

**IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION**

DALI WIRELESS, INC.,	)	
	)	
Plaintiff,	)	
	)	Case No. 2:22-cv-00012-RWS-RSP
v.	)	
	)	
AT&T CORP., AT&T COMMUNICATIONS	)	
LLC, AT&T MOBILITY, AT&T MOBILITY	)	
II LLC, AT&T SERVICES INC., ERICSSON	)	
INC., TELEFONAKTIEBOLAGET LM	)	
ERICSSON, COMMSCOPE HOLDING	)	
COMPANY, INC., COMMSCOPE INC., and	)	
COMMSCOPE TECHNOLOGIES LLC,	)	
	)	
Defendants.	)	

DALI WIRELESS, INC.,	)	
	)	
Plaintiff,	)	Case No. 2:23-cv-00002-RWS-RSP
	)	
v.	)	
	)	
CELLCO PARTNERSHIP d/b/a	)	
VERIZON WIRELESS, VERIZON	)	
CORPORATE SERVICES GROUP INC.,	)	
VERIZON ONLINE LLC, COMMSCOPE	)	
HOLDING COMPANY, INC.,	)	
COMMSCOPE INC., and COMMSCOPE	)	
TECHNOLOGIES LLC,	)	
	)	
Defendants.	)	

**DALI WIRELESS, INC.'S OPENING
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I. INTRODUCTION

Plaintiff Dali Wireless Inc. (“Dali”) submits this Opening Claim Construction Brief in support of its proposed constructions for the claim terms in dispute for U.S. Patent Nos. 8,682,338 (the “’338 Patent”); 11,026,232 (the “’232 Patent”); 10,334,499 (the “’499 Patent”); and 11,006,343 (the “’343 Patent”) (collectively “the Asserted Patents”). Dali’s proposed constructions are supported by the intrinsic record and will assist the jury in understanding the proper meaning of the asserted claims, where necessary.

Defendants lean heavily on claim constructions issued in a prior litigation in the District of Delaware for the disputed terms of the ’338 Patent. However, the Delaware Court’s prior constructions should be rejected because they are internally inconsistent, contrary to the intrinsic evidence, and confusing to a lay factfinder. Defendants’ proposed constructions for the remaining three patents at issue—the ’343 Patent, ’499 Patent, and ’232 Patent—are divorced from the intrinsic evidence, alter the intended scope of the inventions, and, in at least one instance, are contrary to positions that Defendants have taken in co-pending IPRs.

II. BACKGROUND OF THE ASSERTED PATENTS

The ’338, ’232,¹ ’499, and ’343² Patents are directed to addressing the wireless capacity of radio units within a Distributed Antenna System (DAS). In a DAS, a host unit (or digital access unit) receives signals from a mobile network operator and distributes those signals to remote radio units (“RRUs”) placed in and around a building, where those radio units transmit the signals to and from handsets.

¹ The ’232 Patent issued from a continuation of a series of applications, the first of which led to the issuance of ’338 Patent. The two patents share the same disclosure.

² The ’343 Patent issued from a continuation of the application that led to the issuance of ’499 Patent. The two patents share the same disclosure.

Dali invented significant improvements to DAS technology, including addressing capacity issues inside a DAS. Consider a situation in which users gravitate to an office's cafeteria at lunchtime, thus overloading the radio units in the cafeteria. *See, e.g.*, '499 Patent, 6:21-30. The '499, '343, and '232 Patents, for example, claim systems and methods that provide additional radio resources to the cafeteria radio units so the additional lunchtime load can be handled without service interruption. *Id.* Dali's inventions in the Asserted Patents relate to such capacity improvements.

III. Common Terms

A. "radio resources" ('232 Patent, cls. 1, 3, 12, 14, 20; '499 Patent, cls. 1-4, 8-11, 13-16, 18, 19; '343 Patent, cls. 1, 12)

Plaintiff's Proposed Construction	Defendants' Proposed Construction
Plain and ordinary meaning where the plain and ordinary meaning includes RF carriers, CDMA codes, and TDMA time slots, but does not include the underlying data that is transmitted.	Plain and ordinary meaning where the plain and ordinary meaning includes RF carriers, CDMA codes, and TDMA time slots, but does not include the underlying data that is transmitted.
Note: when data is modulated on an RF carrier, the RF carrier is a radio resource, but the data modulated on the RF carrier is not a radio resource	Note: when data is modulated on an RF carrier, the RF carrier is a radio resource, but the data modulated on the RF carrier is not a radio resource.

Plaintiff agrees to adopt the construction by the Court in the co-pending Western District of Texas action *Dali Wireless, Inc. v. Cellco Partnership D/BA Verizon Wireless* that is proposed by Defendants here. *See* Claim Construction Order, Dkt. 31, *Dali Wireless, Inc. v. Cellco Partnership D/BA Verizon Wireless et al.*, Case No. 6:22-cv-01313-ADA (W.D. Tex. Feb. 2, 2023).

B. “is configured to” (’499 Patent, cls. 1, 8; ’343 Patent, cl. 1)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning, which requires being configured, not merely capable of being configured.	Plain and ordinary meaning, which requires being configured, not merely capable of being configured.

Plaintiff agrees to adopt the construction by the Court in the co-pending Western District of Texas action *Dali Wireless, Inc. v. Cellco Partnership D/BA Verizon Wireless et al.* that is proposed by Defendants here. *See* Claim Construction Order, Dkt. 31, *Dali Wireless, Inc. v. Cellco Partnership D/BA Verizon Wireless et al.*, Case No. 6:22-cv-01313-ADA (W.D. Tex. Feb. 2, 2023).

IV. U.S. PATENT NO. 11,026,232**A. “operator hub” (’232 Patent, cls. 1, 12, 20)**

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning	Plain and ordinary meaning, which does not include the one or more central nodes

Claim 1 recites “one or more central nodes that receive a number of a plurality of radio resources from an operator hub,” while claims 12 and 20 recite an operator hub but do not include reference to one or more central nodes. The parties appear to agree that the term “operator hub” should retain its plain and ordinary meaning. Defendants, however, attempt to further restrict the scope of the claim term by requiring that such plain meaning “does not include the one or more central nodes.”

First, there is no need for Defendants’ additional language in the construction. The plain language of claim 1 states that one or more central nodes receive radio resources from the operator hub. The claim language is clear on its face: there is a logical separation between the central nodes and the operator hub. A lay juror would have no difficulty understanding this. On the other hand, substituting the operator hub term with Defendants’ proposed definition makes

the claim confusing and redundant:

“one or more central nodes that receive a number of a plurality of radio resources from an operator hub [which does not include the one or more central nodes].”

See, e.g., TMI Prods. v. Rosen Entm't Sys., L.P., 610 F. App'x 968, 972 (Fed. Cir. 2015) (rejecting claim construction that creates redundancies in the claim language).

Second, Defendants appear to be arguing for something more than required by the claim. While there is no dispute that the central nodes and operator hub must be logically separate, nothing in the patent specification or file history disavows the possibility of the central node and operator hub being physically integrated as a single unit or housed together in a common enclosure. There is nothing in the intrinsic record that unequivocally states that these two elements must be physically separate. Thus, Defendants' imposition of a negative limitation is improper and should be rejected. *See Paltalk Holdings, Inc. v. Microsoft Corp.*, 2008 U.S. Dist. LEXIS 94462, at *49 (E.D. Tex. July 29, 2008) (citing *Omega Eng'g v. Raytek*, 334 F.3d 1314, 1323 (Fed. Cir. 2003)) (declining to import negative limitation in absence of clear disavowal).

B. “an operator hub . . . that provides the plurality of radio resources to a radio access network using the Common Public Radio Interface (CPRI) protocol” ('232 Patent, cl. 1)

Plaintiff's Proposed Construction	Defendants' Proposed Construction
Plain and ordinary meaning except as “radio resources” has been construed above	Plain and ordinary meaning. Note: the phrase “that provides the plurality of radio resources to a radio access network using the Common Public Radio Interface (CPRI) protocol” modifies “operator hub.”

Defendants contend this claim term should be read as the operator hub providing radio resources to a radio access network using the CPRI protocol. The intrinsic evidence, however, supports plain and ordinary reading of this term as the one or more central nodes providing the

radio resources to a radio access network using the CPRI protocol. For example, the specification states that “[o]ne such key function [of the DAU] is determining and/or setting the appropriate amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs.” ’232 Patent at 11:52-56. The patent also states that “[t]he DAUs [e.g., central nodes] and RRUs [remote radio units] frame the individual data packets corresponding to their respective radio signature using the Common Public Interface Standard (CPRI).” *Id.* at 9:13-15. In other words, the DAU or central nodes receive a number of a plurality of radio resources from an operator hub and then provide those radio resources to the remote radio units using the CPRI protocol.

Moreover, the Patent Examiner also read this claim term the same way. As shown below, in his discussion of the *Akman* reference, the Examiner read the claim of the ’232 Patent as the central nodes providing the radio resources to the radio access network using the CPRI protocol:

Akman et al. (US 2010/0075678) teaches Central nodes that enables wireless communications and that provides the plurality of radio resources to a radio access network using the Common Public Radio Interface (CPRI) protocol (Paragraphs 0004 and 0022). However, as a whole, none of the prior art cited alone or in combination provides the motivation to teach wherein one or more central nodes assigns a first subset of the number of the plurality of radio resources to the first access point and a second subset	of the number of the plurality of radio resources to the second access point, the first subset including more radio resources than the second subset, and wherein, in response to a change in need of a number of wireless subscribers coupled to the second access point, the one or more central nodes assign additional radio resources of the plurality of radio resources to the second access point.
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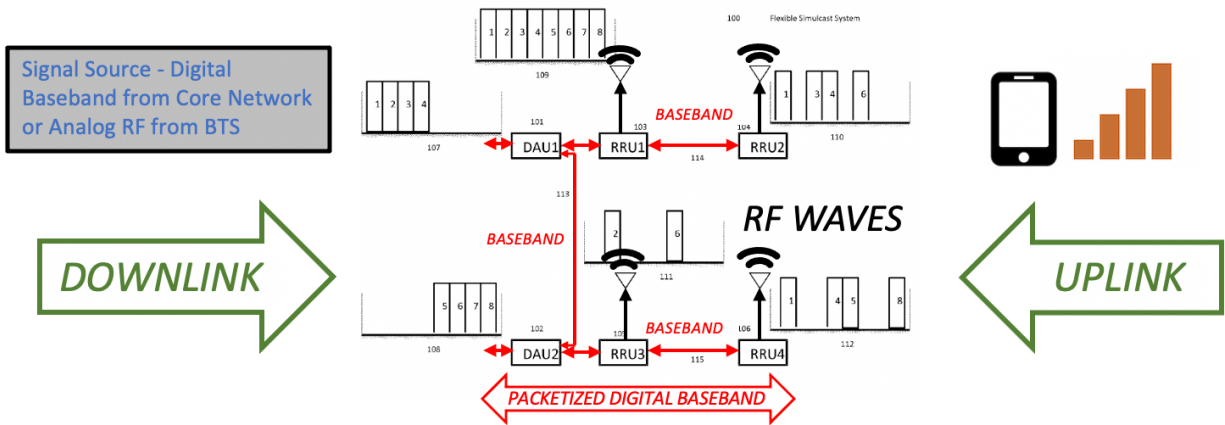
Dali Wireless, Inc. v. Cellco Partnership d/b/a Verizon Wireless et al., Case No. 2:23-cv-00002-RWS-RSP, Dkt. 76-1 (Excerpted ’232 File History) at 2-3 (highlighting added). Thus, this claim term should be construed in accordance with the understanding of a POSITA reading the claim in light of the specification, which is that the one or more central nodes provides the radio resources to a radio access network using the CPRI protocol.

V. U.S. PATENT NO. 8,682,338

A. The '338 Patent DAS

The '338 Patent describes three ways in which the digital access unit (DAU) sends and receives signals to and from a mobile network operator's signal source. *First*, because baseband signals are most suitable for cabled transport among equipment a DAS can use a fully digital baseband signal path from the core network to the RRUs (and vice versa) if the DAU is directly connected to the operator's core network—i.e., no translation between RF and baseband is necessary at the signal source. *Second*, the DAU may send and receive signals to and from the operator via a base station in analog RF format. For this scenario in the downlink direction, the DAU will down-convert the analog RF signals received from the BTS for distribution to the RRUs. '338 Patent at 5:63-67. In the uplink direction, the DAU will up-convert digital baseband signals from the RRUs to analog RF signals for transport back to the BTS. *Id.* at 6:4-9. *Third*, a DAU may send and receive signals from an operator via another DAU for more flexibility and capacity. *Id.* at 6:26-36, Figs. 1-2. This connection is also over a cable in digital baseband format. *Id.* Therefore, when a DAU receives digital downlink baseband signals from another DAU, RF-to-baseband translation is unnecessary.

Within the DAS, signals are typically transported in the downlink and uplink directions between the DAU and the RRUs as digital data packets. *Id.* at 5:52-6-31. Thus, DAUs and RRUs packetize the baseband signals as the last step before transmitting the signals to an RRU or DAU respectively. *Id.* at 5:52-6-31, 7:25-8:7, 8:24-32, 8:48-9:31. In this way, the '338 Patent's DAS performs the functions of packetizing/de-packetizing, digital-to-analog/analog-to-digital conversion, and RF/baseband translation depending on: (1) the direction of the signal flow; (2) the type of signal source; and (3) the specific component or location within the DAS as shown:



B. “translating the uplink and downlink signals between RF and base band as appropriate” (’338 Patent, cl. 1)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning in accordance with the plain and ordinary meaning of “downlink signals” as explained [below], and wherein “translating . . . as appropriate” is a conditional limitation	This phrase “recites ‘as appropriate’ to mean the amount of translation necessary to produce a baseband signal from an RF signal”, according to the construction and reasoning of the Delaware district court.

The parties’ dispute centers on the plain and ordinary meaning of “as appropriate.” Dali’s construction interprets the term “translating the uplink and downlink signals between RF *as appropriate*” to be a conditional limitation such that translation between RF and baseband is only required as necessary or appropriate. Defendants propose an erroneous construction issued by the Delaware Court in which translation between RF and baseband is required *each time*, reading out the conditional nature of “as appropriate,” and instead interpreting it to mean the “amount” of translation necessary to produce a baseband signal from the RF signal.

Defendants’ and the Delaware Court’s construction is unsupported by the intrinsic evidence. While the patent discloses a single non-limiting embodiment which includes a scenario where an RF base station is a downlink signal source to the DAU, such that an RF-to-baseband signal translation is necessary, the same embodiment also includes scenarios where the DAU can receive baseband downlink signals that do not require translation. For example, Figure 1 below

shows an instance in which DAU2 receives a downlink RF signal, while DAU1 receives a downlink baseband signal. '338 Patent at Fig. 1, 6:26-36. This illustrates the claimed step of “translating the uplink and downlink signals between RF and baseband *as appropriate*”: DAU1 receives a downlink RF signal and translates it to baseband, whereas DAU2 receives the already-translated downlink baseband signal from DAU1 and does not need to perform the RF-to-baseband translation.

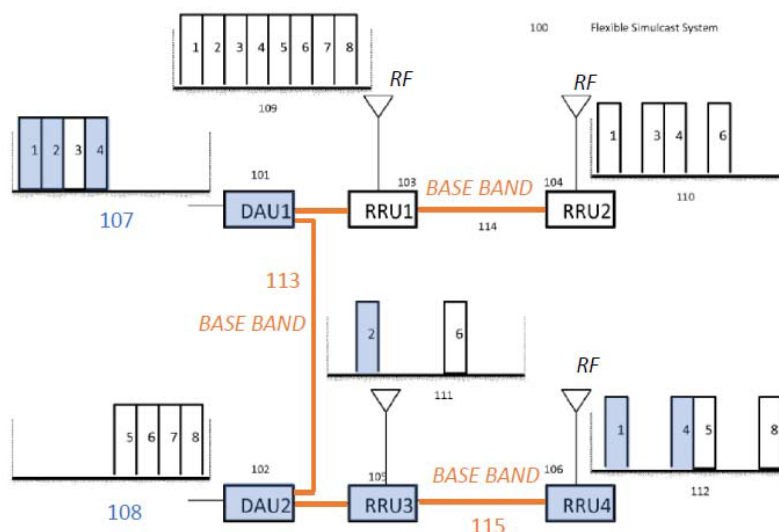


Figure 1: Flexible Simulcast Downlink Example

'338 Patent at Figure 1.

As yet another example of non-RF downlink signals that do not require an RF-to-baseband translation by the DAU, Figure 6 of the specification shows a scenario where Internet downlink VoIP traffic is received at the DAU input. '338 Patent at Fig. 6, 5:1-1-7. Indeed, downlink signals at the DAU are not necessarily RF, and thus, do not necessarily require RF-to-baseband translation.

