms and provisions of which are incorporated herein by reference.

3. The Grantor hereby irrevocably constitutes and appoints Grantee, with full power of substitution, as its true and lawful attorney-in-fact, with full irrevocable power and authority in its place and stead and in its name or otherwise, from time to time in Grantee's sole discretion, at Grantee's sole cost and expense, to take any and all action and to execute and deliver any and all documents and instruments which Grantee may deem reasonably necessary or advisable to (a) accomplish the purposes of perfecting, continuing and preserving, a continuing first priority security interest in the Patents and the goodwill associated therewith in favor of Grantee, and (b) effect a transfer of the Patents and the goodwill associated therewith to Grantee or to Grantee's designees without further consent or authorization of the Grantor upon the occurrence of an Event of Default (as defined in the Security Document) (an "Event of Default"). In furtherance and not in limitation of the foregoing, if an Event of Default has occurred and is continuing, the Grantee is hereby authorized file with the United States Patent and Trademark Office or with such other governmental authorities, the assignment in the form substantially similar to that of Exhibit 1 attached to this Agreement, together with such other instruments and documents as Grantee may deem necessary or appropriate to effectuate the foregoing.

4. Grantee is hereby authorized to file or record this Agreement or any other instrument or documents in such public offices and with such governmental authorities, including the United States Patent and Trademark Office, as Grantee may determine from time to time for the purpose of evidencing the foregoing grant of security.

[REMAINDER OF PAGE INTENTIONALLY LEFT BLANK AND SIGNATURES ON NEXT PAGE]

IN WITNESS WHEREOF, this Patent Security Agreement has been executed and delivered as of the day and year first above written.

GRANTOR

DALI WIRELESS, INC.

By:_____

Name:Albert Lee

Title:CEO

ACCEPTED AND AGREED:

GRANTEE:

DALI RESEARCH (NORTHWIND) LLC

By_____

Title: Authorized Person

EXHIBIT 1

ASSIGNMENT OF PATENTS

This **ASSIGNMENT OF PATENTS** (this "Assignment"), dated as of _____ __, 20__, made by **Dali Wireless, Inc.**, a Delaware corporation ("Assignor"), in favor of **Dali Research (Northwind) LLC**, a Delaware limited liability company (together with its successors and assigns, "Grantee" or "Assignee") and the Assignee as set forth below. For good and valuable consideration, the receipt and adequacy of are hereby acknowledged, Assignor hereby assigns to Grantee the Patents set forth on Exhibit A hereto (the "Patents") as follows:

1. Assignment of Patents. Assignor hereby assigns, transfers, and conveys to _____, a _____ with offices at _____ (the "Assignee") all of Assignor's right, title and interest in and to the Patents together with the goodwill associated therewith and the right to sue for past infringement of the Patents.

3. Filing and Recordation. Assignee is hereby authorized to file or record this Assignment or any other instrument in such public offices and with such governmental authorities, including the United States Patent and Trademark Office, as Assignee may determine from time to time for the purpose of evidencing the foregoing assignment.

IN WITNESS WHEREOF, Assignor has executed this Assignment of Patents as of the date first above written.

ASSIGNOR:

DALI WIRELESS, INC.

By:_____

Name:_____

Title:_____

TITLE	COUNTRY	APPLN. NO.	FILING DATE	PUB NO.	PUB DATE	PATENT NO.	ISSUE DATE	STATUS
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	10/137,556	5/1/02	US 2003-0207680 A1	11/6/03	6,985,704	1/10/06	Issued
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	11/262,079	10/27/05	US 2006-0046665 A1	3/2/06	8,326,238	12/4/12	Issued
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	13/619,538	9/14/12	US-2013-0243124-A1		8,731,495	5/20/14	Issued
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	14/245,190	4/4/14	US-2014-0306762-A1		9,031,521	5/12/15	Issued
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	14/684,678	4/13/15	US-2015-0326349-A1		9,374,196	6/21/16	Issued
SYSTEM AND METHOD FOR DIGITAL MEMORIZED PREDISTORTION FOR WIRELESS COMMUNICATION	United States of America	16/230,750	12/21/18					Pending
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	China	200780023875.1	4/30/07	101479956	7/31/13	ZL200780023875.1	7/31/13	Issued
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	11/799,239	4/30/07	US 2007/0241812 A1		8,064,850	11/22/11	Issued
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	13/301,224	11/21/11	US-2012-0135695-A1	5/31/12	8,620,234	12/31/13	Issued
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	14/095,891	12/3/13	US-2014-0179248-A1		9,054,758	6/9/15	Issued
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	14/691,152	4/20/15	US-2015-0333710-A1		9,742,446	8/22/17	Issued

CommScope Ex. 1002

HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	15/682,431	8/21/17	US-2018-0097530-A1		10,305,521	5/28/19	Issued
HIGH EFFICIENCY LINEARIZATION POWER AMPLIFIER FOR WIRELESS COMMUNICATION	United States of America	16/388,680	4/18/19					Pending
POWER AMPLIFIER PREDISTORTION METHODS AND APPARATUS	United States of America	11/962,025	12/20/07			8,472,897	6/25/13	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	China	200880003130.3	1/28/08	101606315	12/16/09	ZL200880003130.3	7/2/14	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	Macao	J/001490	1/28/08		1/2/15	J/001490	11/13/14	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	United States of America	12/021,241	1/28/08	US 2008-0174365 A1	7/24/08	8,380,143	2/19/13	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	China	201410199319.1	1/28/08	CN 103997301 A	9/28/18	ZL 201410199319.1	9/28/18	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	Hong Kong	14109438.5	9/18/14	1196186A	12/5/14			Published
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	Macao	J/001456	7/2/14					Pending
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	United States of America	13/724,157	12/21/12	US-2013-0147550-A1		9,077,297	7/7/15	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	United States of America	14/788,567	6/30/15	US-2016-0036394-A1		10,097,142	10/9/18	Issued
POWER AMPLIFIER TIME-DELAY INVARIANT PREDISTORTION METHODS AND APPARATUS	United States of America	16/118,329	8/30/18					Pending
ANALOG POWER AMPLIFIER PREDISTORTION METHODS AND APPARATUS	United States of America	12/203,064	9/2/08	US-2009-0085658-A1		8,693,962	4/8/14	Issued

CommScope Ex. 1002

POWER AMPLIFIER PREDISTORTION METHODS AND APPARATUS USING ENVELOPE AND PHASE DETECTOR	United States of America	12/203,076	9/2/08	US-2009-0096521-A1	4/16/09	8,224,266	7/17/12	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	China	200780051434.2	12/20/07	102017553	10/15/14	ZL200780051434.2	10/15/14	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDE-BAND COMMUNICATION SYSTEMS	India	4344/CHENP/2009	12/20/07			283900	6/5/17	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Japan	2009-543544	12/20/07	2010-518660	7/17/13	5236661	4/5/13	Issued
METHOD AND SYSTEM FOR BASED AND PREDISTORITION LEANARIZATION IN MULTI-CHANNEL WIDE-BAND COMMUNICATION SYSTEMS	Macao	J/001620	12/20/07			J/001620	3/10/15	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	11/961,969	12/20/07	US 2008/0152037 A1		8,149,950	4/3/12	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	China	201410462933.2	12/20/07	CN 104202279 A				Published
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	European Patent Office	18187871.1	12/20/07	3416340				Published