Finally, nowhere in the patent is there any teaching of Defendant's proposed construction for translating RF signals to baseband by some “amount of translation necessary to produce a baseband signal from an RF signal.” No portion of the intrinsic record discloses the erroneous

concept of “translation by an amount.” In RF communications, a translation between RF and baseband is a binary process—a signal is either translated or it is not, but there is no “degree” or “amount” of translation. In any event, the patent does not provide any disclosure for translating between RF and baseband *by some amount*.

Dali’s construction, on the other hand, which reflects the term’s plain meaning, is supported by both the intrinsic and extrinsic evidence and is consistent with the proper construction of the “downlink signal” term (which does not limit downlink signals to RF, as explained below, Section V.E). The plain meaning of “translating . . . as appropriate” is that translation occurs—either at the DAU or RRU, in both uplink and downlink directions—as appropriate to ensure the respective uplink and downlink signals are in the format they need to be at the relevant parts of the system.

If a signal is traveling uplink from the DAU to an RF base station and is in baseband, it will be translated to RF. ’338 Patent at 6:4-9. If a signal is traveling downlink between the DAU and RRU and is originally in RF at the DAU downlink input, it will first be translated to baseband to ensure baseband transport between the DAU and RRU. ’338 Patent at 5:64-67. But if the downlink signal is originally in baseband (not RF) then translation is not necessary or appropriate. Ex. D at 39:13-41:3. Likewise, there is no requirement in the claim that translation between RF and baseband in either direction occur in the DAU or the RRU particularly, as the limitation is silent on this; translation just needs to happen at the appropriate place in the system to ensure the signal is in the format it needs to be for the hardware with which it is interfacing. ’338 Patent at 5:64-6:51, *Dali Wireless, Inc. v. Cellco Partnership d/b/a Verizon Wireless et al.* Case No. 2:23-cv-00002-RWS-RSP, Dkt. 76-4 at 39:13-41:3.

The intrinsic evidence supports this meaning. For example, the specification teaches that

“[t]he DAUs then reroute the users to Internet VoIP, Wi-Fi or WiMAX *as appropriate*,” which does not necessitate RF-to-baseband translation. ’338 Patent at 5:1-2; *see also id* at 8:48-55 (“The Digital Down Converters present in each of RRU1, RRU2, RRU3 and RRU4 are dynamically software-configured . . . so that uplink signals of the *appropriate desired signal format(s)* present at the receive antenna ports of the respective RRU1, RRU2, RRU3 and RRU4 are selected based on the desired uplink band(s) to be processed and filtered, converted and transported to the appropriate uplink output port of either DAU1 or DAU2.”) (emphasis added). This is the same meaning of “as appropriate” as in claim 1.³ For these reasons, the Court should reject Defendants’ construction and adopt Dali’s construction.

C. “downlink signals” (’338 Patent, cl. 1)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning which is: signals transmitted in the downlink direction	This term should “be given [its] plain and ordinary meaning, which is ‘signals transmitted in the downlink direction’”, and must be construed in the context of the “translating the uplink and downlink signals between RF and base band as appropriate” phrase in which it appears, and the claim as a whole, according to the construction and reasoning of the Delaware district court

Defendants’ proposed construction for “downlink signals” may appear as merely “signals transmitted in the downlink direction,” but actually imposes an additional requirement that all downlink signals received at the DAU must always be in RF. Defendants advance this construction to serve their construction for the “translation . . . as appropriate” term—requiring that a downlink RF-to-baseband translation must always be performed by the DAU.

³ The inventor and Dali’s expert have also made clear that a POSITA would understand that this is a conditional limitation. *See, e.g., Dali Wireless, Inc. v. Cellco Partnership d/b/a Verizon Wireless et al.* Case No. 2:23-cv-00002-RWS-RSP, Dkt. 76-4 at 39:13-41:3, *id*, Dkt. 76-2 at 4-5, 151.

The intrinsic evidence supports Dali’s proposed construction of downlink signals being simply signals transmitted in the downlink direction—i.e., downlink signals are agnostic concerning the format and can be RF or baseband. For example, as discussed above in Section V.D, Figure 1 shows an instance in which DAU1 receives a downlink RF signal, while DAU2 receives a downlink baseband signal from DAU1. ’338 Patent at Fig. 1, 6:26-36.⁴ Figure 6 provides another example of a non-RF downlink signal input at the DAU that does not necessitate a downlink RF-to-baseband translation; Internet downlink VoIP traffic. ’338 Patent at Fig 6, 5:1-7.

The surrounding claim language also supports Dali’s construction. As the Delaware Court’s original *Markman* order correctly reasoned, “bare reference to downlink signals is not limited to RF signals [as] *the patentee knew how to distinguish the two.*” *Dali Wireless, Inc. v. Cellco Partnership d/b/a Verizon Wireless et al.* Case No. 2:23-cv-00002-RWS-RSP, Dkt. 63-20 (D. Del. Dkt. 122) at 9 (emphasis added). Claim element 1[a] recites “providing one more remote radio units, each remote radio unit configured to transmit one or more **downlink RF signals** and to receive one or more uplink RF signals.” In contrast, claim element 1[c] recites “translating the uplink and **downlink signals** between RF and baseband as appropriate.” Thus, the Court should adopt the proper construction for downlink signals as signals transmitted in the downlink direction.

⁴ This example supports the proper construction for the claim step “translating the uplink and downlink signals between RF and baseband *as appropriate*”: DAU1 receives a downlink RF signal and translates it to baseband, whereas DAU2 receives the already-translated downlink baseband signal and does not need to perform the RF-to-baseband translation. ’338 Patent at Fig. 1.

D. “packetizing the uplink and downlink baseband signals” (’338 Patent, cl. 1)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning in accordance with the plain and ordinary meaning of “downlink signals” as explained above. A POSITA would understand antecedent basis for “baseband signals” is present by implication	“packetizing the uplink and downlink baseband signals that were produced in the ‘translating’ step”, according to the construction and reasoning of the Delaware court

Defendants require the packetizing to be performed on the baseband signals that were produced from the translating step *even if such translation did not occur* (e.g., downlink signals already in baseband that do not need RF-to-baseband translation). To the contrary, a POSITA reading the claim in light of the specification would reasonably understand that “the uplink and downlink base band signals” in the packetizing step simply refer to signals in the baseband format at the DAU or remote radio unit. Nothing in the claim language requires the “packetizing” step to refer only to baseband signals that *were actually translated* from RF in the previous step. As detailed in Section V.B above, downlink signals in the previous step are translated *only as appropriate*—i.e., depending on whether the downlink signal at the DAU’s downlink input was RF. ’338 Patent at 5:63-67. In other words, if such downlink signal was RF, then it is translated to baseband, and the translated downlink baseband signal is packetized; if a downlink signal received at the DAU is already at baseband, then the downlink baseband signal is packetized. Conversely, RF uplink signals received over the air at the remote radio unit are translated to baseband, and such uplink baseband signals are packetized for transport back to the DAU.

Thus, under the plain and ordinary meaning of this term, packetization is performed on baseband signals, irrespective of whether the baseband signals were the product of an RF-to-baseband translation in the previous step. Indeed, proper construction of the “translating . . . as

appropriate” step will also resolve the parties’ dispute for this term.

E. “routing and switching the packetized signals among the one or more remote radio units via the at least one digital access unit” (’338 Patent, cl. 1)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning in accordance with the plain and ordinary meaning of “downlink signals” as explained above	This phrase “refers to ‘the packetized signals’ produced by the packetizing step and includes both uplink baseband signals and downlink baseband signals that were previously packetized,” according to the construction and reasoning of the Delaware district court The “routing and switching . . . via the at least one DAU” portion of this phrase should be construed as “routing and switching . . . through the at least one DAU,” according to the construction and reasoning of the Delaware district court

1. Claim 1 requires routing and switching of only the downlink packetized signals, which were translated as appropriate.

The parties do not dispute that the claim requires routing and switching of the packetized downlink signals produced in the packetizing step. But Defendants contend that this claim term requires (1) routing and switching of the previously-translated downlink signals from the translation step and (2) routing and switching of both uplink and downlink signals from the packetizing step. Thus, the dispute is whether packetizing must be performed only on the downlink baseband signals produced in the previous translation step, or any downlink baseband signals—translated or not. As explained above, those packetized downlink signals refer only to translated downlink baseband signals as appropriate—depending on whether the downlink signal received at the DAU was RF. Thus, proper construction of the “translating . . . as appropriate” step will also resolve the parties’ dispute for the first portion of this term.

The parties also dispute whether the claim requires routing and switching of both uplink

and downlink baseband signals. Defendants propose a construction that requires both, which is wholly unsupported by the intrinsic evidence. The construction also ignores surrounding express claim language that informs a POSITA as to which direction signals are routed and switched. The claim recites in part: “routing and switching the packetized signals *among the one or more remote radio units via the at least one DAU.*” ’338 Patent at 13:23-25. A POSITA would understand that the operative phrase “among the one or more remote radio units via the at least one DAU” means that the only packetized signals that must be routed and switched in this context are in the *downlink direction towards the RRUs*, not in the uplink direction from the RRUs towards the DAU, because routing and switching signals among the RRUs means transporting the signals to the RRUs. *Id.* This is also supported by the intrinsic record—“signals are digitized, packetized, routed and switched *to the desired RRU.*” ’338 Patent at 8:30-32 (emphasis added).

Only packetized signals in the downlink direction are routed and switched *via* the DAU to the one or more RRUs as expressly recited in the claim and as supported by the specification. The claim does not require routing and switching the packetized uplink signals among the one or more remote radio units via the at least one DAU because uplink signals—by definition—flow in the direction *from* the RRUs towards the DAU. Defendants’ proposal (and the Delaware Court’s erroneous construction) instead reads in a nonsensical requirement that signals traveling uplink from the RRUs to the DAUs are routed and switched back to the RRUs from which they originated.⁵ Thus, the plain and ordinary meaning of this term, in light of the express claim

⁵ The Delaware Court understood that there is “little sense in routing and switching packetized uplink baseband signals,” but added “that is not my concern when the claim language is clear.” This was clear legal error contradicting both intrinsic and extrinsic evidence showing a POSITA would understand that only downlink signals are routed and switched among the RRUs.

language as well as the specification, only requires routing and switching in the downlink direction.

2. Claim 1 does not require routing and switching to be performed by the at least one digital access unit.

Dali does not dispute that the plain and ordinary meaning of “routing and switching . . . via the at least one digital access unit” should mean the packetized signal must pass through the at least one digital access unit. Defendants’ construction, however, appears to impose extraneous limitations requiring the digital access unit to decide the routes each packet must take and perform the switching all on its own. Thus, the crux of the dispute here is whether the digital access unit must physically perform the switching of packetized signals, or whether another component—separate from the digital access unit—may perform the switching as long as it occurs through or through the agency of the digital access unit.⁶ But nothing in the claim or the intrinsic record requires the digital access unit to perform the actual step of “routing and switching.” Accordingly, this term should be afforded its plain and ordinary meaning such that as long as the packetized signal has passed through the at least one digital access unit, the digital access unit need not actually perform the switching.

VI. U.S. PATENT NO. 9,197,358

The ’358 Patent discloses a new way to minimize radio-frequency interference in a Distributed Antenna Systems (DAS) experienced by mobile phones communicating in adjacent cells, called inter-cell interference, by carefully assigning the communication frequencies (e.g. “carrier frequencies”) of the adjacent cells to eliminate overlaps of common frequencies. ’358

⁶ The Delaware Court agreed with Dali that the claim does not require the switching to be performed by the digital access unit as long as the packetized signal has passed through the digital access unit. *Dali Wireless, Inc. v. Cellco Partnership d/b/a Verizon Wireless et al.* Case No. 2:23-cv-00002-RWS-RSP, Dkt. 63-21 (D. Del. Dkt. 321) at 10.

Patent at 1:39-49, 5:39-43, 6:25-29, 6:49-53, 7:51-8:45, 9:5-34. For example, a mobile phone user in the outer region of a cell may experience interference from radio frequencies being used in adjacent cells particularly when the cells are using the same or similar frequencies. *Id.* In the '358 Patent, the radio resources are arranged so that no two adjoining groupings of DRUs are using the same frequencies. '358 Patent at 7:15-31. In this manner, interference is reduced because the edge of one grouping of DRUs is operating on different frequencies than the adjoining grouping of DRUs facilitating improved system performance. *Id.*

However, a disadvantage of this technique is that only the portion of the available bandwidth associated with a frequency assigned to a cell is available to users of that cell. For example, if there are three frequencies associated with a particular source, and one is assigned to each of three cells, users in each cell only have a third of all the available bandwidth to use. *E.g.* '358 Patent at 7:27-32. Because intercell interference is most prevalent at the outer regions of the cell (the cell edges), a solution to this problem is to assign unique frequencies for use by mobile users in outer regions (i.e. users near each other) but allow more frequencies to be re-used in the inner regions of the cell where intercell interference between cells is less of a problem due to sufficient distance between the cells and their users. *Id.* at 7:27-30, 34-46, 56-67. Fig 1B annotated below with "F1" through "F4" indicating unique frequencies demonstrates an assignment of frequencies to the outer regions of each cell such that interference from other cells will be diminished.

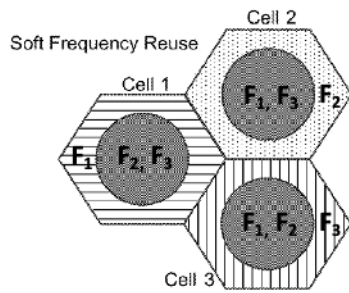


FIG. 1C

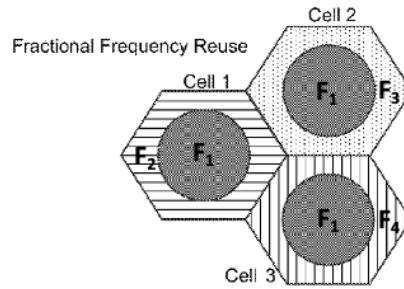


FIG. 1B

In annotated Figure 1B above, each cell utilizes half of the available bandwidth, *e.g.* Cell 1 uses F_1 and F_2 of the available F_1 - F_4 . In annotated Fig. 1C above illustrating the use of available frequencies F_1 - F_3 , since the center areas of the cell are not as susceptible to intercell interference as the outer regions, other unused frequencies can be added to the center regions, further increasing bandwidth. '358 Patent 7:65-67.

A. “a [first/second] communications unit” ('358 Patent, cls. 7, 9, 11, 15)

Plaintiff's Proposed Construction	Defendants' Proposed Construction
Plain and ordinary meaning	A communications unit can include a plurality of remote antenna units.

The term “communications unit” is well known to one of skill in the art and requires no further construction. In contrast, Defendant’s proposal is likely to confuse the fact finder because the inclusion of the undefined term “remote antenna units” is ambiguous as to what such a term entails and improperly reads claims using this term on prior art despite intrinsic evidence and previous decisions expressly explaining the difference. *E.g.*, IPR2021-00492, Paper 8. As discussed below, because Defendant’s construction is unnecessary and unhelpful, the Court should reject it in favor of plain and ordinary meaning.

As used in the claims, each “communications unit” is required to create two “footprints” using two different frequencies. As the claims make clear, a “communications unit” is analogous

to a single “remote unit” or “Digital Remote Unit.” For example, claim 7 provides a “set of communications units” that includes “a first” and “a second communication unit.” Claim 8 further recites that the “set of communications units includes a plurality of remote units” Similarly, claim 15 recites “a first” and “a second communications unit” creating two footprints using two different frequencies. Claim 16 recites that these communications units are each a single DRU (digital remote unit). Thus, the first or second communications unit is not “a plurality of” units, but rather the “set of communications units” forms the “plurality of” units referenced in Defendant’s proposed construction. In contrast, the first or second communications unit is not recited in the claims as being comprised of a “plurality of remote antenna units.”

Furthermore, the phrase “remote antenna unit” is ambiguous because it is unclear whether this simply means an additional co-located antenna within the communications unit, an antenna coupled with an amplifier, or something more sophisticated. The patent only mentions this term in the “Background of the Invention” section, where it appears to be analogous to what the patent describes elsewhere as a Digital Remote Unit or DRU. *Compare* ‘358 Patent at 1:20-26 *with id.* at 1:52-56. Because the phrase is ambiguous, the Court should not inject it into an otherwise well-understood “communications unit” term.

Finally, the Court should not adopt a construction of “communications unit” that allows multiple “communication units” to create the two footprints at different frequencies as such a construction not only contravenes the plain language of the claims, but also would read on prior art – a position already rejected by the PTAB. *See, e.g.*, IPR2021-00492, Paper 8 at 21-22.

B. “distributing communications frequencies” (’358 Patent, cl. 7)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning with the understanding that “distributing” essentially implicates a DAS	This language from the preamble of claim 7 is not a limitation.

The term “distributing communications frequencies” provides necessary features to claim 7 and as such is a claim limitation. *Storage Tech. Corp. v. Cisco Sys., Inc.*, 329 F.3d 823, 835 (Fed. Cir. 2003) (when additional steps are underscored as important by the specification, the preamble is a claim limitation). The ‘358 Patent describes the invention as the use of frequency reuse schemes in a distributed antenna system (DAS). *E.g.* ‘358 Patent at 5:49-54, 6:44-61, 8:55-9:8. While claim 7 recites steps that are the result of the assignment of frequencies to various footprints, the preamble is the portion of the claim that makes clear that the system is making the frequency assignments. The preamble of claim 7 adds the step of “distributing communication frequencies”, a function described as being performed within a DAS when frequencies are distributed or assigned from a DAU to a plurality of DRUs and therefore must be construed as a limitation for claim 7 to recite the concept of using frequency reuse in a DAS.

The District Court for the Northern District of California construed this same claim term from the same patent at issue here and held that the preamble was a limitation: “the preamble is needed to give the claim life and meaning. The Court need not construe ‘distributing communications frequencies’ with the understanding that ‘distributing’ essentially implicates a DAS.” *Dali Wireless, Inc. v. Corning Optical Communications LLC*, Case No. 20-cv-06469, Dkt. No. 85 at 38 (NDCA 2021). The Court should adopt the holding of the District Court for the Northern District of California and find the preamble limiting.

C. “geographic footprint” / “geographical footprint (’358 Patent, cls. 7, 9, 11, 15, 18

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
radio coverage area meaning an area defined by user accessible frequenc(ies)	radio coverage area

The parties’ disagreement as to the term “a geographic footprint” is what defines the “radio coverage area.”

Consistent with Dali's proposed construction, the specification of the '358 Patent describes creating "geographic footprints" using two methods based on a user's location in the cell. The first method creates geographic footprints using different power levels, with a first set of frequencies associated with a first power level and a second set of frequencies associated with a second power level. '358 Patent at 10:25-40 ("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 power level, using frequencies in the horizontal stripe / shaded / vertical stripe / etc. frequency bands."); *Id.* at Dependent Claim 17 ("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."). Here, the "radio coverage area" is defined by the user's accessibility to the frequency – that is whether the user is assigned to the specific frequency and located within the power range of the first or second set of frequencies.

The second method creates geographic footprints by assigning frequencies to users based on their location from the communication unit. '358 Patent at 16:29-34. The specification explains creating an interior and exterior *area* for each cell based on a parameter α and the Radius R of the cell. *Id.* A user is within the interior or exterior region depending on whether their location as determined by the user's uplink power is below or above a threshold, T_p . *Id.* at 16:35-40. The geographic footprints are created by assigning radio resource blocks, referred to RBs, depending on whether the user is located in the interior or the exterior of the cell. *Id.* at 16:45-18:4. Thus, the "radio coverage area" is defined by the user's accessibility to the frequency – that is whether the user is assigned to the specific frequency associated with the first

or second set and located in the interior or exterior of the cell associated with the first or second set.

D. “host unit” (’358 Patent, cls. 8, 15)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Plain and ordinary meaning	A unit that distributes communications frequencies between an operator network and antenna units.

The term “host unit” is well-known in art and does not require construction. Dependent claim 8 claims a host unit in communication with the set of communications units as part of the “distributing communication frequencies” of independent claim 7. Likewise, independent claim 15 requires a “host unit” and a first and second communications unit “coupled to the host unit” whereby the first and second communications unit are operable to transmit and receive using various distributed frequencies. Nowhere does the claim suggest or even require “[a] unit that distributes communication frequencies *between an operator network and antenna units*” as proposed by the Defendants and instead only requires transmitting and receiving communications as part of being coupled to the host unit. As such, the Court should decline to adopt Defendant’s proposed construction.

E. “the first frequency band and the second frequency band” (’358 Patent, cl. 20)

Plaintiff’s Proposed Construction	Defendants’ Proposed Construction
Not indefinite. Plain and ordinary meaning.	Indefinite.

The parties’ dispute here appears to stem from the fact that claim 20 uses the term “frequency band,” whereas its independent claim uses the term “frequency range.” One of ordinary skill would understand that “frequency band” and “frequency range” refer to the same thing, especially given that the ’358 Patent uses the terms interchangeably when the band is a contiguous range. For example, the ’358 Patent describes the relationship between bands and

ranges as follows: “the first frequency band comprises a first contiguous range of frequencies and the second frequency band comprises a second contiguous range of frequencies adjacent to the first frequency band.” ’358 Patent at 4:13-16; *also* 3:61-4:1 (“a first frequency band characterized by a first frequency range . . . a second frequency band characterized by a second frequency range”). When read in conjunction with the specification, the scope of claim 20 is not ambiguous, and therefore not indefinite.

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Respectfully submitted,

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CERTIFICATE OF SERVICE

I hereby certify that on March 2, 2023, I electronically filed the foregoing with the Clerk of the Court using the CM/ECF system which will send notification of such filing to all counsel of record.

By: /s/ Cristofer Leffler
Cristofer I. Leffler

US008682338B2

(12) **United States Patent**
Lemson et al.

(10) **Patent No.:** **US 8,682,338 B2**
(45) **Date of Patent:** ***Mar. 25, 2014**

(54) **REMOTELY RECONFIGURABLE
DISTRIBUTED ANTENNA SYSTEM AND
METHODS**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 184 days.

This patent is subject to a terminal dis-
claimer.

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(57) **ABSTRACT**

The present disclosure is a novel utility of a software defined
radio (SDR) based Distributed Antenna System (DAS) that is
field reconfigurable and support multi-modulation schemes
(modulation-independent), multi-carriers, multi-frequency
bands and multi-channels. The present disclosure enables a
high degree of flexibility to manage, control, enhance, facili-
tate the usage and performance of a distributed wireless net-
work such as flexible simulcast, automatic traffic load-bal-
ancing, network and radio resource optimization, network
calibration, autonomous/assisted commissioning, carrier
pooling, automatic frequency selection, frequency carrier
placement, traffic monitoring, traffic tagging, pilot beacon,
etc. As a result, the SDR DAS can increase the efficiency and
traffic capacity of the operators' wireless network.

12 Claims, 7 Drawing Sheets

(21) Appl. No.: **13/211,243**

(22) Filed: **Aug. 16, 2011**

(65) **Prior Publication Data**

US 2012/0039320 A1 Feb. 16, 2012

Related U.S. Application Data

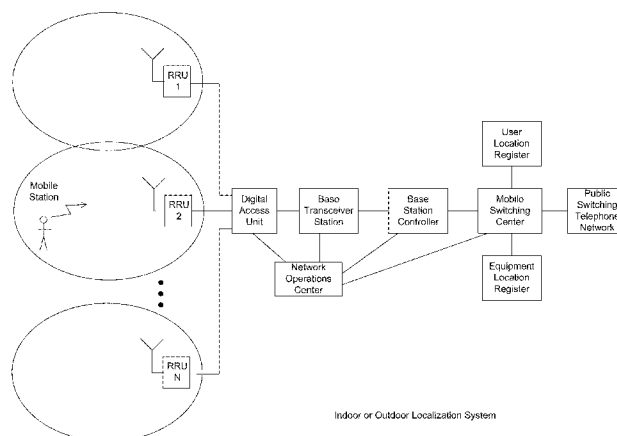
(60) Provisional application No. 61/382,836, filed on Sep.
14, 2010.

(51) **Int. Cl.**
H04W 72/00 (2009.01)

(52) **U.S. Cl.**
USPC **455/453; 455/445; 455/450**

(58) **Field of Classification Search**
USPC 455/562.1, 436, 443-445, 447,
455/450-454, 464, 509; 370/328, 310.2,
370/338

See application file for complete search history.



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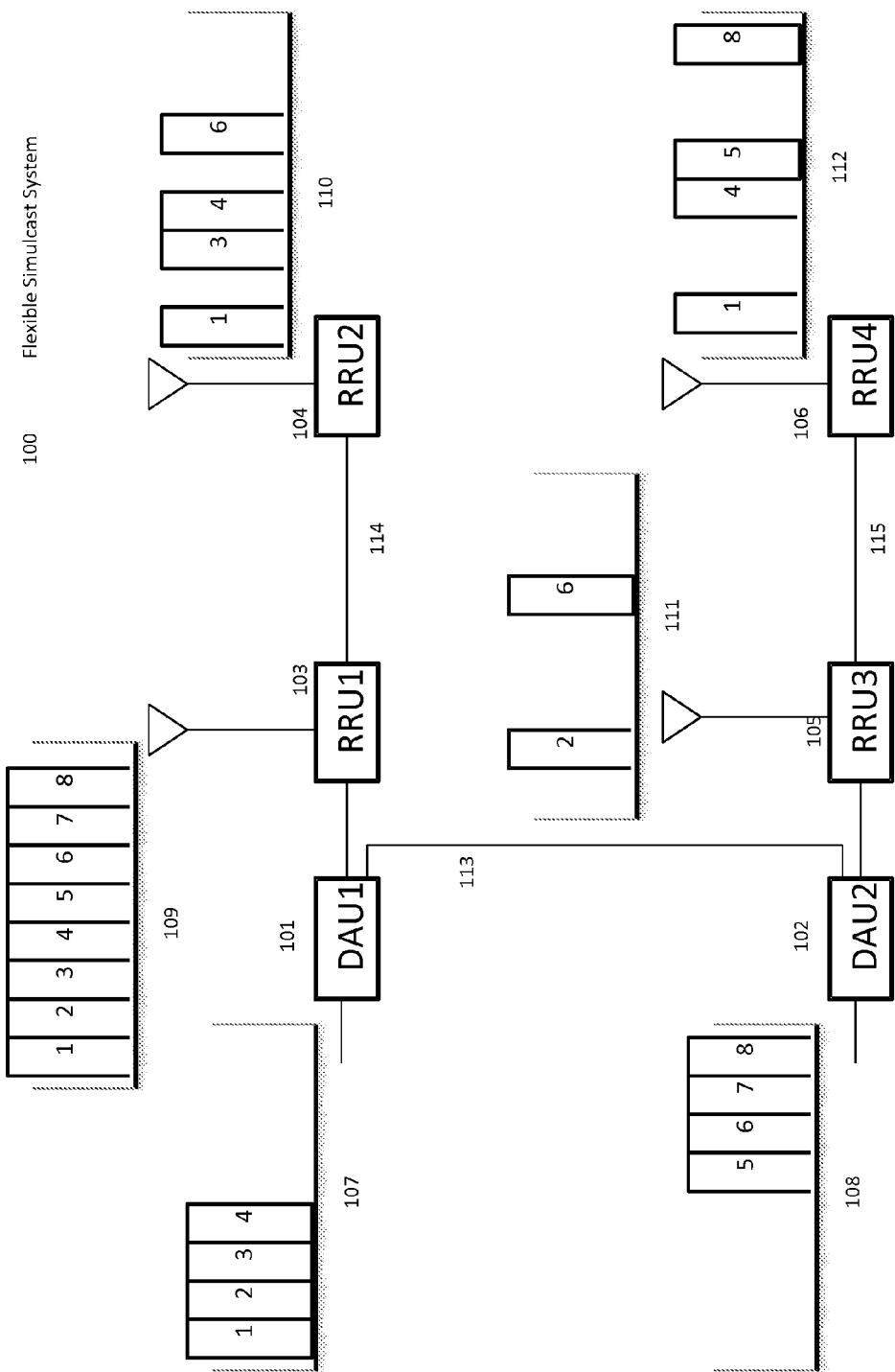