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METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Hong Kong	15105454.1	12/20/07	1205382A	12/11/15			Published
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	13/404,679	2/24/12	US-2012-0147993-A1	6/14/12	8,509,347	8/13/13	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	13/887,133	5/3/13	US-2013-0315291-A1		8,855,234	10/7/14	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	14/480,285	9/8/14	US-2015-0092830-A1		9,246,731	1/26/16	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	14/991,264	1/8/16	US-2016-0269210-A1		9,913,194	3/6/18	Issued
METHOD AND SYSTEM FOR BASEBAND PREDISTORTION LINEARIZATION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	15/875,936	1/19/18	US-2018-0279197-A1				Published
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	China	200880021049.8	4/23/08	101720528	6/2/10	ZL200880021049.8	3/19/14	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	Germany	08746721.3	4/23/08	2143209		60 2008 056 496.7	8/15/18	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	European Patent Office	08746721.3	4/23/08	2143209	8/15/18	2143209	8/15/18	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	France	08746721.3	4/23/08	2143209		2143209	8/15/18	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	United Kingdom	08746721.3	4/23/08	2143209		2143209	8/15/18	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	India	7544/DELNP/2009	4/23/08	28/2010				Published

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DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	Japan	2010-506483	4/23/08	2010-525758	7/22/10	5591106	8/8/14	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	Republic of Korea	10-2009-7024361	4/23/08	10-2010-0017270	3/24/15	10-1503548	3/11/15	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	Macao	J/001446	4/23/08		9/29/14	J/001446	8/25/14	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	Netherlands	08746721.3	4/23/08	2143209		2143209	8/15/18	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	United States of America	12/108,502	4/23/08	US-2008-0265996-A1		8,811,917	8/19/14	Issued
METHOD FOR UPDATING COEFFICENTS OF A PREDISTORTION CIRCUIT AND ADAPTATION CIRCUIT	Republic of Korea	10-2014-7021366	4/23/08		12/22/16	10-1688710	12/15/16	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	United States of America	14/271,881	5/7/14	US-2014-0327481-A1		9,768,739	9/19/17	Issued
DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM	United States of America	15/684,580	8/23/17	US-2018-0102747-A1				Published
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	China	200880021149.0	4/23/08	102089966	2/3/16	ZL 2008800211490	2/3/16	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	Germany	08829011.9	4/23/08	2145385		60 2008 057 483.0	10/17/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	European Patent Office	08829011.9	4/23/08	2145385	10/17/18	2145385	10/17/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	France	08829011.9	4/23/08	2145385		2145385	10/17/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	United Kingdom	08829011.9	4/23/08	2145385		2145385	10/17/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	India	7514/DELNP/2009	4/23/08	27/2010	9/10/18	300878	9/10/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	Japan	2010-504909	4/23/08	2010-530148	4/16/14	5474764	2/14/14	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	Republic of Korea	10-2009-7024268	4/23/08	10-2010-0017214	1/20/15	10-1484796	1/14/15	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	Macao	J/002140	4/23/08		9/13/16	J/002140	8/9/16	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	Netherlands	08829011.9	4/23/08	2145385		2145385	10/17/18	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER	United States of America	12/108,507	4/23/08	US 2008-0284509 A1	11/20/08	7,688,135	3/30/10	Issued
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	China	200880126324.2	12/8/08	102150361	11/9/16	ZL 2008801263242	11/9/16	Issued

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BASEBAND-DERIVED RF DIGITAL PREDISTORTION	European Patent Office	08873193.0	12/8/08	2248255				Published
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	India	4196/CHENP/2010	12/8/08	01/2011				Published
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	Japan	2010-536550	12/8/08	2011-511493	7/31/13	5250636	4/19/13	Issued
BASEBAND-DERIVED WIDEBAND RF DIGITAL PREDISTORTION SYSTEM	Republic of Korea	10-2010-7015019	12/8/08	10-2010-0108546	10/25/16	10-1669173	10/19/16	Issued
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	Macao	J/002468	12/8/08		5/4/17	J/002468	4/11/17	Issued
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	United States of America	12/330,451	12/8/08	US 2009-0146736 A1		8,213,884	7/3/12	Issued
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	United States of America	13/481,389	5/25/12	US-2012-0230382-A1	9/13/12	8,401,499	3/19/13	Issued
BASEBAND-DERIVED RF DIGITAL PREDISTORTION	United States of America	13/776,163	2/25/13	US-2013-0214861-A1		8,548,403	10/1/13	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	China	201080025887.X	4/26/10	CN 102460385 A	5/16/12	ZL201080025887X	3/2/16	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	European Patent Office	10767899.7	4/26/10	2 430 531	3/21/12			Allowed
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	Indonesia	W-00 2012 01448	4/26/10		12/19/17	ID P 000 048 875	12/19/17	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	India	8527/CHENP/2011	4/26/10	8527/CHENP/2011				Published
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	Republic of Korea	10-2011-7027891	4/26/10			10-1967471	4/3/19	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	Macao	J/002198	4/26/10		10/17/16	J/002198	9/12/16	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	United States of America	12/767,669	4/26/10	US 2010-0271957 A1	10/28/10	9,026,067	5/5/15	Issued
REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	Japan	2015-178686	4/26/10					Pending

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REMOTELY RECONFIGURABLE POWER AMPLIFIER SYSTEM AND METHOD	Japan	2017-253609	4/26/10					Pending
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER WITH POWER TRACKING	United States of America	12/603,419	10/21/09	US-2010-0176885-A1	7/15/10	8,274,332	9/25/12	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER WITH POWER TRACKING	United States of America	13/553,967	7/20/12	US-2013-0009707-A1	1/10/13	8,618,883	12/31/13	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER WITH POWER TRACKING	United States of America	14/087,682	11/22/13	US-2014-0191805-A1		9,184,703	11/10/15	Issued
N-WAY DOHERTY DISTRIBUTED POWER AMPLIFIER WITH POWER TRACKING	United States of America	14/885,890	10/16/15	US-2016-0173040-A1		10,298,177	5/21/19	Issued
MULTI-BAND WIDEBAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM AND METHOD	China	201080064338.3	12/21/10	CN 102939716A		ZL 201080064338.3	2/3/16	Issued
MULTI-BAND WIDEBAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM AND METHOD	Macao	J/2106	12/21/10			J/002106	7/29/16	Issued
MULTI-BAND WIDEBAND POWER AMPLIFIER DIGITAL PREDISTORITION SYSTEM AND METHOD	United States of America	12/928,934	12/21/10	US-2012-0154038-A1	6/21/12	8,351,877	1/8/13	Issued
DIGITAL PREDISTORTION SYSTEM AND METHOD FOR AMPLIFYING SIGNALS	China	201610003690.5	12/21/10	CN 105634415A	3/8/19	ZL 201610003690.5	3/8/19	Issued
A MULTI-BAND DIGITAL PREDISTORTION SYSTEM AND A METHOD FOR AMPLIFYING SIGNALS	Hong Kong	16112532.2	12/21/10	1224439A	8/18/17			Published
DIGITAL PREDISTORTION SYSTEM AND METHOD FOR AMPLIFYING SIGNALS	Macao	J/3685	12/21/10					Pending
MULTI-BAND WIDE BAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM	United States of America	13/705,022	12/4/12	US-2013-0094612-A1		8,467,747	6/18/13	Issued