Figure 1: Flexible Simulcast Downlink Example

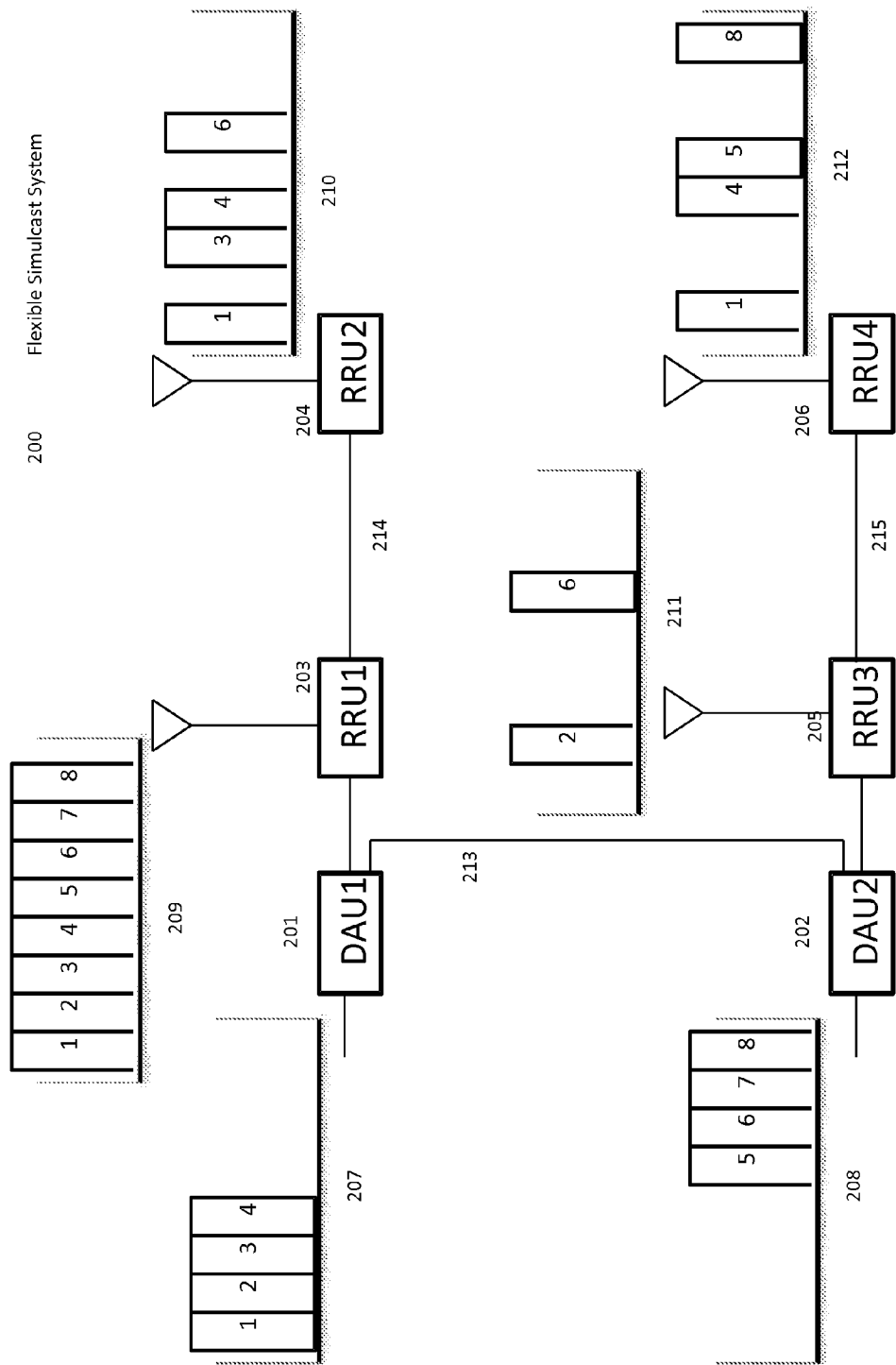


Figure 2: Flexible Simulcast Uplink Example

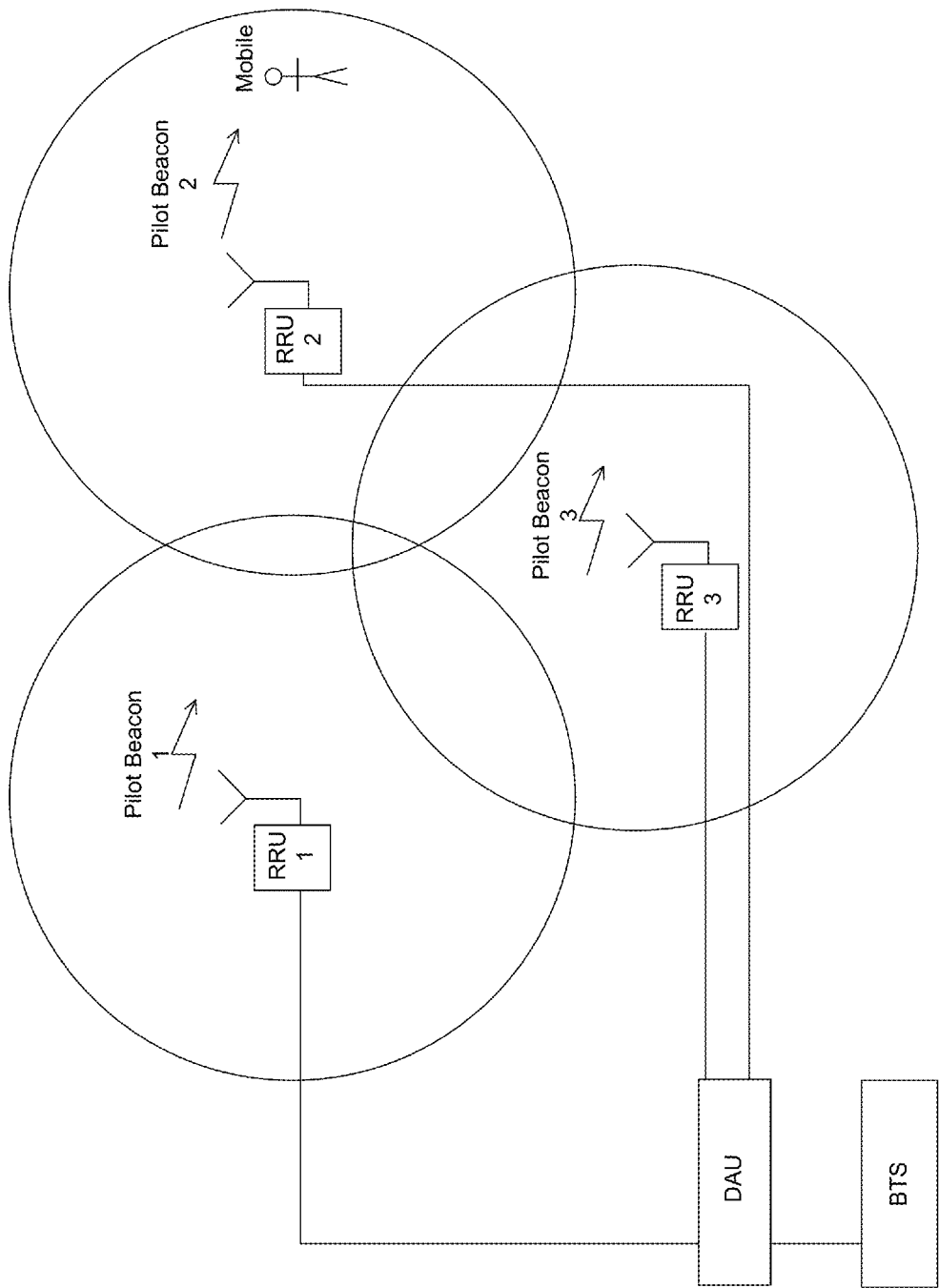


Figure 3 Pilot Beacon Indoor Localization System for CDMA and WCDMA

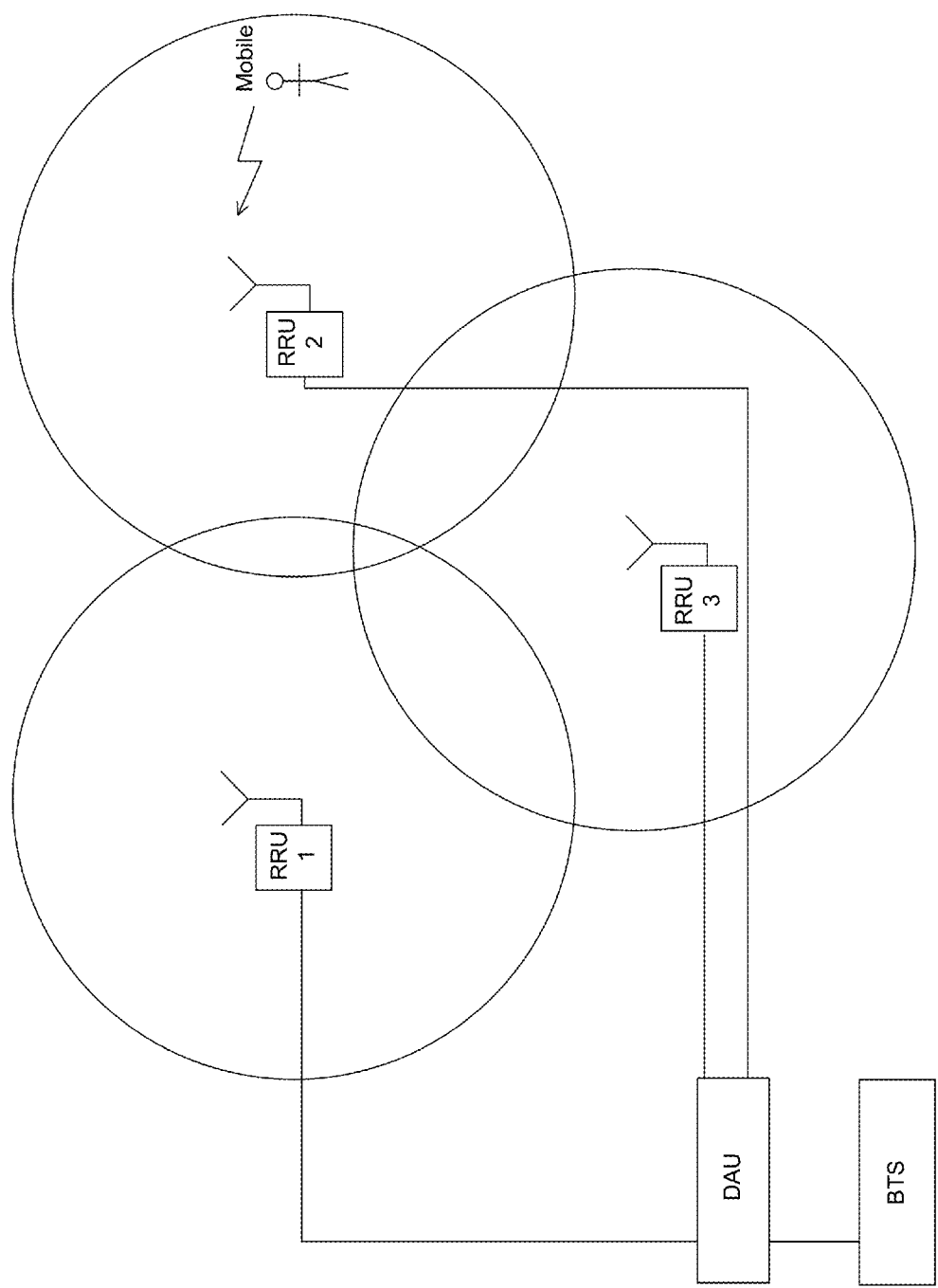


Figure 4 Indoor Localization System of GSM and LTE

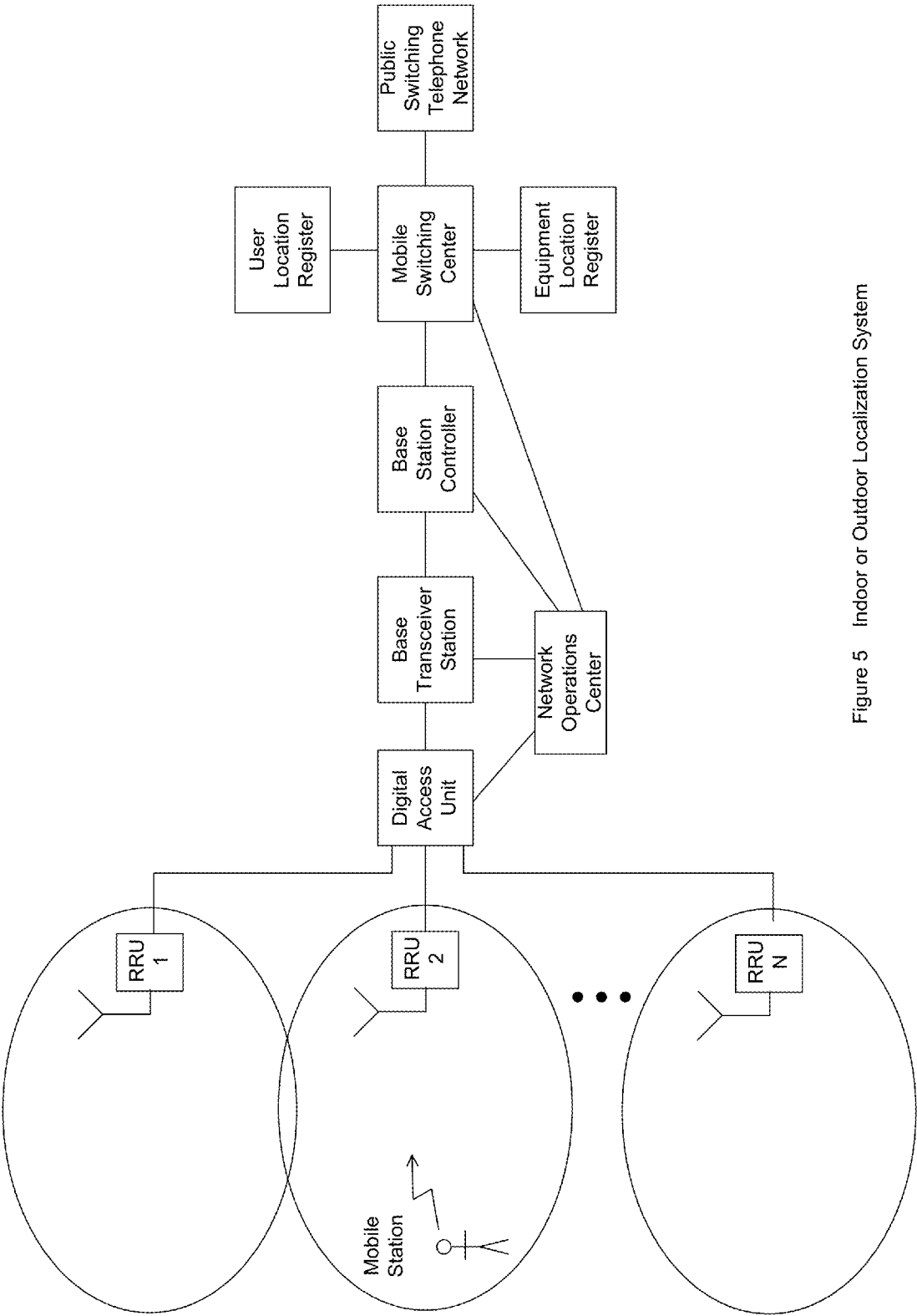


Figure 5 Indoor or Outdoor Localization System

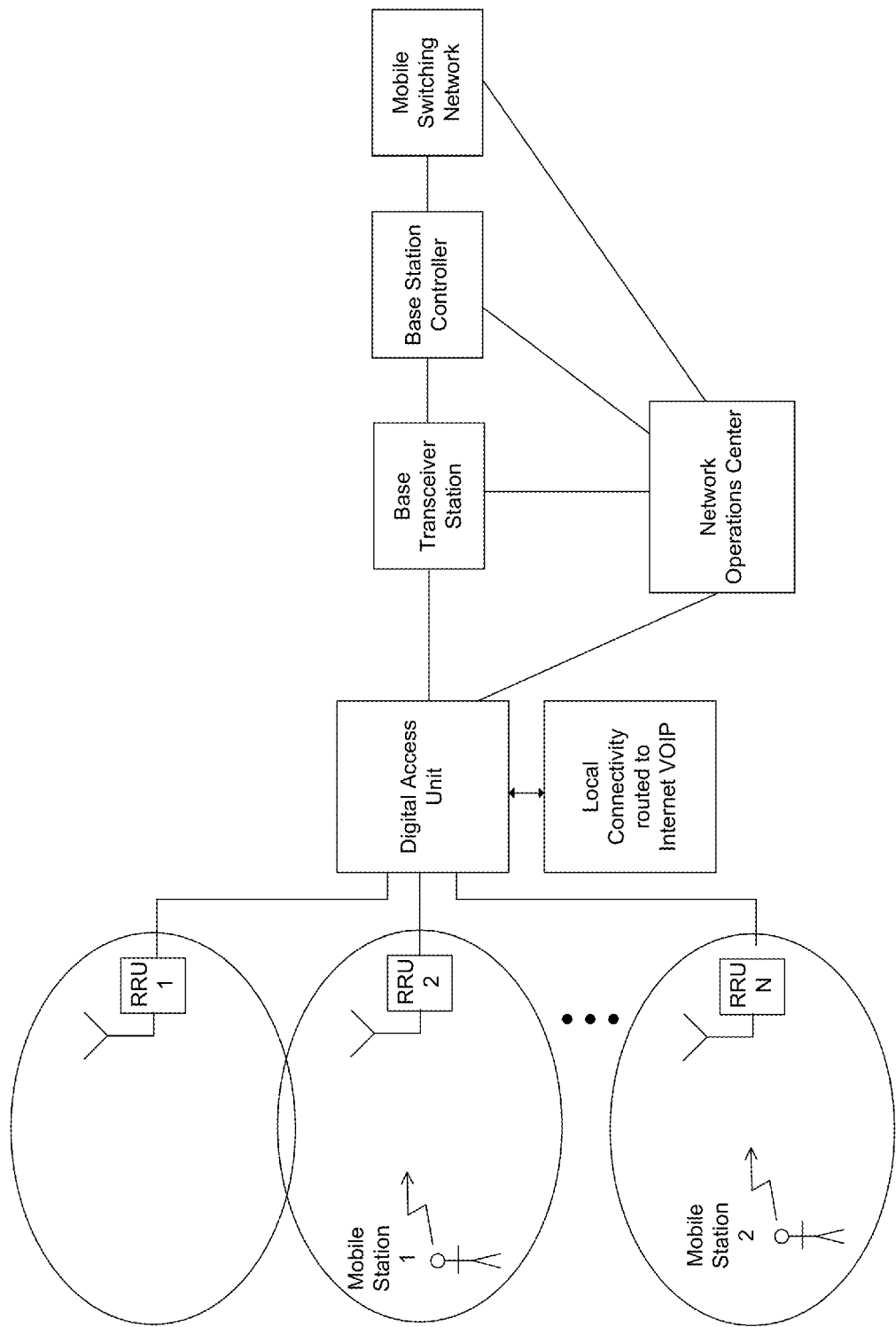


Figure 6 Local Connectivity

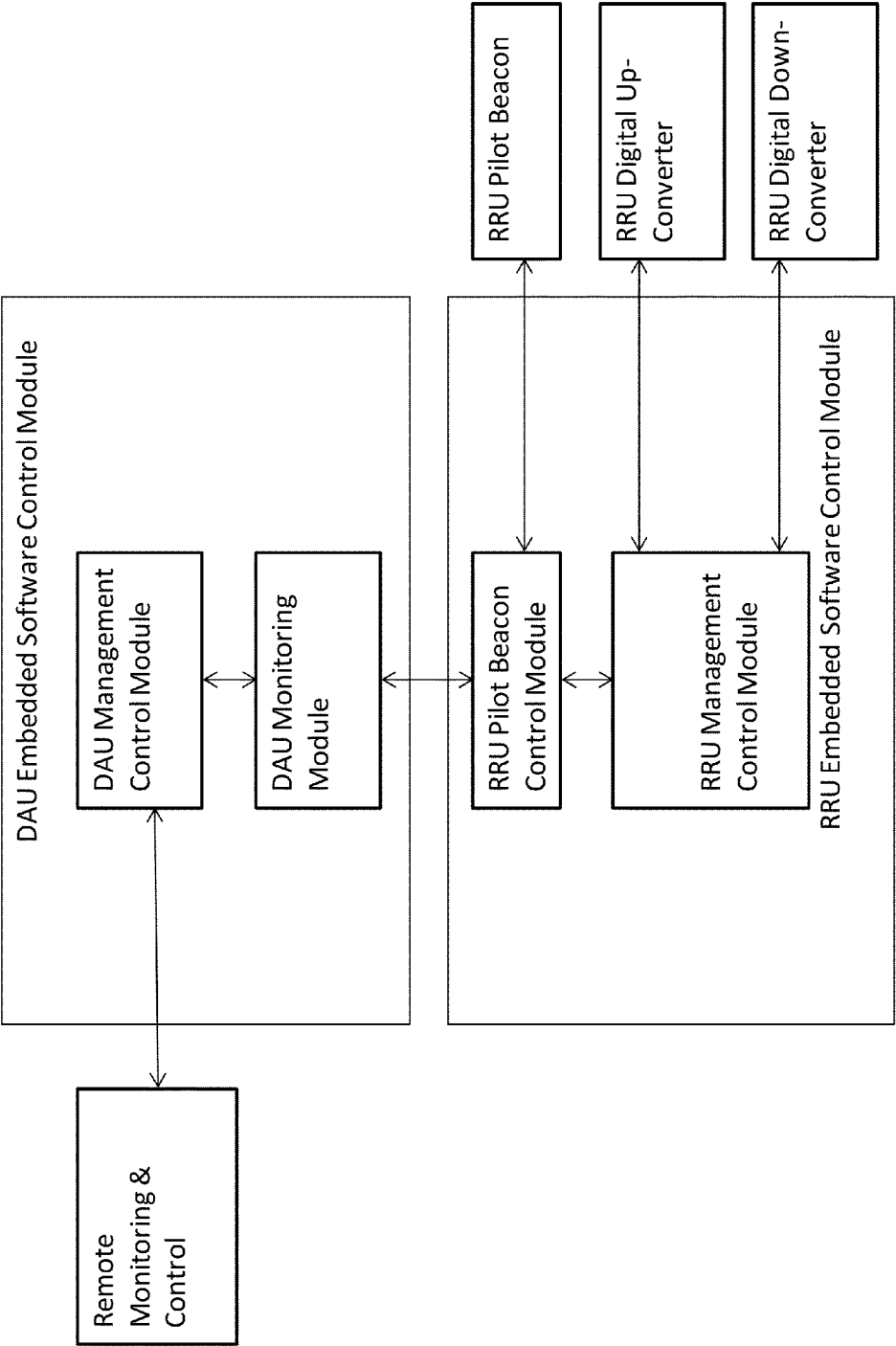


Figure 7: Embedded Software Control Modules

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REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS

RELATED APPLICATIONS

This application claims the benefit of U.S. Patent Application Ser. No. 61/382,836, filed on Sep. 14, 2010, entitled REMOTELY RECONFIGURABLE DISTRIBUTED ANTENNA SYSTEM AND METHODS, which is hereby incorporated by reference for all purposes.