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MULTI-BAND WIDE BAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM	United States of America	13/894,987	5/15/13	US-2013-0251066-A1		8,903,337	12/2/14	Issued
MULTI-BAND WIDE BAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM	United States of America	14/553,828	11/25/14	US-2015-0171899-A1		9,379,745	6/28/16	Issued
MULTI-BAND WIDE BAND POWER AMPLIFIER DIGITAL PREDISTORTION SYSTEM	United States of America	15/181,033	6/13/16	US-2017-0047952-A1				Published
REMOTE RADIO HEAD UNIT WITH WIDEBAND POWER AMPLIFIER AND METHOD	China	201080064329.4	12/21/10	CN 102948081A	6/1/16	ZL 201080064329.4	6/1/16	Issued
REMOTE RADIO HEAD UNIT WITH WIDEBAND POWER AMPLIFIER AND METHOD	Macao	J/2296	12/21/10			J/002296	12/14/16	Issued
REMOTE RADIO HEAD UNIT SYSTEM WITH WIDEBAND POWER AMPLIFIER AND METHOD	United States of America	12/928,933	12/21/10	US 2011-0158081 A1		8,730,786	5/20/14	Issued
SYSTEM FOR IMPROVING ISOLATION BETWEEN TRANSMITTERS AND RECEIVERS	Hong Kong	17103802.3	12/21/10	1230352A	12/1/17			Published
REMOTE RADIO HEAD UNIT SYSTEM WITH WIDEBAND POWER AMPLIFIER AND METHOD	United States of America	14/248,597	4/9/14	US-2014-0219174-A1		9,106,453	8/11/15	Issued
REMOTE RADIO HEAD UNIT SYSTEM WITH WIDEBAND POWER AMPLIFIER	United States of America	14/754,908	6/30/15	US-2015-0382363-A1		9,814,053	11/7/17	Issued
REMOTE RADIO HEAD UNIT SYSTEM WITH WIDEBAND POWER AMPLIFIER	United States of America	15/718,469	9/28/17	US-2018-0152947-A1		10,153,789	12/11/18	Issued
REMOTE RADIO HEAD UNIT SYSTEM WITH WIDEBAND POWER AMPLIFIER	United States of America	16/213,103	12/7/18					Pending
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	China	201080064414.0	12/21/10	CN 102948071A		ZL 201080064414.0	6/22/16	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Germany	10838778.8	12/21/10	2517353	10/31/12	60 2010 032 691.8	4/20/16	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	European Patent Office	10838778.8	12/21/10	2517353	10/31/12	2517353	4/20/16	Issued

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MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	United Kingdom	10838778.8	12/21/10	2517353	10/31/12	2517353	4/20/16	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Indonesia	W00201202630	12/21/10	2014/04399	5/17/18	IDP000051138	5/17/18	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	India	6164/CHENP/2012	12/21/10	2012CN06164				Published
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Japan	2012-545469	12/21/10	2013-515423		5761646	6/19/15	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Republic of Korea	10-2012-7019385	12/21/10			10-1815329	12/28/17	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Macao	J/2312	12/21/10			J/002312	1/4/17	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	United States of America	12/928,931	12/21/10	US-2011-0156815-A1		8,804,870	8/12/14	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	European Patent Office	16166094.9	12/21/10	3068047				Published
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Hong Kong	17101974.9	12/21/10	1228604A	11/3/17			Published
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	Indonesia	P00201803072	12/21/10					Pending
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	United States of America	14/337,004	7/21/14	US-2015-0010110-A1		9,866,414	1/9/18	Issued
MODULATION AGNOSTIC DIGITAL HYBRID MODE POWER AMPLIFIER SYSTEM AND METHOD	United States of America	15/827,794	11/30/17	US-2018-0227152-A1				Published
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	China	201080064443.7	12/21/10	CN 102870494A	4/20/16	ZL 201080064443.7	4/20/16	Issued

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HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Germany	10848623.4	12/21/10	2524568	11/21/12	60 2010 036 118.7	8/31/16	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	European Patent Office	10848623.4	12/21/10	2524568	8/31/16	2524568	8/31/16	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	France	10848623.4	12/21/10	2524568	11/21/12	2524568	8/31/16	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United Kingdom	10848623.4	12/21/10	2524568	11/21/12	2524568	8/31/16	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Indonesia	W00201202631	12/21/10	2013/00167 A	3/21/16	IDP000040 655	3/21/16	Issued
HIGH EFFICIENCY REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	India	6163/CHENP/2012	12/21/10	2012CN06163				Published
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Japan	2012-545471	12/21/10	2013-515424		5744910	5/15/15	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM FOR WIRELESS COMMUNICATIONS	Republic of Korea	10-2012-7019387	12/21/10			10-1763970	7/26/17	Issued

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HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Macao	J/2206	12/21/10			J/002206	10/18/16	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United States of America	12/928,943	12/21/10	US-2012-0155572-A1	6/21/12	8,542,768	9/24/13	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Germany	16181745.7	12/21/10	3110231		60 2010 050 454.9	5/2/18	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	European Patent Office	16181745.7	12/21/10	3110231	5/2/18	3110231	5/2/18	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	France	16181745.7	12/21/10	3110231		3110231	5/2/18	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United Kingdom	16181745.7	12/21/10	3110231		3110231	5/2/18	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Hong Kong	17105876.9	12/21/10	1232372A	1/18/19	1232372B	1/18/19	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	Netherlands	16181745.7	12/21/10	3110231		3110231	5/2/18	Issued

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HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United States of America	14/020,425	9/6/13	US-2014-0079153-A1		8,824,595	9/2/14	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United States of America	14/335,647	7/18/14	US-2015-0080054-A1		9,048,797	6/2/15	Issued
HIGH EFFICIENCY, REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT SYSTEM AND METHOD FOR WIRELESS COMMUNICATIONS	United States of America	14/703,579	5/4/15	US-2015-0381217-A1		9,948,332	4/17/18	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	China	201180050053.9	8/16/11	CN 103180844 A	10/3/17	ZL 201180050053.9	10/3/17	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	11818694.9	8/16/11	2606435				Published
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	Indonesia	W00 201300982	8/16/11	2014/01150		IDP000048511	11/9/17	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	India	1764/CHENP/2013	8/16/11					Published
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	Japan	2013-524941	8/16/11	2013-541255		5911149	4/8/16	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2013-7006774	8/16/11			10-1662879	9/28/16	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	Macao	J/2833	8/16/11			J/002833	2/15/18	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/211,236	8/16/11	US-2012-0069880-A1		8,848,766	9/30/14	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	China	201710791641.7	8/16/11	CN 107682021A				Published

REMOTELY RECONFIGURABLE REMOTE RADIO HEAD UNIT	Hong Kong	18109794.9	8/16/11	1250427A	12/14/18			Published
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2016-7026899	8/16/11			10-1835254	2/27/18	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/479,875	9/8/14	US-2015-0055593-A1		9,826,508	11/21/17	Issued
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	15/786,396	10/17/17	US-2018-0184404-A1				Allowed
NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	16/406,252	5/8/19					Pending
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	China	201180050052.4	8/16/11	CN 103597807A		ZL 201180050052.4	9/30/15	Issued
REMOTELY CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	European Patent Office	11818695.6	8/16/11	2606571				Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Hong Kong	14106888.6	8/16/11	1193522A	8/12/16	HK1193522	8/12/16	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Indonesia	W00 201300983	8/16/11	2015/05508				Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	India	1763/CHENP/2013	8/16/11					Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Japan	2013-524942	8/16/11	2014-500635		5859538	12/25/15	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Republic of Korea	10-2013-7006776	8/16/11			10-1610447	4/1/16	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Macao	J/1934	8/16/11			J/001934	3/23/16	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	13/211,243	8/16/11	US-2012-0039320-A1		8,682,338	3/25/14	Issued