FIELD OF THE INVENTION

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 software defined radio (SDR).

BACKGROUND OF THE INVENTION

Wireless and mobile network operators face the continuing challenge of building networks that effectively manage high data-traffic growth rates. Mobility and an increased level of multimedia content for end users requires end-to-end network adaptations that support both new services and the increased demand for broadband and flat-rate Internet access. One of the most difficult challenges faced by network operators is caused by the physical movement of subscribers from one location to another, and particularly when wireless subscribers congregate in large numbers at one location. A notable example is a business enterprise facility during lunchtime, when a large number of wireless subscribers visit a cafeteria location in the building. At that time, a large number of subscribers have moved away from their offices and usual work areas. It's likely that during lunchtime there are many locations throughout the facility where there are very few subscribers. If the indoor wireless network resources were properly sized during the design process for subscriber loading as it is during normal working hours when subscribers are in their normal work areas, it is very likely that the lunchtime scenario will present some unexpected challenges with regard to available wireless capacity and data throughput.

To accommodate this variation in subscriber loading, there are several candidate prior art approaches.

One approach is to deploy many low-power high-capacity base stations throughout the facility. The quantity of base stations is determined based on the coverage of each base station and the total space to be covered. Each of these base stations is provisioned with enough radio resources, i.e., capacity and broadband data throughput to accommodate the maximum subscriber loading which occurs during the course of the workday and work week. Although this approach typically yields a high quality of service, the notable disadvantage of this approach is that during a major part of the time many of the base stations' capacity is being wasted. Since a typical indoor wireless network deployment involves capital and operational costs which are assessed on a per-subscriber basis for each base station, the typically high total life cycle cost for a given enterprise facility is far from optimal.

A second candidate approach involves deployment of a DAS along with a centralized group of base stations dedicated to the DAS. A conventional DAS deployment falls into one of two categories. The first type of DAS is "fixed", where the system configuration doesn't change based on time of day or other information about usage. The remote units associated

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with the DAS are set up during the design process so that a particular block of base station radio resources is thought to be enough to serve each small group of DAS remote units. A notable disadvantage of this approach is that most enterprises seem to undergo frequent re-arrangements and re-organizations of various groups within the enterprise. Therefore, it's highly likely that the initial setup will need to be changed from time to time, requiring deployment of additional staff and contract resources with appropriate levels of expertise regarding wireless networks.

The second type of DAS is equipped with a type of network switch which allows the location and quantity of DAS remote units associated with any particular centralized base station to be changed manually. Although this approach would seem to allow dynamic reconfiguration based on the needs of the enterprise or based on time of day, it frequently requires deployment of additional staff resources for real-time management of the network. Another issue is that it's not always correct or best to make the same DAS remote unit configuration changes back and forth on each day of the week at the same times of day. Frequently it is difficult or impractical for an enterprise IT manager to monitor the subscriber loading on each base station. And it is almost certain that the enterprise IT manager has no practical way to determine the loading at a given time of day for each DAS remote unit; they can only guess.

Another major limitation of prior art DAS deployments is related to their installation, commissioning and optimization process. Some challenging issues which must be overcome include selecting remote unit antenna locations to ensure proper coverage while minimizing downlink interference from outdoor macro cell sites, minimizing uplink interference to outdoor macro cell sites, and ensuring proper intra-system handovers while indoors and while moving from outdoors to indoors (and vice-versa). The process of performing such deployment optimization is frequently characterized as trial-and-error and as such, the results may not be consistent with a high quality of service.

A major limitation of prior art DAS equipment employing digital transmission links such as optical fiber or wired Ethernet is the fact that the prior-art RF-to-digital conversion techniques utilize an approach whereby the system converts a single broad RF bandwidth of e.g., 10 to 25 MHz to digital. Therefore all the signals, whether weak or strong, desired or undesired, contained within that broad bandwidth are converted to digital, whether those signals are desired or not. This approach frequently leads to inefficiencies within the DAS which limit the DAS network capacity. It would be preferable to employ an alternative approach yielding greater efficiencies and improved flexibility, particularly for neutral host applications.

In 2008 the FCC further clarified its E-911 requirements with regard to Phase 2 accuracy for mobile wireless networks. The information required in Phase 2 is the mobile phone number and the physical location, within a few dozen yards, from which the call was made. The Canadian government is reportedly considering enacting similar requirements. Also the FCC is eager to see US mobile network operators provide positioning services with enhanced accuracy for E-911 for indoor subscribers. There is a reported effort within the FCC to try to mandate Phase 2 accuracy indoors, within the next 2 years.

Many wireless networks employ mobile and fixed broadband wireless terminals which employ GPS-based E-911 location services. It has been demonstrated that GPS signals from satellites outdoors don't propagate well into the indoor space. Therefore an alternative, more robust E-911 location

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determination approach is required for indoors, particularly if the FCC requirements are changed to be more stringent.

Several US operators have expressed concern about how they can practically and cost-effectively obtain these enhanced location accuracy capabilities. Operators are very eager to identify a cost-effective approach which can be deployed indoors for enhanced location accuracy.

One proposed approach toward indoor location accuracy enhancement for CDMA networks would employ a separate unit known as a CDMA Pilot Beacon. A notable disadvantage of this approach for an indoor DAS application is that since the CDMA Pilot Beacon unit is a separate and dedicated device and not integrated within the DAS, it would likely be costly to deploy. The Pilot Beacon approach for CDMA networks employs a Pilot Beacon with a unique PN code (in that area) which effectively divides a particular CDMA network coverage area (e.g., indoors) into multiple small zones (which each correspond to the coverage area of a low-power Pilot Beacon). Each Pilot Beacon's location, PN code and RF Power level are known by the network. Each Pilot Beacon must be synchronized to the CDMA network, via GPS or local base station connection. A variable delay setting permits each Pilot Beacon to have the appropriate system timing to permit triangulation and/or Cell ID position determination. One optional but potentially costly enhancement to this approach would employ a Wireless Modem for each Pilot Beacon to provide remote Alarms, Control and Monitoring of each CDMA Pilot Beacon. No known solution for indoor location accuracy enhancement has been publicly proposed for WCDMA networks.

One candidate technically-proven approach toward indoor location accuracy enhancement for GSM networks would employ a separate unit known as a Location Measurement Unit or LMU. A notable disadvantage of this approach for an indoor DAS application is that, since the LMU is a separate and dedicated device and not integrated within the DAS, it is costly to deploy. Each LMU requires a backhaul facility to a central server which analyzes the LMU measurements. The LMU backhaul cost adds to the total cost of deploying the enhanced accuracy E-911 solution for GSM networks. Despite the availability of the already technically-proven LMU approach, it has not been widely deployed in conjunction with indoor DAS.

Based on the prior art approaches described herein, it is apparent that a highly efficient, easily deployed and dynamically reconfigurable wireless network is not achievable with prior art systems and capabilities.

SUMMARY OF THE INVENTION

The present invention substantially overcomes the limitations of the prior art discussed above. The advanced system architecture of the present invention provides a high degree of flexibility to manage, control, enhance and facilitate radio resource efficiency, usage and overall performance of the distributed wireless network. This advanced system architecture enables specialized applications and enhancements including flexible simulcast, automatic traffic load-balancing, network and radio resource optimization, network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, radio frequency carrier placement, traffic monitoring, traffic tagging, and indoor location determination using pilot beacons. The present invention can also serve multiple operators, multi-mode radios (modulation-independent) and multi-frequency bands per operator to increase the efficiency and traffic capacity of the operators' wireless networks.

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Accordingly, it is an object of the present invention to provide a capability for Flexible Simulcast. With Flexible Simulcast, the amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs by each RRU Access Module can be set via software control as described hereinafter to meet desired capacity and throughput objectives or wireless subscriber needs. To achieve these and other objects, an aspect of the present invention employs software-programmable frequency selective Digital Up-Converters (DUCs) and Digital Down-Converters (DDCs). A software-defined Remote Radio Head architecture is used for cost-effective optimization of the radio performance. Frequency selective DDCs and DUCs at the Remote Radio Head enable a high signal to noise ratio (SNR) which maximize the throughput data rate. An embodiment shown in FIG. 1 depicts a basic structure and provides an example of a Flexible Simulcast downlink transport scenario. FIG. 2 depicts an embodiment of a basic structure of a Flexible Simulcast uplink transport scenario.

It is a further object of the present invention to facilitate conversion and transport of several discrete relatively narrow RF bandwidths. In another aspect of the invention, an embodiment converts only that plurality of specific, relatively narrow bandwidths that carry useful information. Thus, this aspect of the present invention allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and facilitates transport of more operators' band segments over the optical fiber. To achieve the above result, the present invention utilizes frequency-selective filtering at the Remote Radio Head which enhances the system performance. In some embodiments of this aspect of the invention, noise reduction via frequency-selective filtering at the Remote Radio Head is utilized for maximizing the SNR and consequently maximizing the data throughput. It is a further object of the present invention to provide CDMA and WCDMA indoor location accuracy enhancement. In an aspect of the present invention, an embodiment provides enhanced location accuracy performance by employing pilot beacons. FIG. 3 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU). The Remote Radio Heads have a unique beacon that is distinct and identifies that particular indoor cell. The mobile user will use the beacon information to assist in the localization to a particular cell.

It is a further object of the present invention to enhance GSM and LTE indoor location accuracy. In another aspect, an embodiment of the present invention provides localization of a user based on the radio signature of the mobile device. FIG. 4 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU). In accordance with the invention, each Remote Radio Head provides unique header information on data received by that Remote Radio Head. The system of the invention uses this header information in conjunction with the mobile user's radio signature to localize the user to a particular cell.

It is a further object of the present invention to re-route local traffic to Internet VoIP, Wi-Fi or WiMAX. In this aspect of the invention, an embodiment determines the radio signatures of the individual users within a DAU or Island of DAUs and uses this information to identify if the users are located within the coverage area associated with a specific DAU or Island of DAUs. The DAUs track the radio signatures of all the active users within its network and record a running data base containing information pertaining to them. One embodiment of the present invention is for the Network Operations Center (NOC) to inform the DAU that, e.g., two specific users are collocated within the same DAU or Island of DAUs, as

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depicted in FIG. 6. The DAUs then reroute the users to Internet VoIP, Wi-Fi or WiMAX as appropriate. Another embodiment of the present invention is to determine the Internet Protocol (IP) addresses of the individual users' Wi-Fi connections. If the individual users' IP addresses are within the same DAU or Island of DAUs, the data call for these users is rerouted over the internal network.

Applications of the present invention are suitable to be employed with distributed base stations, distributed antenna systems, distributed repeaters, mobile equipment and wireless terminals, portable wireless devices, and other wireless communication systems such as microwave and satellite communications. The present invention is also field upgradable through a link such as an Ethernet connection to a remote computing center.

Appendix I is a glossary of terms used herein, including acronyms.

THE FIGURES

Further objects and advantages of the present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram according to one embodiment of the invention showing the basic structure and an example of a Flexible Simulcast downlink transport scenario based on having 2 DAU and 4 DRU.

FIG. 2 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a Flexible Simulcast uplink transport scenario based on having 2 DAU and 4 DRU.

FIG. 3 shows an embodiment of an indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU).

FIG. 4 shows an embodiment of an indoor system in accordance with the invention which employs multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU).

FIG. 5 illustrates an embodiment of a cellular network system employing multiple Remote Radio Heads according to the present invention.

FIG. 6 is a depiction of local connectivity according to one embodiment of the present invention.

FIG. 7 illustrates an embodiment of the basic structure of the embedded software control modules which manage key functions of the DAU and RRU, in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a novel Reconfigurable Distributed Antenna System that provides a high degree of flexibility to manage, control, re-configure, enhance and facilitate the radio resource efficiency, usage and overall performance of the distributed wireless network. An embodiment of the Reconfigurable Distributed Antenna System in accordance with the present invention is shown in FIG. 1. The Flexible Simulcast System 100 can be used to explain the operation of Flexible Simulcast with regard to downlink signals. The system employs a Digital Access Unit functionality (hereinafter "DAU"). The DAU serves as an interface to the base station (BTS). The DAU is (at one end) connected to the BTS, and on the other side connected to multiple RRUs. For the downlink (DL) path, RF signals received from the BTS are separately down-converted, digitized, and converted to baseband (using a Digital Down-Converter). Data streams are then I/Q

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mapped and framed. Specific parallel data streams are then independently serialized and translated to optical signals using pluggable SFP modules, and delivered to different RRUs over optical fiber cable. For the uplink (UL) path optical signals received from RRUs are de-serialized, deframed, and up-converted digitally using a Digital Up-Converter. Data streams are then independently converted to the analog domain and up-converted to the appropriate RF frequency band. The RF signal is then delivered to the BTS. An embodiment of the system is mainly comprised of DAU1 indicated at 101, RRU1 indicated at 103, RRU2 indicated at 104, DAU2 indicated at 102, RRU3 indicated at 105, and RRU4 indicated at 106. A composite downlink input signal 107 from, e.g., a base station belonging to one wireless operator enters DAU1 at the DAU1 RF input port. Composite signal 107 is comprised of Carriers 1-4. A second composite downlink input signal from e.g., a second base station belonging to the same wireless operator enters DAU2 at the DAU2 RF input port. Composite signal 108 is comprised of Carriers 5-8. The functionality of DAU1, DAU2, RRU1, RRU2, RRU3 and RRU4 are explained in detail by U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and attached hereto as an appendix. One optical output of DAU1 is fed to RRU1. A second optical output of DAU1 is fed via bidirectional optical cable 113 to DAU2. This connection facilitates networking of DAU1 and DAU2, which means that all of Carriers 1-8 are available within DAU1 and DAU2 to transport to RRU1, RRU2, RRU3 and RRU4 depending on software settings within the networked DAU system comprised of DAU1 and DAU2. The software settings within RRU1 are configured either manually or automatically such that Carriers 1-8 are present in the downlink output signal 109 at the antenna port of RRU1. The presence of all 8 carriers means that RRU1 is potentially able to access the full capacity of both base stations feeding DAU1 and DAU2. A possible application for RRU1 is in a wireless distribution system is e.g., a cafeteria in an enterprise building during the lunch hour where a large number of wireless subscribers are gathered. RRU2 is fed by a second optical port of RRU1 via bidirectional optical cable 114 to RRU2. Optical cable 114 performs the function of daisy chaining RRU2 with RRU1. The software settings within RRU2 are configured either manually or automatically such that Carriers 1, 3, 4 and 6 are present in downlink output signal 110 at the antenna port of RRU2. The capacity of RRU2 is set to a much lower value than RRU1 by virtue of its specific Digital Up Converter settings. The individual Remote Radio Units have integrated frequency selective DUCs and DDCs with gain control for each carrier. The DAUs can remotely turn on and off the individual carriers via the gain control parameters.

In a similar manner as described previously for RRU1, the software settings within RRU3 are configured either manually or automatically such that Carriers 2 and 6 are present in downlink output signal 111 at the antenna port of RRU3. Compared to the downlink signal 110 at the antenna port of RRU2, the capacity of RRU3 which is configured via the software settings of RRU3 is much less than the capacity of RRU2. RRU4 is fed by a second optical port of RRU3 via bidirectional optical cable 115 to RRU4. Optical cable 115 performs the function of daisy chaining RRU4 with RRU3. The software settings within RRU4 are configured either manually or automatically such that Carriers 1, 4, 5 and 8 are present in downlink output signal 112 at the antenna port of RRU4. The capacity of RRU4 is set to a much lower value than RRU1. The relative capacity settings of RRU1, RRU2, RRU3 and RRU4 and can be adjusted dynamically as dis-

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cussed in connection with FIG. 7 to meet the capacity needs within the coverage zones determined by the physical positions of antennas connected to RRU1, RRU2, RRU3 and RRU4 respectively.

The present invention facilitates conversion and transport of several discrete relatively narrow RF bandwidths. This approach allows conversion of only those multiple specific relatively narrow bandwidths which carry useful or specific information. This approach also allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and allows transport of more individual operators' band segments over the optical fiber. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, Digital Up Converters located within the RRU which are dynamically software-programmable as discussed hereinafter can be re-configured to transport from the DAU input to any specific RRU output any specific narrow frequency band or bands, RF carriers or RF channels which are available at the respective RF input port of either DAU. This capability is illustrated in FIG. 1 where only specific frequency bands or RF carriers appear at the output of a given RRU.

A related capability of the present invention is that not only can the Digital Up Converters located within each RRU be configured to transport any specific narrow frequency band from the DAU input to any specific RRU output, but also the Digital Up Converters within each RRU can be configured to transport any specific time slot or time slots of each carrier from the DAU input to any specific RRU output. The DAU detects which carriers and corresponding time slots are active. This information is relayed to the individual RRUs via the management control and monitoring protocol software discussed hereinafter. This information is then used, as appropriate, by the RRUs for turning off and on individual carriers and their corresponding time slots.

Referring to FIG. 1 of the instant patent application, an alternative embodiment of the present invention may be described as follows. In a previous description of FIG. 1, a previous embodiment involved having downlink signals from two separate base stations belonging to the same wireless operator enter DAU1 and DAU2 input ports respectively. In an alternative embodiment, a second composite downlink input signal from e.g., a second base station belonging to a different wireless operator enters DAU2 at the DAU2 RF input port. In this embodiment, signals belonging to both the first operator and the second operator are converted and transported to RRU1, RRU2, RRU3 and RRU4 respectively. This embodiment provides an example of a neutral host wireless system, where multiple wireless operators share a common infrastructure comprised of DAU1, DAU2, RRU1, RRU2, RRU3 and RRU4. All the previously mentioned features and advantages accrue to each of the two wireless operators.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, the Digital Up Converters present in the RRU can be programmed to process various signal formats and modulation types including FDMA, CDMA, TDMA, OFDMA and others. Also, the Digital Up Converters present in the respective RRUs can be programmed to operate with signals to be transmitted within various frequency bands subject to the capabilities and limitations of the system architecture disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed

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Aug. 17, 2010. In one embodiment of the present invention where a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1, the transmitted signal at the antenna ports of RRU1, RRU2 and RRU4 will be a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to carrier 1 at the input port to DAU1.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, it is understood that the Digital Up Converters present in the respective RRUs can be programmed to transmit any desired composite signal format to each of the respective RRU antenna ports. As an example, the Digital Up Converters present in RRU1 and RRU2 can be dynamically software-reconfigured as described previously so that the signal present at the antenna port of RRU1 would correspond to the spectral profile shown in FIG. 1 as 110, and also that the signal present at the antenna port of RRU2 would correspond to the spectral profile shown in FIG. 1 as 109. The application for such a dynamic rearrangement of RRU capacity would be e.g., if a company meeting were suddenly convened in the area of the enterprise corresponding to the coverage area of RRU2. Although the description of some embodiments in the instant application refers to base station signals 107 and 108 as being on different frequencies, the system and method of the present invention readily supports configurations where one or more of the carriers which are part of base station signals 107 and 108 and are identical frequencies, since the base station signals are digitized, packetized, routed and switched to the desired RRU.

Another embodiment of the Distributed Antenna System in accordance with the present invention is shown in FIG. 2. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also as shown in FIG. 2 the Flexible Simulcast System 200 can be used to explain the operation of Flexible Simulcast with regard to uplink signals. As discussed previously with regard to downlink signals and by referring to FIG. 1, the uplink system shown in FIG. 2 is mainly comprised of DAU1 indicated at 201, RRU1 indicated at 203, RRU2 indicated at 204, DAU2 indicated at 202, RRU3 indicated at 205, and RRU4 indicated at 206. In a manner similar to the downlink operation explained by referring to FIG. 1, the operation of the uplink system shown in FIG. 2 can be understood as follows.

The Digital Down Converters present in each of RRU1, RRU2, RRU3 and RRU4 are dynamically software-configured as described previously so that uplink signals of the appropriate desired signal format(s) present at the receive antenna ports of the respective RRU1, RRU2, RRU3 and RRU4 are selected based on the desired uplink band(s) to be processed and filtered, converted and transported to the appropriate uplink output port of either DAU1 or DAU2. The DAUs and RRUs frame the individual data packets corresponding to their respective radio signature using the Common Public Interface Standard (CPRI). Other Interface standards are applicable provided they uniquely identify data packets with respective RRUs. Header information is transmitted along with the data packet which identifies the RRU and DAU that corresponds to the individual data packet.

In one example for the embodiment shown in FIG. 2, RRU1 and RRU3 are configured to receive uplink signals within the Carrier 2 bandwidth, whereas RRU2 and RRU4 are both configured to reject uplink signals within the Carrier 2 bandwidth. When RRU3 receives a strong enough signal at its

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receive antenna port within the Carrier 2 bandwidth to be properly filtered and processed, the Digital Down Converters within RRU3 facilitate processing and conversion. Similarly, when RRU1 receives a strong enough signal at its receive antenna port within the Carrier 2 bandwidth to be properly filtered and processed, the Digital Down Converters within RRU1 facilitate processing and conversion. The signals from RRU1 and RRU3 are combined based on the active signal combining algorithm, and are fed to the base station connected to the uplink output port of DAU1. The term simulcast is frequently used to describe the operation of RRU1 and RRU3 with regard to uplink and downlink signals within Carrier 2 bandwidth. The term Flexible Simulcast refers to the fact that the present invention supports dynamic and/or manual rearrangement of which specific RRU are involved in the signal combining process for each Carrier bandwidth.

Referring to FIG. 2, the Digital Down Converters present in RRU1 are configured to receive and process signals within Carrier 1-8 bandwidths. The Digital Down Converters present in RRU2 are configured to receive and process signals within Carrier 1, 3, 4 and 6 bandwidths. The Digital Down Converters present in RRU3 are configured to receive and process signals within Carrier 2 and 6 bandwidths. The Digital Down Converters present in RRU4 are configured to receive and process signals within Carrier 1, 4, 5 and 8 bandwidths. The respective high-speed digital signals resulting from processing performed within each of the four RRU are routed to the two DAUs. As described previously, the uplink signals from the four RRUs are combined within the respective DAU corresponding to each base station.

An aspect of the present invention includes an integrated Pilot Beacon function within the each RRU. In an embodiment, each RRU comprises a unique software programmable Pilot Beacon as discussed hereinafter. This approach is intended for use in CDMA and/or WCDMA indoor DAS networks. A very similar approach can be effective for indoor location accuracy enhancement for other types of networks such as LTE and WiMAX. Because each RRU is already controlled and monitored via the DAUs which comprise the network, there is no need for costly deployment of additional dedicated wireless modems for remote monitoring and control of pilot beacons.

An RRU-integrated Pilot Beacon approach is employed for both CDMA and WCDMA networks. Each operational pilot beacon function within an RRU employs a unique PN code (in that area) which effectively divides the WCDMA or CDMA indoor network coverage area into multiple small "zones" (which each correspond to the coverage area of a low-power Pilot Beacon). Each Pilot Beacon's location, PN code and RF Power level are known by the network. Each Pilot Beacon is synchronized to the WCDMA or CDMA network, via its connection to the DAU.

Unlike the transmit signal from a base station which is "dynamic", the Pilot Beacon transmit signal will be effectively "static" and its downlink messages will not change over time based on network conditions.

For a WCDMA network, in Idle mode each mobile subscriber terminal is able to perform Pilot Signal measurements of downlink signals transmitted by base stations and Pilot Beacons. When the WCDMA mobile subscriber terminal transitions to Active mode, it reports to the serving cell all its Pilot Signal measurements for base stations and for Pilot Beacons. For CDMA networks, the operation is very similar. For some RRU deployed in an indoor network, the RRU can be provisioned as either a Pilot Beacon or to serve mobile subscribers in a particular operator bandwidth, but not both.

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For a WCDMA network, existing inherent capabilities of the globally-standardized networks are employed. The WCDMA mobile subscriber terminal is able to measure the strongest CPICH RSCP (Pilot Signal Code Power) in either Idle mode or any of several active modes. Also, measurements of CPICH Ec/No by the mobile subscriber terminal in either Idle mode or any of several active modes are possible. As a result, the mobile subscriber terminal reports all available RSCP and Ec/No measurements via the serving base station (whether indoor or outdoor) to the network. Based on that information, the most likely mobile subscriber terminal location is calculated and/or determined. For CDMA networks, the operation is very similar to the process described herein.

A previously described embodiment of the present invention referring to FIG. 1 involved having a wideband CDMA signal present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. In the previously described embodiment, the transmitted signal at the antenna ports of RRU1, RRU2 and RRU4 is a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to carrier 1 at the input port to DAU1. An alternative embodiment of the present invention is one where a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. However, in the alternative embodiment the transmitted signal at the antenna port of RRU1 differs slightly from the previous embodiment. In the alternative embodiment, a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. The transmitted signal from RRU1 is a combination of the wideband CDMA signal which was present at the input port to DAU1, along with a specialized WCDMA pilot beacon signal. The WCDMA pilot beacon signal is intentionally set well below the level of the base station pilot signal.

A further alternative embodiment can be explained referring to FIG. 1 which applies in the case where CDMA signals are generated by the base station connected to the input port of DAU1. In this further alternative embodiment of the present invention, the transmitted signal at the antenna port of RRU1 is a combination of the CDMA signal which was present at the input port to DAU1, along with a specialized CDMA pilot beacon signal. The CDMA pilot beacon signal is intentionally set well below the level of the base station pilot signal.

An embodiment of the present invention provides enhanced accuracy for determining location of indoor wireless subscribers. FIG. 4 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU). Each Remote Radio Head provides a unique header information on data received by that Remote Radio Head. This header information in conjunction with the mobile user's radio signature are used to localize the user to a particular cell. The DAU signal processing can identify the individual carriers and their corresponding time slots. A header is included with each data packet that uniquely identifies the corresponding RRU. The DAU can detect the carrier frequency and the corresponding time slot associated with the individual RRUs. The DAU has a running data base that identifies each carrier frequency and time slot with a respective RRU. The carrier frequency and time slot is the radio signature that uniquely identifies the GSM user.

The DAU communicates with a Network Operation Center (NOC) via a Ethernet connection or an external modem, as depicted in FIG. 5. Once a E911 call is initiated the Mobile Switching Center (MSC) in conjunction with the NOC can identify the corresponding Base Transceiver Station (BTS) where the user has placed the call. The user can be localized

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within a BTS cell. The NOC then makes a request to the individual DAUs to determine if the E911 radio signature is active in their indoor cell. The DAU checks its data base for the active carrier frequency and time slot. If that radio signature is active in the DAU, then that DAU will provide the NOC

A further embodiment of the present invention includes LTE to provide enhanced accuracy for determining the location of indoor wireless subscribers. GSM uses individual carriers and time slots to distinguish users whereas LTE uses multiple carriers and time slot information to distinguish users. The DAU can simultaneously detect multiple carriers and their corresponding time slots to uniquely identify the LTE user. The DAU has a running data base that identifies the carrier frequencies and time slot radio signature for the respective RRU. This information can be retrieved from the NOC once a request is made to the DAU.

Referring next to FIG. 7, the DAU embedded software control module and RRU embedded software control module can be better understood in connection with the operation of key functions of the DAU and RRU. One such key function is determining and/or setting the appropriate amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs to meet desired capacity and throughput objectives. The DAU embedded software control module comprises a DAU Monitoring module that detects which carriers and corresponding time slots are active for each RRU. The DAU embedded software control module also comprises a DAU Management Control module which communicates with the RRU over a fiber optic link control channel via a control protocol with the RRU Management Control module. In turn, the RRU Management Control module sets the individual parameters of all the RRU Digital Up-Converters to enable or disable specific radio resources from being transmitted by a particular RRU or group of RRUs, and also sets the individual parameters of all the RRU Digital Down-Converters to enable or disable specific uplink radio resources from being processed by a particular RRU or group of RRUs.

In an embodiment, an algorithm operating within the DAU Monitoring module, that detects which carriers and corresponding time slots for each carrier are active for each RRU, provides information to the DAU Management Control module to help identify when, e.g., a particular downlink carrier is loaded by a percentage greater than a predetermined threshold whose value is communicated to the DAU Management Control module by the DAU's Remote Monitoring and Control function. If that occurs, the DAU Management Control module adaptively modifies the system configuration to slowly begin to deploy additional radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular RRU which need those radio resources within its coverage area. At the same time, in at least some embodiments the DAU Management Control module adaptively modifies the system configuration to slowly begin to remove certain radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular RRU which no longer needs those radio resources within its coverage area. Another such key function of the DAU embedded software control module and RRU embedded software control module is determining and/or setting and/or analyzing the appropriate transmission parameters and monitoring parameters for the integrated Pilot Beacon function contained within each RRU. These Pilot Beacon transmission and monitoring parameters include Beacon Enable/Disable, Beacon Carrier Frequencies, Beacon Transmit Power, Beacon PN Code, Beacon Downlink BCH Message Content, Beacon Alarm, Beacon Delay Setting

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and Beacon Delay Adjustment Resolution. The RRU Pilot Beacon Control module communicates with the pilot beacon generator function in the RRU to set and monitor the pilot beacon parameters as listed herein.

In summary, the Reconfigurable Distributed Antenna System of the present invention described herein efficiently conserves resources and reduces costs. The reconfigurable system is adaptive or manually field-programmable, since the algorithms can be adjusted like software in the digital processor at any time.

Although the present invention has been described with reference to the preferred embodiments, it will be understood that the invention is not limited to the details described thereof. Various substitutions and modifications have been suggested in the foregoing description, and others will occur to those of ordinary skill in the art. Therefore, all such substitutions and modifications are intended to be embraced within the scope of the invention as defined in the appended claims.

APPENDIX I

Glossary of Terms

ACLR	Adjacent Channel Leakage Ratio
ACPR	Adjacent Channel Power Ratio
ADC	Analog to Digital Converter
AQDM	Analog Quadrature Demodulator
AQM	Analog Quadrature Modulator
AQDMC	Analog Quadrature Demodulator Corrector
AQMC	Analog Quadrature Modulator Corrector
BPF	Bandpass Filter
BTS	Base Transceiver System or Base Station
CDMA	Code Division Multiple Access
CFR	Crest Factor Reduction
DAC	Digital to Analog Converter
DAU	Digital Access Unit
DET	Detector
DHMPA	Digital Hybrid Mode Power Amplifier
DDC	Digital Down Converter
DNC	Down Converter
DPA	Doherty Power Amplifier
DQDM	Digital Quadrature Demodulator
DQM	Digital Quadrature Modulator
DSP	Digital Signal Processing
DUC	Digital Up Converter
EER	Envelope Elimination and Restoration
EF	Envelope Following
ET	Envelope Tracking
EVM	Error Vector Magnitude
FFLPA	Feedforward Linear Power Amplifier
FIR	Finite Impulse Response
FPGA	Field-Programmable Gate Array
GSM	Global System for Mobile communications
I-Q	In-phase/Quadrature
IF	Intermediate Frequency
LINC	Linear Amplification using Nonlinear Components
LO	Local Oscillator
LPF	Low Pass Filter
MCPA	Multi-Carrier Power Amplifier
MDS	Multi-Directional Search
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
PD	Digital Baseband Predistortion
PLL	Phase Locked Loop
PN	Pseudo-Noise
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RRH	Remote Radio Head
RRU	Remote Radio Head Unit
SAW	Surface Acoustic Wave Filter
UMTS	Universal Mobile Telecommunications System
UPC	Up Converter
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

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What is claimed is:

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

providing one or more remote radio units, each remote radio unit configured to transmit one or more downlink RF signals and to receive one or more uplink RF signals; providing at least one digital access unit configured to communicate with the one or more remote radio units; translating the uplink and downlink signals between RF and base band as appropriate;

packetizing the uplink and downlink base band signals, wherein the packetized signals correspond to a plurality of carriers;

configuring each remote radio unit to receive or transmit a respective subset of the plurality of carriers, each respective subset of the plurality of carriers including a number of carriers;

reconfiguring each remote radio unit by:

determining a load percentage for each remote radio unit; and

increasing or decreasing the number of carriers in the respective subset of the plurality of carriers based on the load percentage; and

routing and switching the packetized signals among the one or more remote radio units via the at least one digital access unit according to a result of the reconfiguring.

2. The method of claim 1 wherein each carrier corresponds to a respective RF band.

3. The method of claim 1 wherein determining the load percentage comprises detecting which carriers are active for each remote radio unit.

4. The method of claim 1 wherein the at least one digital access unit comprises a first digital access unit and a second digital access unit configured to communicate with each other via a first optical cable.

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5. The method of claim 4 wherein the one or more remote radio units comprise a first remote radio unit and a second remote radio unit, the first remote radio unit configured to communicate with the first digital access unit via a second optical cable, and the second remote radio unit configured to communicate with the second digital access unit via a third optical cable.

6. The method of claim 5 wherein the first digital access unit is configured to communicate with a first base station, and the second digital access unit is configured to communicate with a second base station.

7. The method of claim 6 wherein the first base station transmits or receives RF signals corresponding to a first number of carriers, and the second base station transmits or receives RF signals corresponding to a second number of carriers.

8. The method of claim 7 wherein the first number of carriers and the second number of carriers correspond to different RF bands.

9. The method of claim 7 wherein the first remote radio unit is configured to receive or transmit RF signals corresponding to one of the second number of carriers.