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SYSTEM FOR TRANSMITTING SIGNALS AND DISTRIBUTED ANTENNA SYSTEM	China	201510502030.7	8/16/11	CN 105208083A	9/21/18	ZL 201510502030.7	9/21/18	Issued
SYSTEM FOR TRANSMITTING SIGNALS AND DISTRIBUTED ANTENNA SYSTEM	Hong Kong	16105628.1	8/16/11	1217583A	1/13/17			Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Japan	2018-124665	8/16/11					Pending
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Macao	J/3488	8/16/11					Pending
REMOTELY RECONFIGUREABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	14/169,719	1/31/14	US-2014-0286247-A1		9,419,714	8/16/16	Issued
A METHOD OF OPERATING A DISTRIBUTED ANTENNA SYSTEM AND A METHOD OF COMMUNICATING IN THE SYSTEM	China	201510531485.1	8/16/11	CN 105141513A	12/14/18	ZL 201510531485.1	12/14/18	Issued
METHOD FOR OPERATING A DISTRIBUTED ANTENNA SYSTEM AND METHOD OF COMMUNICATING IN THE SYSTEM	Hong Kong	16105230.1	8/16/11	1217385A	1/6/17			Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Japan	2015-245373	8/16/11			6144327	5/19/17	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Republic of Korea	10-2015-7024302	8/16/11			10-1829517	2/8/18	Issued
A METHOD OF OPERATING A DISTRIBUTED ANTENNA SYSTEM AND A METHOD OF COMMUNICATING IN THE SYSTEM	Macao	J/3540	8/16/11					Pending
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	14/949,405	11/23/15	US-2016-0080082-A1		9,531,473	12/27/16	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Japan	2017-094314	8/16/11		7/25/18	6364109	7/6/18	Issued

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REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	Republic of Korea	10-2018-7003797	8/16/11	20180017234				Published
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	15/205,820	7/8/16	US-2017-0070897-A1		9,820,171	11/14/17	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	15/391,408	12/27/16	US-2017-0238318-A1		10,159,074	12/18/18	Issued
REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS	United States of America	16/175,520	10/30/18					Pending
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	China	201180050066.6	8/16/11	CN 103201958A	1/18/17	ZL 201180050066.6	1/18/17	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	11818697.2	8/16/11	2606576				Published
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Indonesia	W00 201300670	8/16/11					Pending
DAISY CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	India	1856/CHENP/2013	8/16/11					Published
DAISY CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Japan	2013-525983	8/16/11	2013-541875		6005646	9/16/16	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIDUTED ANTENNA SYSTEM	Republic of Korea	10-2013-7006775	8/16/11			10-1874655	6/28/18	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Macao	J/2551	8/16/11			J/002551	6/9/17	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/211,247	8/16/11	US-2012-0039254-A1		8,737,300	5/27/14	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/913,207	6/7/13	US-2013-0272202-A1		9,148,324	9/29/15	Issued
DAISY-CHAINED RING OF REMOTE UNITS	China	201611139142.1	8/16/11	CN 106921549A				Published

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DAISY-CHAINED RING OF REMOTE UNITS	Hong Kong	17112719.6	8/16/11	1238815A	5/4/18			Published
DAISY-CHAINED RING OF REMOTE UNITS	Macao							Unfiled
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/260,145	4/23/14	US-2014-0313884-A1		9,137,078	9/15/15	Issued
A METHOD OF COMMUNICATING IN A DISTRIBUTED ANTENNA SYSTEM	China	201610011597.9	8/16/11	CN105634585A				Allowed
A METHOD OF COMMUNICATING IN A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	16112531.3	8/16/11	1224444A	8/18/17			Published
A METHOD AND SYSTEM FOR ROUTING AND SWITCHING SIGNALS	Indonesia	P00201801237	8/16/11					Pending
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Japan	2016-139702	8/16/11			6405342	9/21/18	Issued
A METHOD OF COMMUNICATING IN A DISTRIBUTED ANTENNA SYSTEM	Macao							Unfiled
DISTRIBUTED ANTENNA SYSTEM	United States of America	14/800,515	7/15/15	US-2016-0014782-A1		9,419,837	8/16/16	Issued
TRANSPORT OF WIRELESS COMMUNICATIONS	China	201611138820.2	8/16/11	CN 106850735A				Published
WIRELESS COMMUNICATION TRANSMISSION	Hong Kong	17111546.7	8/16/11	1238016A	4/20/18			Published
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Indonesia	P00201703225	8/16/11	2018/00031				Published
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Japan	2016-174930	8/16/11			6463707	1/11/19	Issued
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2018-7018518	8/16/11	20180078335		10-1947975	2/7/19	Issued
TRANSPORT OF WIRELESS COMMUNICATIONS	Macao							Unfiled
DISTRIBUTED ANTENNA SYSTEM	United States of America	15/223,819	7/29/16	US-2017-0055198-A1		10,080,178	9/18/18	Issued

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DIGITAL REMOTE UNITS IN A DISTRIBUTED ANTENNA SYSTEM	China	201611138760.4	8/16/11	CN 107018055A				Published
DIGITAL REMOTE UNIT IN DISTRIBUTED ANTENNA SYSTEM	Hong Kong	17113376.8	8/16/11	1239987A	5/11/18			Published
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Japan	2019-000096	8/16/11					Pending
DAISY-CHAINED RING OF REMOTE UNITS FOR A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2019-7003593	8/16/11	20190015636				Published
DIGITAL REMOTE UNITS IN A DISTRIBUTED ANTENNA SYSTEM	Macao							Unfiled
DISTRIBUTED ANTENNA SYSTEM	United States of America	16/059,434	8/9/18	US-2019-0110239-A1				Allowed
TRANSPORT OF WIRELESS COMMUNICATIONS	China	201611139152.5	8/16/11	CN 107104869A				Published
WIRELESS COMMUNICATION TRANSMISSION	Hong Kong	18100385.3	8/16/11	1241165A	6/1/18			Published
TRANSPORT OF WIRELESS COMMUNICATIONS	Macao							Unfiled
DISTRIBUTED ANTENNA SYSTEM	United States of America	16/410,860	5/13/19					Pending
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	China	201280042828.2	9/4/12	CN 103999436A	8/24/16	ZL 201280042828.2	8/24/16	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	European Patent Office	12827424.8	9/4/12	2749123				Published
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	Hong Kong	15101013.4	9/4/12	1200622A	10/20/17	HK1200622	10/20/17	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	Macao	J/2359	9/4/12			J/002359	2/14/17	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	United States of America	13/602,818	9/4/12	US-2014-0072064-A1		8,817,848	8/26/14	Issued

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SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	United States of America	14/333,277	7/16/14	US-2015-0078471-A1		9,148,203	9/29/15	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR REDUCING UPLINK NOISE	United States of America	14/831,626	8/20/15	US-2015-0358054-A1		9,954,585	4/24/18	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	China	201280045910.0	9/24/12	CN 103858337A	5/3/17	ZL 201280045910.0	5/3/17	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Hong Kong	14109157.4	9/24/12	1195829A	4/27/18	HK1195829	4/27/18	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Japan	2014-532074	9/24/12	2014-526863		6080854	1/27/17	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Republic of Korea	10-2014-7010583	9/24/12					Allowed
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	Macao	J/1529	9/24/12			J/001529	6/23/17	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	13/625,760	9/24/12	US-2013-0077713-A1		8,873,674	10/28/14	Issued

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SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	14/480,267	9/8/14	US-2014-0376661-A1		9,197,259	11/24/15	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	14/918,371	10/20/15	US-2016-0191087-A1		10,256,853	4/9/19	Issued
SYSTEM AND METHOD FOR INCREASING BANDWIDTH FOR DIGITAL PREDISTORTION IN MULTI-CHANNEL WIDEBAND COMMUNICATION SYSTEMS	United States of America	16/279,535	2/19/19					Pending
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR BANDWIDTH COMPRESSION AND TRANSPORT OF SIGNALS IN NONCONTIGUOUS FREQUENCY BLOCKS	United States of America	13/686,036	11/27/12	US-2014-0010168-A1		8,724,664	5/13/14	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR BANDWIDTH COMPRESSION AND TRANSPORT OF SIGNALS IN NONCONTIGUOUS FREQUENCY BLOCKS	United States of America	14/225,673	3/26/14	US-2014-0206282-A1		9,236,897	1/12/16	Issued
SOFTWARE CONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHOD FOR BANDWIDTH COMPRESSION AND TRANSPORT OF SIGNALS IN NONCONTIGUOUS FREQUENCY BLOCKS	United States of America	14/960,177	12/4/15	US-2016-0226784-A1		9,722,939	8/1/17	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United Arab Emirates	471/2014	11/6/12					Pending
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Australia	2012336027	11/6/12		4/13/17	2012336027	7/28/17	Issued

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SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Brazil	BR 11 2014 010895 1	11/6/12					Pending
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	China	201280066105.6	11/6/12	CN 104040368A	8/22/17	ZL 201280066105.6	8/22/17	Issued
RESOURCE ALLOCATION IN A DISTRIBUTED ANTENNA SYSTEM	Germany	12847270.1	11/6/12	EP 2776857 A1		60 2012 047 724.5	6/20/18	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Eurasian Patent Office	201400556	11/6/12					Pending
RESOURCE ALLOCATION IN A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	12847270.1	11/6/12	EP 2776857 A1	6/20/18	2776857	6/20/18	Issued
RESOURCE ALLOCATION IN A DISTRIBUTED ANTENNA SYSTEM	France	12847270.1	11/6/12	EP 2776857 A1		2776857	6/20/18	Issued
RESOURCE ALLOCATION IN A DISTRIBUTED ANTENNA SYSTEM	United Kingdom	12847270.1	11/6/12	EP 2776857 A1		2776857	6/20/18	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Hong Kong	15101263.1	11/6/12	1200916A	7/13/18	HK1200916	7/13/18	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Indonesia	P00 2014 03239	11/6/12	2015/04205				Published
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Israel	232439	11/6/12		4/30/19			Pending
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	India	4237/CHENP/2014	11/6/12					Published
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Japan	2014-540195	11/6/12	2014-534783		6101277	3/3/17	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2014-7015429	11/6/12					Pending
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Macao	J/2816	11/6/12			J/002816	2/12/18	Issued
RESOURCE ALLOCATION IN A DISTRIBUTED ANTENNA SYSTEM	Netherlands	12847270.1	11/6/12	EP 2776857 A1		2776857	6/20/18	Issued

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SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Singapore	11201402105S	11/6/12			11201402105S	7/26/16	Issued
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	13/670,162	11/6/12	US-2013-0114963-A1				Published
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Australia	2017204786	11/6/12					Pending
SOFT HAND-OFF AND ROUTING DATA IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	China	201710619658.4	11/6/12	CN 107529172A				Published
SOFT HAND-OFF IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	European Patent Office	18178591.6	11/6/12	3445078				Published
SOFT HAND-OFF AND ROUTING DATA IN VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Hong Kong	18106058.6	11/6/12	1247019A	9/14/18			Published
VIRTUALIZED WIRELESS NETWORK	United Arab Emirates	472/2014	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	Australia	2012336026	11/6/12		7/21/16	2012336026	11/3/16	Issued
VIRTUALIZED WIRELESS NETWORK	Brazil	11 2014 011034 4	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	China	201280066289.6	11/6/12	CN 104081795B	12/21/18	ZL 201280066289.6	12/21/18	Issued
VIRTUALIZED WIRELESS NETWORK	Eurasian Patent Office	201400555	11/6/12	201400555				Published
VIRTUALIZED WIRELESS NETWORK	European Patent Office	12848304.7	11/6/12	EP 2777302				Published
VIRTUALIZED WIRELESS NETWORK	Hong Kong	15102186.3	11/6/12	1202012A	9/11/15			Published
VIRTUALIZED WIRELESS NETWORK	Indonesia	P00 2014 03237	11/6/12	2015/03305				Allowed
VIRTUALIZED WIRELESS NETWORK	Israel	232438	11/6/12			232438	7/31/18	Issued
VIRTUALIZED WIRELESS NETWORK	India	4232/CHENP/2014	11/6/12	2014CN04232				Published
VIRTUALIZED WIRELESS NETWORK	Japan	2014-540194	11/6/12	2015-505427		6158818	6/16/17	Issued
VIRTUALIZED WIRELESS NETWORK	Republic of Korea	10-2014-7015432	11/6/12					Pending

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VIRTUALIZED WIRELESS NETWORK	Macao	J/1714	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	Malaysia	PI 2014001321	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	Singapore	11201402104T	11/6/12			11201402104T	2/2/18	Issued
VIRTUALIZED WIRELESS NETWORK	United States of America	13/670,290	11/6/12	US-2013-0128810-A1		10,264,626	4/16/19	Issued
VIRTUALIZED WIRELESS NETWORK	China	201811416669.3	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	Japan	2017-113169	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK	Singapore	10201800761X	11/6/12	10201800761X				Published
VIRTUALIZED WIRELESS MESH NETWORK	United States of America	15/857,356	12/28/17	US-2018-0249532-A1				Published
VIRTUALIZED WIRELESS NETWORK	Australia	2018247240	11/6/12					Pending
VIRTUALIZED WIRELESS NETWORK WITH PILOT BEACONS	United States of America	13/671,203	11/7/12	US-2013-0114486-A1		9,420,628	8/16/16	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Brazil	BR 11 2014 018841 6	1/31/13					Pending
A SYSTEM FOR ROUTING SIGNALS IN A DISTRIBUTED ANTENNA SYSTEM	China	201380007517.7	1/31/13	CN 104221293A	2/22/17	ZL 201380007517.7	2/22/17	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	European Patent Office	13744144.0	1/31/13	2 810 373				Published
SYSTEM FOR ROUTING SIGNALS IN A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	15104338.6	1/31/13	1204164A	3/29/18	HK1204164	3/29/18	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Israel	233785	1/31/13					Pending
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	India	5859/CHENP/2014	1/31/13	2014CN05859				Published
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Japan	2014-554989	1/31/13			6193265	8/18/17	Issued

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DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2014-7024349	1/31/13					Pending
A SYSTEM FOR ROUTING SIGNALS IN A DISTRIBUTED ANTENNA SYSTEM	Macao	J/2563	1/31/13			J/002563	6/23/17	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	13/754,702	1/30/13	US-2014-0037292-A1		9,025,956	5/5/15	Issued
DATA TRANSMISSION IN VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Hong Kong	17113429.5	1/31/13	1239969A	5/11/18			Published
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Japan	2017-154789	1/31/13					Pending
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	14/678,779	4/3/15	US-2015-0326957-A1		9,621,971	4/11/17	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	15/445,467	2/28/17	US-2017-0303019-A1		10,051,350	8/14/18	Issued
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	16/039,182	7/18/18	US-2019-0082243-A1				Published
FREQUENCY TRANSLATION IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	13/753,288	1/29/13	US-2014-0036770-A1		9,723,612	8/1/17	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Brazil	BR 11 2014 020305 9	2/19/13					Pending
METHODS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	China	201380009723.1	2/19/13	CN104160725A	5/1/18	ZL 201380009723.1	5/1/18	Issued
EVOLUTIONARY ALOGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Germany	13749837.4	2/19/13	2815591		60 2013 025 498.2	8/23/17	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	13749837.4	2/19/13	2815591	8/23/17	2815591	8/23/17	Issued