10. The method of claim 7 wherein the second remote radio unit is configured to receive or transmit RF signals corresponding to one of the first number of carriers.

11. The method of claim 6 wherein the first base station and the second base station are associated with different wireless operators.

12. The method of claim 6 wherein the first base station and the second base station are associated with a common wireless operator.

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(12) **United States Patent**
Hejazi et al.(10) **Patent No.:** **US 9,197,358 B2**(45) **Date of Patent:** **Nov. 24, 2015**(54) **METHOD AND SYSTEM FOR SOFT
FREQUENCY REUSE IN A DISTRIBUTED
ANTENNA SYSTEM**(71) Applicant: **DALI SYSTEMS CO. LTD.**, George
Town, Grand Cayman, KY (US)(72) Inventors: **Seyed Amin Hejazi**, Burnaby (CA);
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Grand Cayman (KY)(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.(21) Appl. No.: **13/894,309**(22) Filed: **May 14, 2013**(65) **Prior Publication Data**

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(2013.01); **H04J 11/0023** (2013.01); **H04W**
28/06 (2013.01); **H04W 72/04** (2013.01)(58) **Field of Classification Search**CPC H04L 1/00; H04W 28/06; H04W 52/04;
H04W 72/04; H04J 11/0023
USPC 370/329, 330, 335, 336, 338, 341-347;
455/403, 429, 427, 430, 446, 447, 450,
455/452.1, 509, 517

See application file for complete search history.

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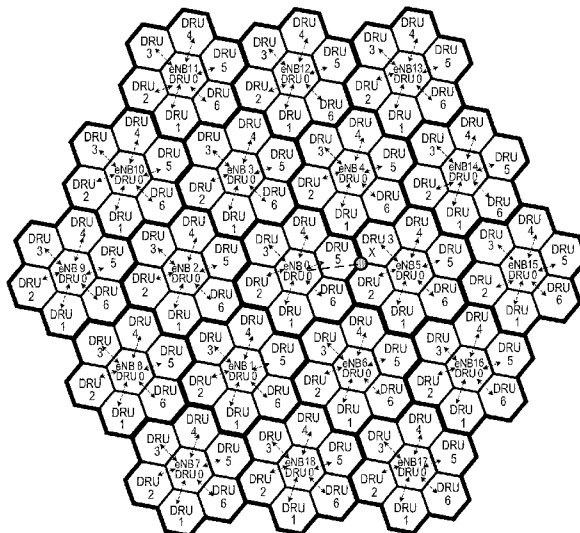
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Primary Examiner — Dady Chery(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend &
Stockton LLP(57) **ABSTRACT**

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.