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EVOLUTIONARY ALOGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	France	13749837.4	2/19/13	2815591		2815591	8/23/17	Issued
EVOLUTIONARY ALOGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	United Kingdom	13749837.4	2/19/13	2815591		2815591	8/23/17	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	15103517.1	2/19/13	1203022A	10/9/15			Published
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Israel	233975	2/19/13		4/30/18	233975	7/31/18	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	India	6777/DELNP/2014	2/19/13	2014DN06777				Published
DATA TRANSPORT IN A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	Japan	2014-557866	2/19/13			6320939	4/13/18	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2014-7025637	2/19/13					Pending
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	Macao	J/3166	2/19/13			J/003166	10/9/18	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/770,113	2/19/13	US-2014-0057627-A1		9,148,839	9/29/15	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA	European Patent Office	17185342.7	2/19/13	3258722				Published

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EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/837,850	8/27/15	US-2016-0073313-A1		9,854,494	12/26/17	Issued
EVOLUTIONARY ALGORITHMS FOR GEOGRAPHIC LOAD BALANCING USING A DISTRIBUTED ANTENNA SYSTEM	United States of America	15/782,309	10/12/17	US-2018-0160356-A1				Published
HYBRID DATA TRANSPORT FOR A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	13/777,185	2/26/13	US-2014-0072299-A1		9,537,572	1/3/17	Issued
HYBRID DATA TRANSPORT FOR A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	15/383,121	12/19/16	US-2017-0104538-A1		10,063,319	8/28/18	Issued
HYBRID DATA TRANSPORT FOR A VIRTUALIZED DISTRIBUTED ANTENNA SYSTEM	United States of America	16/054,678	8/3/18	US-2019-0036606-A1				Published
METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/894,309	5/14/13	US-2014-0233468-A1		9,197,358	11/24/15	Issued
METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/887,922	10/20/15	US-2016-0113014-A1		9,538,536	1/3/17	Issued
METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	15/383,431	12/19/16	US-2017-0230836-A1		9,942,771	4/10/18	Issued
METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	15/912,859	3/6/18	US-2018-0332477-A1				Allowed
METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM	United States of America							Unfiled
SELF-OPTIMIZING DISTRIBUTED ANTENNA SYSTEM USING SOFT FREQUENCY REUSE	United States of America	13/935,157	7/3/13	US-2014-0161057-A1		9,363,768	6/7/16	Issued
SELF-OPTIMIZING DISTRIBUTED ANTENNA SYSTEM USING SOFT FREQUENCY REUSE	United States of America	15/154,073	5/13/16	US-2017-0013568-A1		9,769,766	9/19/17	Issued
SELF-OPTIMIZING DISTRIBUTED ANTENNA SYSTEM USING SOFT FREQUENCY REUSE	United States of America	15/676,631	8/14/17	US-2018-0092045-A1				Allowed

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METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Brazil	BR 11 2015 001348 1	7/18/13					Pending
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	China	201380039353.6	7/18/13	CN 104584501A				Allowed
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	European Patent Office	13823723.5	7/18/13	2875620				Published
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Hong Kong	15108803.3	7/18/13	1208291A	2/26/16			Published
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Israel	236619	7/18/13		8/30/18	236619	12/1/18	Issued
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	India	211/CHENP/2015	7/18/13	2015CN00211				Published
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Japan	2015-524332	7/18/13	2015-525036				Allowed

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METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Republic of Korea	10-2015-7004064	7/18/13					Pending
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Macao							Unfiled
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	United States of America	13/945,736	7/18/13	US-2014-0159810-A1		9,225,296	12/29/15	Issued
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	Israel	259447	7/18/13					Pending
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	United States of America	14/956,040	12/1/15	US-2016-0344351-A1		10,263,569	4/16/19	Issued
METHOD AND SYSTEM FOR ALIGNING SIGNALS WIDELY SPACED IN FREQUENCY FOR WIDEBAND DIGITAL PREDISTORTION IN WIRELESS COMMUNICATION SYSTEMS	United States of America	16/352,065	3/13/19					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	United Arab Emirates	125/2015	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Australia	2013296819	7/26/13		8/31/17	2013296819	12/18/17	Issued

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OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Brazil	BR 11 2015 001916 1	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	China	201380040757.7	7/26/13	CN 104956732B	4/30/19	ZL 201380040757.7	4/30/19	Issued
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Eurasian Patent Office	201500184	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	13825612.8	7/26/13	2880888				Published
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	16101919.8	7/26/13	1214067A	7/15/16			Published
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Indonesia	P00201500998	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Israel	236631	7/26/13			236631	12/1/18	Issued
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	India	244/CHENP/2015	7/26/13					Published
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Japan	2015-525473	7/26/13		8/15/18	6373837	7/27/18	Issued
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2015-7004047	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Macao							Unfiled
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Malaysia	PI 2015000254	7/26/13					Pending
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Singapore	11201500770U	7/26/13			11201500770U	5/22/17	Issued
OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/950,160	7/24/13	US-2014-0162664-A1				Published

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OPTIMIZATION OF TRAFFIC LOAD IN A DISTRIBUTED ANTENNA SYSTEM	Australia	2017268613	7/26/13					Pending
A SYSTEM FOR DYNAMICALLY ROUTING SIGNALS	China	201910237775.3	7/26/13					Pending
TIME SYNCHRONIZED ROUTING IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	13/960,346	8/6/13	US-2014-0162713-A1		9,439,242	9/6/16	Issued
TIME SYNCHRONIZED ROUTING IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	15/251,293	8/30/16	US-2017-0118734-A1		10,045,314	8/7/18	Issued
TIME SYNCHRONIZED ROUTING IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	16/038,613	7/18/18	US-2019-0082407-A1				Published
POWER AMPLIFIER PROTECTION USING A CYCLIC REDUNDANCY CHECK ON THE DIGITAL TRANSPORT OF DATA	United States of America	14/095,706	12/3/13	US-2014-0223266-A1		9,559,806	1/31/17	Issued
DAS INTEGRATED DIGITAL OFF-AIR REPEATER	United States of America	14/044,668	10/2/13	US-2014-0169263-A1		9,112,549	8/18/15	Issued
DAS INTEGRATED DIGITAL OFF-AIR REPEATER	United States of America	14/743,789	6/18/15	US-2016-0007264-A1		9,622,148	4/11/17	Issued
DAS INTEGRATED DIGITAL OFF-AIR REPEATER	United States of America	16/230,253	12/21/18					Pending
WIDE BANDWIDTH DIGITAL PREDISTORTION SYSTEM WITH REDUCED SAMPLING RATE	United States of America	13/777,194	2/26/13	US-2014-0241461-A1		8,913,689	12/16/14	Issued
WIDE BANDWIDTH DIGITAL PREDISTORTION SYSTEM WITH REDUCED SAMPLING RATE	United States of America	14/552,231	11/24/14	US-2015-0180519-A1		9,258,022	2/9/16	Issued
WIDE BANDWIDTH DIGITAL PREDISTORTION SYSTEM WITH REDUCED SAMPLING RATE	United States of America	14/987,093	1/4/16	US-2016-0261294-A1		9,673,848	6/6/17	Issued
WIDE BANDWIDTH DIGITAL PREDISTORTION SYSTEM WITH REDUCED SAMPLING RATE	United States of America	15/492,902	4/20/17	US-2017-0353199-A1		10,218,392	2/26/19	Issued
WIDE BANDWIDTH DIGITAL PREDISTORTION SYSTEM WITH REDUCED SAMPLING RATE	United States of America	16/240,433	1/4/19					Pending
INDOOR LOCALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	14/168,328	1/30/14	US-2014-0313075-A1		9,671,496	6/6/17	Issued

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INDOOR LOCALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	15/582,776	5/1/17	US-2017-0363743-A1		10,180,497	1/15/19	Issued
INDOOR LOCALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	16/205,567	11/30/18					Pending
FEEDBACK BASED INDOOR LOCALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	14/171,600	2/3/14	US-2014-0306841-A1		9,476,984	10/25/16	Issued
FEEDBACK BASED INDOOR LOCALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	15/279,136	9/28/16	US-2017-0146662-A1				Allowed
INDOOR LOCALIZATION USING ANALOG OFF-AIR ACCESS UNITS	United States of America	14/183,297	2/18/14	US-2014-0320340-A1				Published
METHOD AND SYSTEM FOR WI-FI DATA TRANSMISSION	United States of America	14/189,044	2/25/14	US-2014-0314061-A1		9,955,361	4/24/18	Issued
METHOD AND SYSTEM FOR WI-FI DATA TRANSMISSION	United States of America	15/907,153	2/27/18	US-2018-0324599-A1				Published
INDOOR TRILATERALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	14/199,617	3/6/14	US-2014-0313076-A1		9,958,548	5/1/18	Issued
INDOOR TRILATERALIZATION USING DIGITAL OFF-AIR ACCESS UNITS	United States of America	15/917,342	3/9/18	US-2018-0329068-A1				Published
REAL-TIME LOCATING SYSTEM USING GPS TIME DIFFERENCE OF ARRIVAL WITH DIGITAL OFF-AIR ACCESS UNITS AND REMOTE UNITS	United States of America	14/257,209	4/21/14	US-2014-0340255-A1		9,851,445	12/26/17	Issued
REAL-TIME LOCATING SYSTEM USING GPS TIME DIFFERENCE OF ARRIVAL WITH DIGITAL OFF-AIR ACCESS UNITS AND REMOTE UNITS	United States of America	15/819,279	11/21/17	US-2018-0239025-A1				Published
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Brazil	BR 11 2016 014197 0	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	China	201480069382.1	12/18/14	CN 105830373B	4/23/19	ZL 201480069382.1	4/23/19	Issued
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	European Patent Office	14872389.3	12/18/14	3084992				Published

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DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Hong Kong	17100236.5	12/18/14	1226878A				Published
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Indonesia	P00201604728	12/18/14	2017/10943				Published
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Israel	246210	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	India	201617023992	12/18/14					Published
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Japan	2016-541192	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Republic of Korea	10-2016-7019353	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Macao							Unfiled
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Malaysia	PI 2016001132	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Singapore	11201605002Q	12/18/14					Allowed
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	United States of America	14/574,071	12/17/14	US-2015-0207545-A1		9,847,816	12/19/17	Issued
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Australia	2019202190	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	China	201910227542.5	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	Singapore	10201904722T	12/18/14					Pending
DIGITAL TRANSPORT OF DATA OVER DISTRIBUTED ANTENNA NETWORK	United States of America	15/812,018	11/14/17	US-2018-0212650-A1				Allowed

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NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Brazil	BR 11 2016 015642 0	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	China	201580003669.9	1/6/15	CN 105874824A				Published
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	European Patent Office	15733064.8	1/6/15	3092832				Published
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Hong Kong	17100234.7	1/6/15	1226892A				Published
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Indonesia	P00 2016 05228	1/6/15	2017/10346				Published
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Israel	246326	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	India	201617024698	1/6/15					Published
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Japan	2016-562732	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Republic of Korea	10-2016-7020351	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Malaysia	PI 2016001173	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Singapore	11201605464T	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	United States of America	14/590,447	1/6/15	US-2015-0303999-A1				Allowed
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Australia	2019202185	1/6/15					Pending
NETWORK SWITCH FOR A DISTRIBUTED ANTENNA NETWORK	Singapore	10201805615W	1/6/15	10201805615W				Published

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DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/580,585	12/23/14	US-2015-0303998-A1				Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Brazil	BR 11 2016 014663 8	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	China	201480070750.4	12/23/14	CN 105917675A				Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	14874737.1	12/23/14	3087762				Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	17100988.5	12/23/14	1227599A				Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Indonesia	P00201604818	12/23/14	2017/09815				Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Israel	246242	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	India	201617024316	12/23/14					Published
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Japan	2016-560881	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2016-7020070	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Malaysia	PI 2016001159	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Singapore	11201605115V	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	United States of America							Unfiled
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Australia	2019202115	12/23/14					Pending
DIGITAL MULTIPLEXER IN A DISTRIBUTED ANTENNA SYSTEM	Singapore	10201805212Y	12/23/14	10201805212Y				Published
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Australia	2015218375	2/13/15					Pending
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Switzerland	15749690.2	2/13/15	3105968		3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	China	201580008198.0	2/13/15	CN 105993139A				Published

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SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Germany	15749690.2	2/13/15	3105968		602015020944.3	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	European Patent Office	15749690.2	2/13/15	3105968	12/5/18	3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Spain	15749690.2	2/13/15	3105968		3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	France	15749690.2	2/13/15	3105968		3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	United Kingdom	15749690.2	2/13/15	3105968		3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Hong Kong	17102313.7	2/13/15	1229081A	11/10/17			Published
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Japan	2016-551758	2/13/15					Pending
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Macao							Unfiled
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	Netherlands	15749690.2	2/13/15	3105968		3105968	12/5/18	Issued
SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	United States of America	14/621,192	2/12/15	US-2015-0304044-A1		10,284,296	5/7/19	Issued

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SYSTEM AND METHOD FOR PERFORMANCE OPTIMIZATION IN AND THROUGH A DISTRIBUTED ANTENNA SYSTEM	United States of America	16/360,980	3/21/19					Pending
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Australia	2015227155	3/5/15					Pending
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Brazil	BR 11 2016 020285 6	3/5/15					Pending
DISTRIBUTED ANTENNA SYSTEM WITH REMOTE RADIO HEADS	China	201580011639.2	3/5/15	CN 106170932A				Allowed
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	European Patent Office	15758873.2	3/5/15	3114780				Published
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Hong Kong	17104046.7	3/5/15	1230802A	12/8/17			Published
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Israel	247415	3/5/15					Pending
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	India	201617029173	3/5/15	201617029173				Published
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Japan	2016-555465	3/5/15					Pending
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Republic of Korea	10-2016-7027525	3/5/15					Pending
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	Macao							Unfiled
DISTRIBUTED RADIO SYSTEM WITH REMOTE RADIO HEADS	United States of America	14/639,418	3/5/15	US-2015-0256358-A1				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Australia	2016244115	4/4/16	2016244115				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Brazil	BR1120170211440	4/4/16					Pending
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	China	201680030803.9	4/4/16	CN 107850631 A				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	European Patent Office	16774416.8	4/4/16	3278122				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Hong Kong	18106961.2	4/4/16					Pending

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METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Indonesia	PID201707729	4/4/16	2018/05650				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	India	201717038921	4/4/16	201717038921				Published
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Japan	2017-551651	4/4/16					Pending
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE TDD ARCHITECTURE	Republic of Korea	10-2017-7032015	4/4/16					Pending
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Macao							Unfiled
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	Singapore	11201708119W	4/4/16					Pending
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	United States of America	15/090,402	4/4/16	US-2016-0360500-A1		9,854,553	12/26/17	Issued
METHOD AND SYSTEM FOR LINK SYNCHRONIZATION IN AN LTE-TDD ARCHITECTURE	United States of America	15/820,299	11/21/17	US-2018-0227870-A1				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Australia	2016289947	7/6/16	2016289947				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Brazil	BR 11 2018 000161 9	7/6/16					Pending
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	China	201680051423.3	7/6/16	CN 108450059 A				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	European Patent Office	16821901.2	7/6/16	3320369				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Hong Kong	18113025.2	7/6/16					Pending
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Israel	256721	7/6/16					Pending
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	India	201817003865	7/6/16	201817003865				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Japan	2018-500520	7/6/16	2018524929				Published
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Republic of Korea	10-2018-7003658	7/6/16					Pending

CommScope Ex. 1002

DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Macao							Unfiled
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	Singapore	11201800110P	7/6/16					Pending
DISTRIBUTED ANTENNA SYSTEM NETWORK ANALYTICS	United States of America	15/203,015	7/6/16	US-2017-0013585-A1				Published
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	Australia	2016357315	11/21/16	2016357315				Published
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	China	2016800795294	11/21/16	CN 108604912 A				Published
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	European Patent Office	16867324.2	11/21/16	3378167				Published
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	Hong Kong	18113803.0	11/21/16					Pending
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	Macao							Unfiled
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	Singapore	11201804193X	11/21/16					Pending
VIRTUAL RADIO ACCESS NETWORK USING SOFTWARE-DEFINED NETWORK OF REMOTES AND DIGITAL MULTIPLEXING SWITCHES	United States of America	15/358,060	11/21/16	US-2017-0250927-A1				Published

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REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	Australia	2017261802	5/12/17					Pending
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	China	2017800434163	5/12/17					Pending
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	European Patent Office	17796989.6	5/12/17	3456115				Published
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	Japan	2018-559301	5/12/17					Pending
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	Republic of Korea	10-2018-7035997	5/12/17					Pending
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	Singapore	11201809610Y	5/12/17					Pending
REDUNDANCY IN A PUBLIC SAFETY DISTRIBUTED ANTENNA SYSTEM	United States of America	15/594,323	5/12/17	US-2017-0366268-A1				Published

CommScope Ex. 1002

PTO/AIA/80 (07-17)
Approved for use through 03/31/2021. OMB 0651-0035
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

[X] Practitioners associated with Customer Number: 167137

OR

[ ] Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number	Name	Registration Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73(c).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(c) to:

[X] The address associated with Customer Number: 167137

OR

[ ]

Firm or Individual name		
Address		
City	State	Zip
Country		
Telephone	Email	

Assignee name and address: Dali Systems Co. Ltd.
No. 309 Ugland House, South Church Street, George Town
Grand Cayman KY1-1104, Cayman Islands

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/AIA/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of the practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee.

Signature	Date December 13, 2019
Name Albert Lee, Ph.D.	Telephone
Title Founder, Chairman and Chief Executive Officer	

This collection of information is required by 37 CFR 1.31, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public, which is to update (and by the USPTO to process) the file of a patent or reexamination proceeding. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 18 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Electronic Acknowledgement Receipt	
EFS ID:	38533557
Application Number:	13894309
International Application Number:	
Confirmation Number:	4407
Title of Invention:	METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM
First Named Inventor/Applicant Name:	Seyed Amin Hejazi
Customer Number:	27076
Filer:	Jason Vick/Joanne Vos
Filer Authorized By:	Jason Vick
Attorney Docket Number:	91172-866895(103600US)
Receipt Date:	09-FEB-2020
Filing Date:	14-MAY-2013
Time Stamp:	17:51:10
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Statement_Under_373c_w_POA_10333-38.pdf	234699 d0c5e6a58a796579e41c1ab6e5e1c30425668b1b	yes	3

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Assignee showing of ownership per 37 CFR 3.73	1	2
	Power of Attorney	3	3
Warnings:			
Information:			
	Total Files Size (in bytes):	234699	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
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STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: DALI SYSTEMS CO. LTD.

Application No./Patent No.: 13/894,309 Filed/Issue Date: May 14, 2013

Titled: METHOD AND SYSTEM FOR SOFT FREQUENCY REUSE IN A DISTRIBUTED ANTENNA SYSTEM

DALI SYSTEMS CO. LTD., a Corporation

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose **one** of options 1, 2, 3 or 4 below):

1. ☑ The assignee of the entire right, title, and interest.

2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

   ☐ The extent (by percentage) of its ownership interest is _____%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

   ☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose **one** of options A or B below):

A. ☑ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 044711, Frame 0319, or for which a copy thereof is attached.

B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

   1. From: _____ To: _____

      The document was recorded in the United States Patent and Trademark Office at

      Reel _____, Frame _____, or for which a copy thereof is attached.

   2. From: _____ To: _____

      The document was recorded in the United States Patent and Trademark Office at

      Reel _____, Frame _____, or for which a copy thereof is attached.

This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

4. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

5. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

6. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Jason H. Vick/	February 9, 2020
Signature	Date
Jason H. Vick	45,285
Printed or Typed Name	Title or Registration Number

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

27076
DORSEY & WHITNEY LLP - SEATTLE
INTELLECTUAL PROPERTY DEPARTMENT
COLUMBIA CENTER
701 FIFTH AVENUE, SUITE 6100
SEATTLE, WA 98104-7043

POWER OF ATTORNEY NOTICE

OC000000114644260

Date Mailed: 02/12/2020

NOTICE REGARDING CHANGE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 02/09/2020.

- The Power of Attorney to you in this application has been revoked by the applicant. Future correspondence will be mailed to the new address of record(37 CFR 1.33).

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/sleutchit/

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/894,309	05/14/2013	Seyed Amin Hejazi	91172-866895(103600US)

CONFIRMATION NO. 4407

POA ACCEPTANCE LETTER

167137
SHERIDAN ROSS PC
1560 Broadway
Suite 1200
Denver, CO 80202

OC000000114644276

Date Mailed: 02/12/2020

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 02/09/2020.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/sleutchit/

AO 120 (Rev. 08/10)

TO:	REPORT ON THE FILING OR DETERMINATION OF AN ACTION REGARDING A PATENT OR TRADEMARK
Mail Stop 8 Director of the U.S. Patent and Trademark Office P.O. Box 1450 Alexandria, VA 22313-1450	

In Compliance with 35 U.S.C. § 290 and/or 15 U.S.C. § 1116 you are hereby advised that a court action has been filed in the U.S. District Court Eastern District of Texas on the following

☐ Trademarks or ☑ Patents. (☐ the patent action involves 35 U.S.C. § 292.):

DOCKET NO.	DATE FILED	U.S. DISTRICT COURT
2:22-cv-12	1/7/2022	Eastern District of Texas

PLAINTIFF	DEFENDANT
DALI WIRELESS, INC.	AT&T CORP., et al

	PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1	8,682,338	3/25/2014	Dali Wireless, Inc.
2	9,197,358	11/24/2015	Dali Wireless, Inc.
3	11,026,232	6/1/2021	Dali Wireless, Inc.
4	10,334,499	6/25/2019	Dali Wireless, Inc.
5			

In the above---entitled case, the following patent(s)/ trademark(s) have been included:

DATE INCLUDED	INCLUDED BY ☐ Amendment ☐ Answer ☐ Cross Bill ☐ Other Pleading	
PATENT OR TRADEMARK NO.	DATE OF PATENT OR TRADEMARK	HOLDER OF PATENT OR TRADEMARK
1		
2		
3		
4		
5		

In the above---entitled case, the following decision has been rendered or judgement issued:

DECISION/JUDGEMENT

CLERK	(BY) DEPUTY CLERK	DATE

Copy 1---Upon initiation of action, mail this copy to Director Copy 3---Upon termination of action, mail this copy to Director
Copy 2---Upon filing document adding patent(s), mail this copy to Director Copy 4---Case file copy