21 Claims, 9 Drawing Sheets

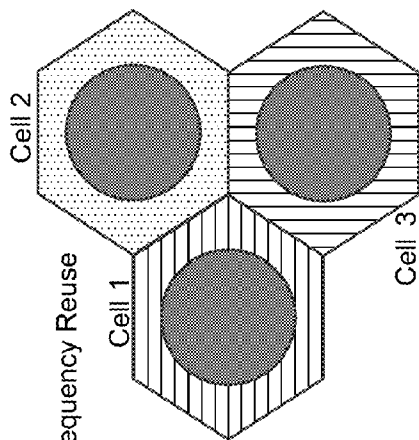


FIG. 1B

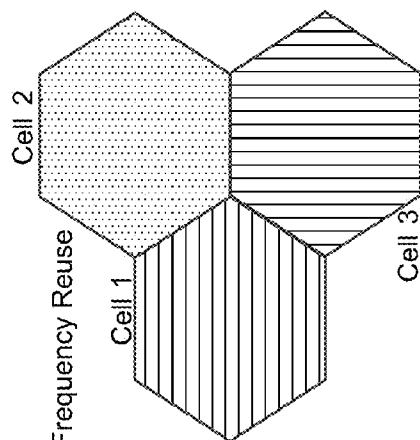


FIG. 1A

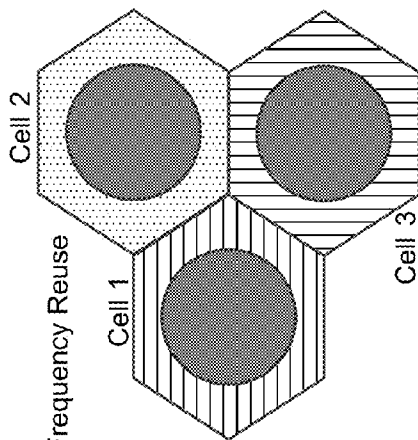


FIG. 1C

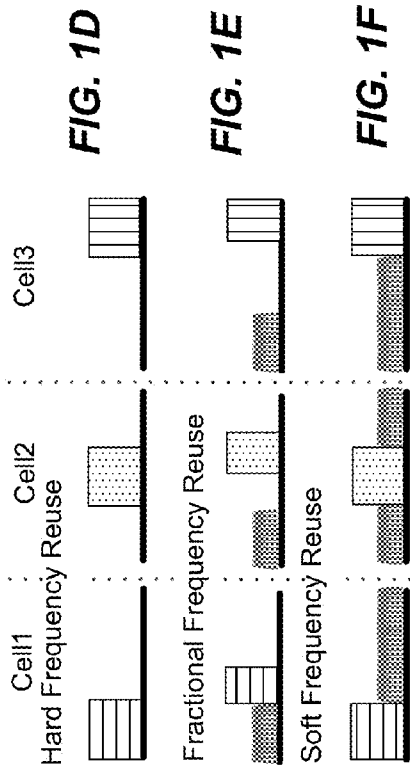


FIG. 1D

FIG. 1E

FIG. 1F

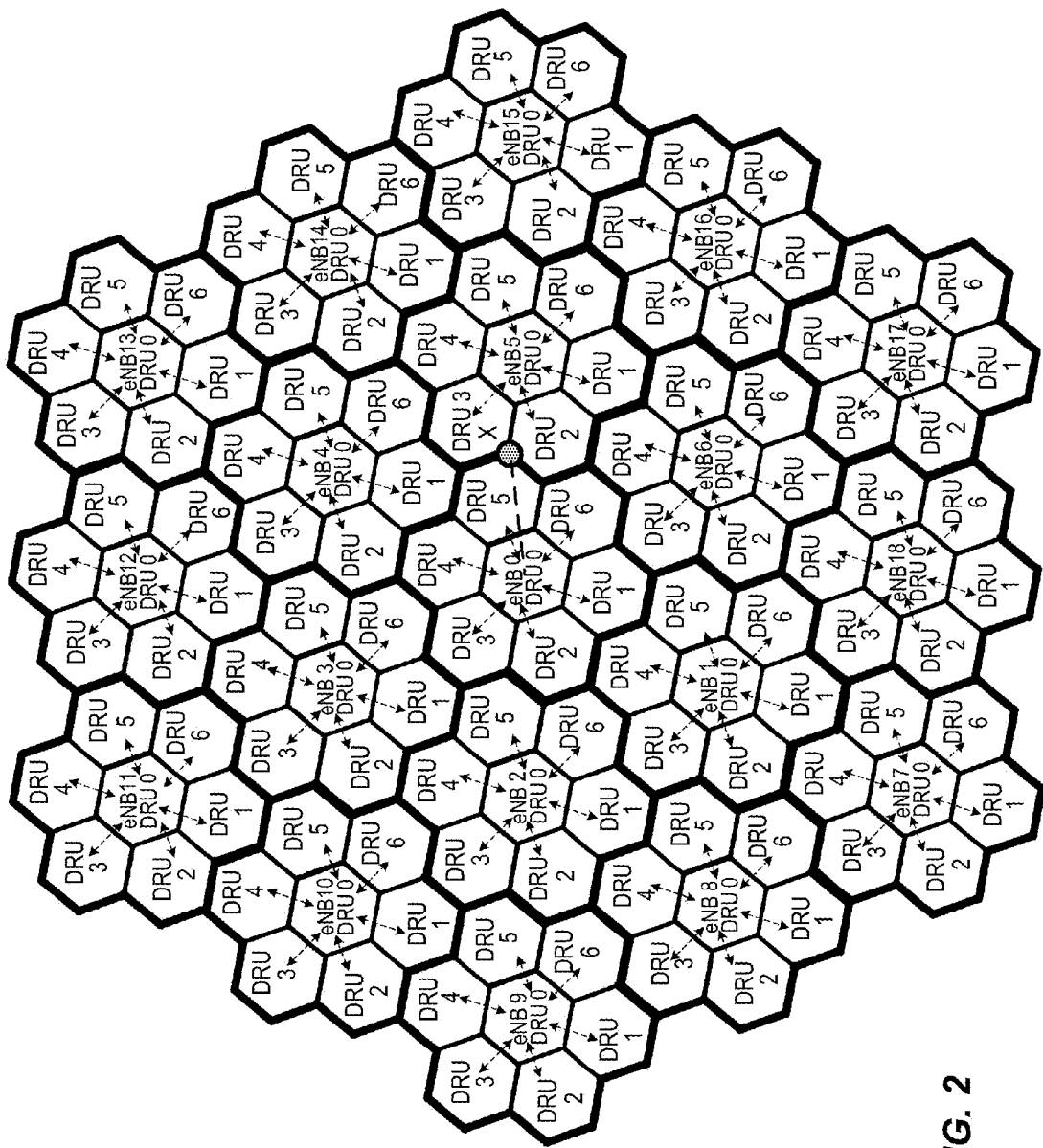


FIG. 2

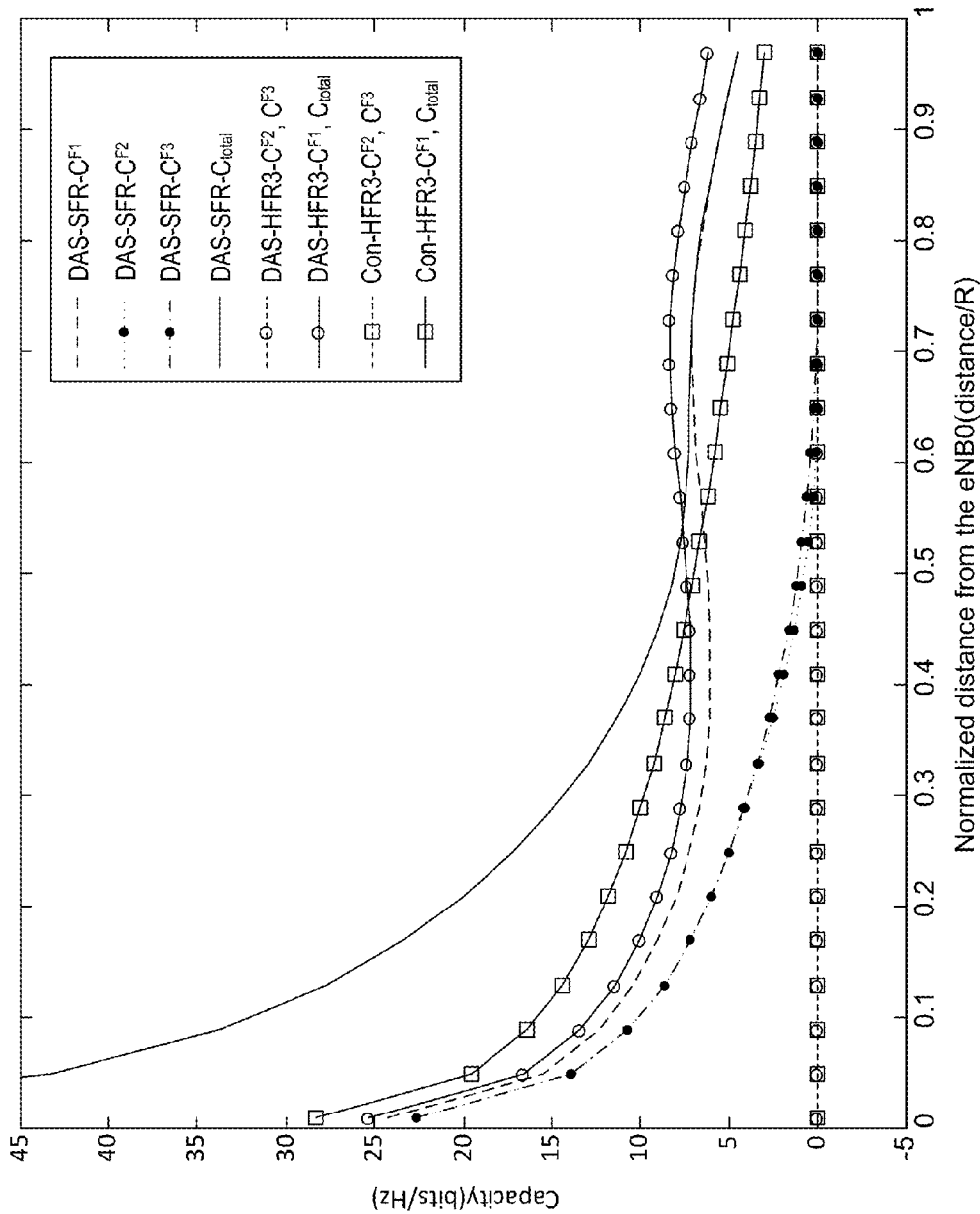


FIG. 3

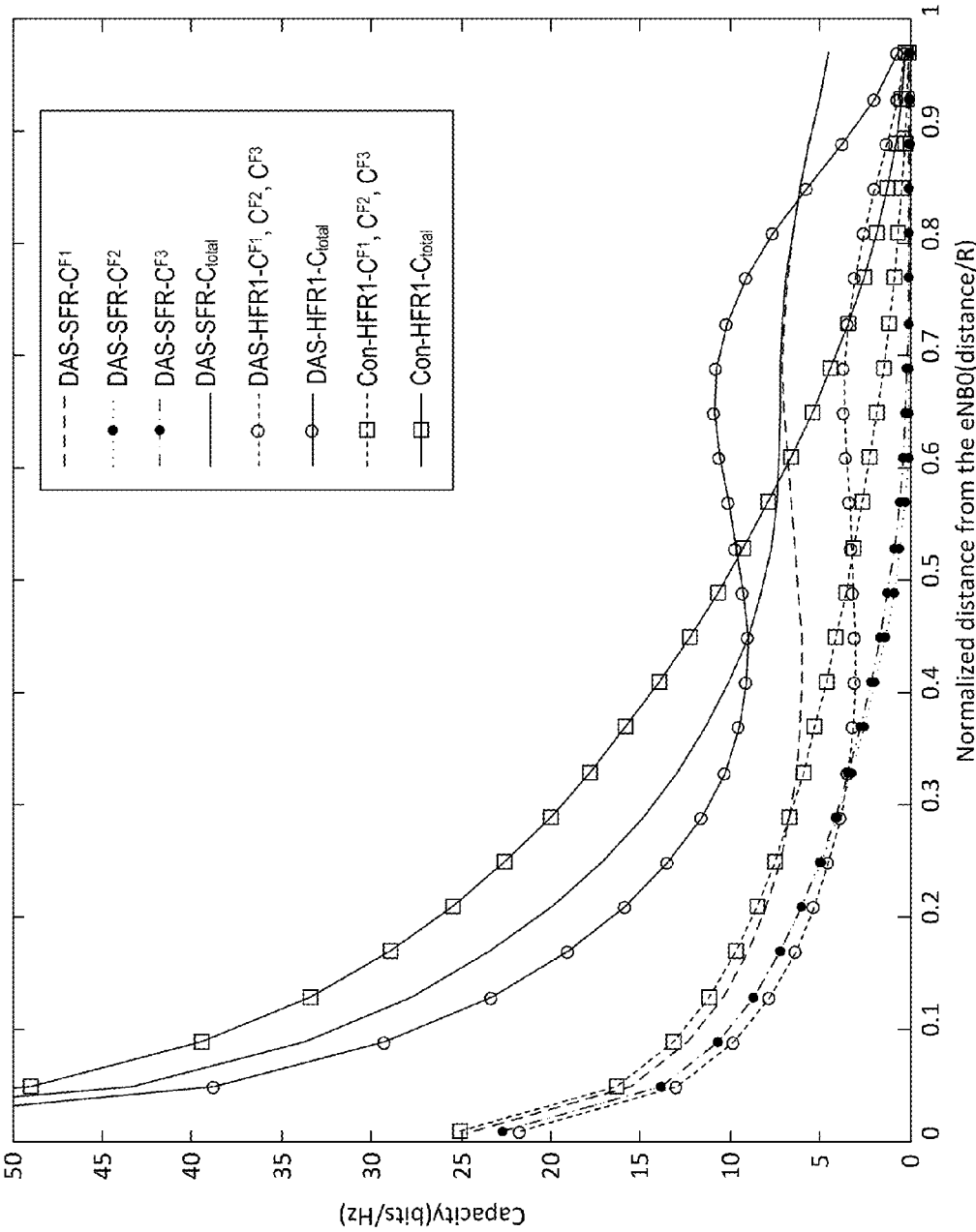


FIG. 4

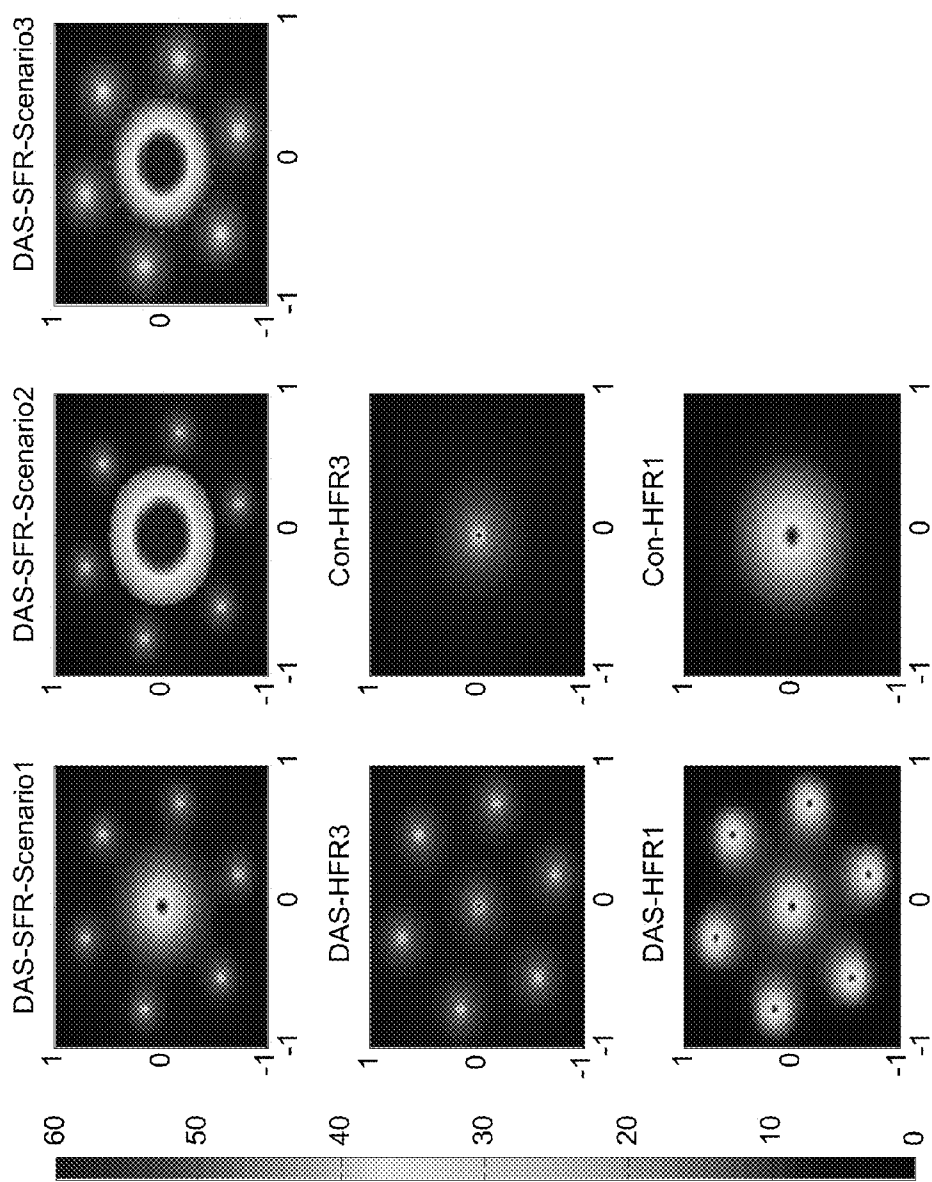


FIG. 5

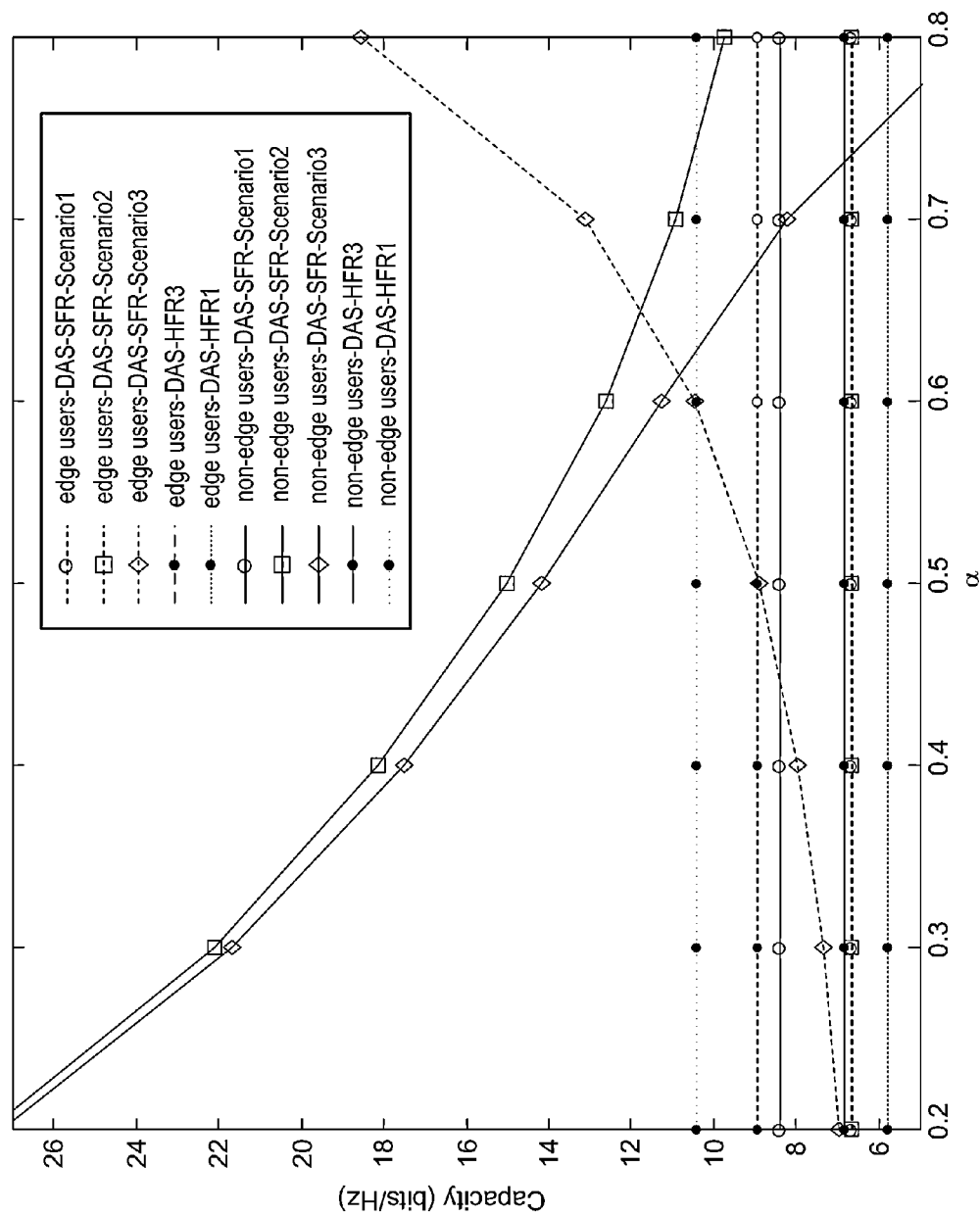


FIG. 6

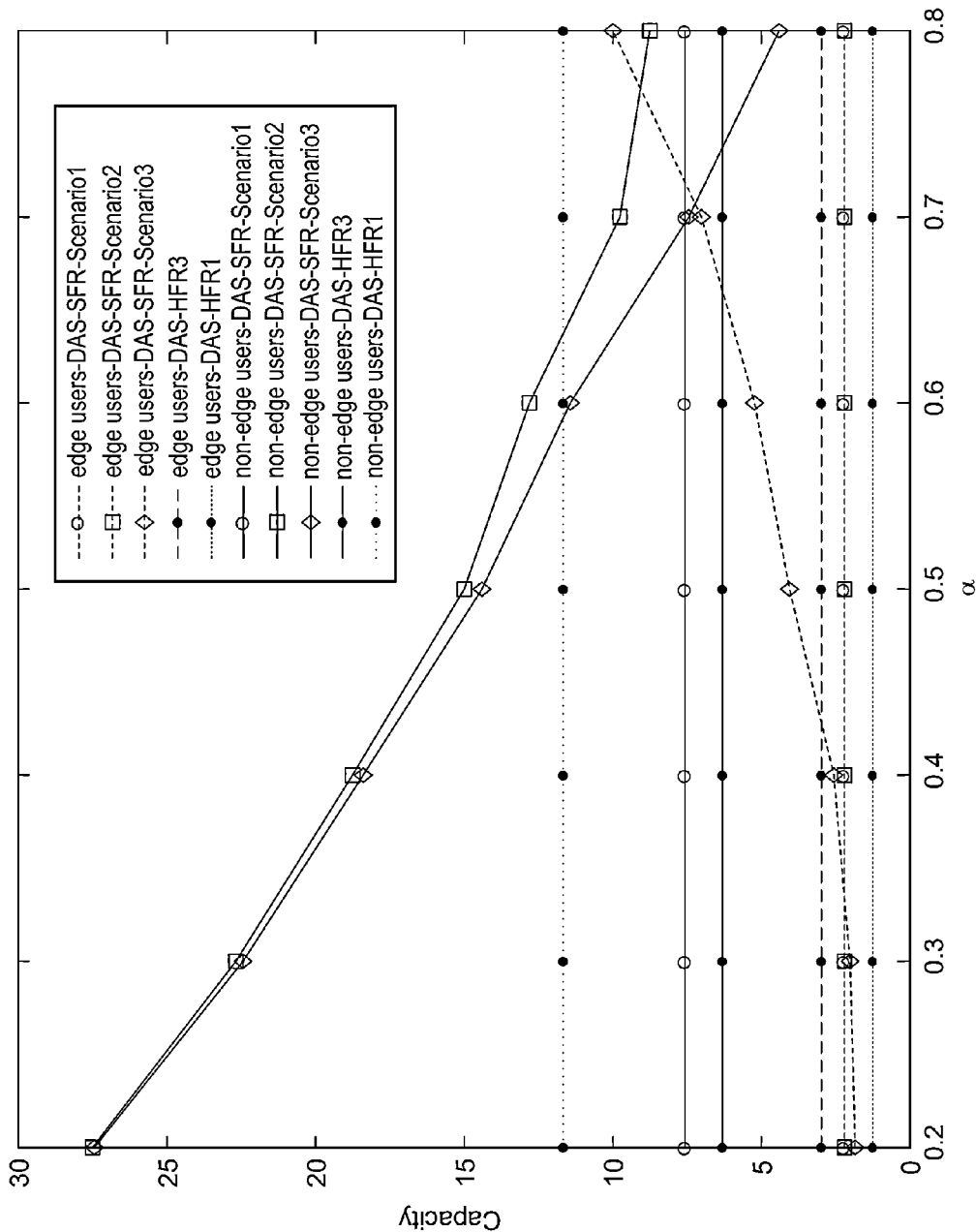


FIG. 7

800

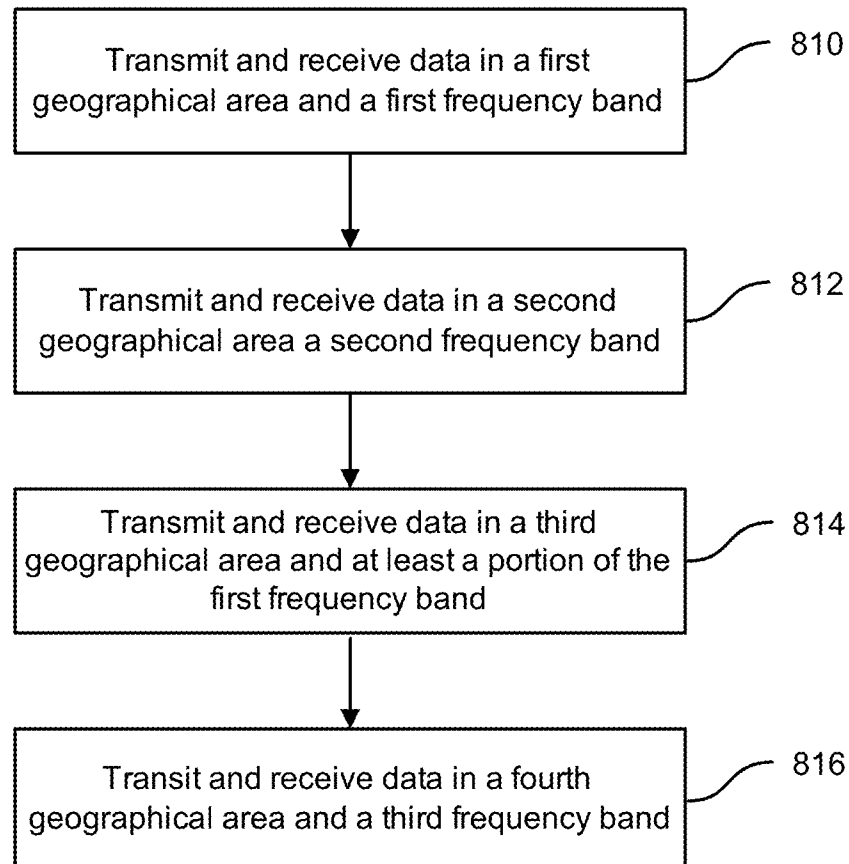


FIG. 8

900

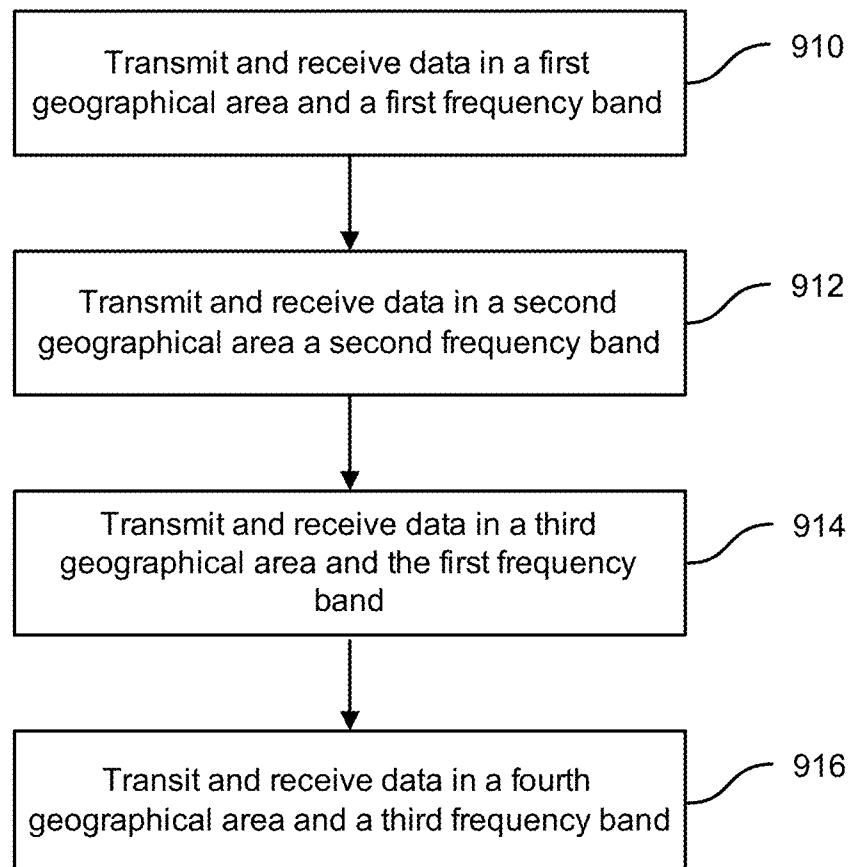


FIG. 9

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

CROSS-REFERENCES TO RELATED APPLICATIONS

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

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.

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.

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

SUMMARY OF THE INVENTION

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.

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

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over a fourth geographic footprint including and surrounding the third geographic footprint.

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.

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.

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 communicate 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.

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.

According to another embodiment of the present invention, a method of distributing communications frequencies is pro-

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vided. 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.

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.

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.

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.

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

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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.

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.

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.

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.

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

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

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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;

FIG. 1E illustrates, for the Fractional Reuse case, the transmit/receive power as a function of frequency according to embodiments of the present invention;

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;

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

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

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

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;

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

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.

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

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

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.

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

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

Referring to FIGS. 1C-1F, frequencies in the grey frequency band (~upper $\frac{2}{3}$ 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.

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. 1F, 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. 1F: 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.

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 opti-

mization 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.

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.

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.

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).

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 eNB1, 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).

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.

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.

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.

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.

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

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lower power broadcast from the DRU in the cell (i.e., grey spectra) is also increased for SFR in comparison to FFR.

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).

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.

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.

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.

System Architecture (DAS-SFR)

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

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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.

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 $P_n^{(i,f)}=P$.

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.

Resource Allocation Scenarios:

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 ($F_i, i=1, 2, 3$).

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:

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.

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.

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.

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.

Channel Model and Received Signal

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 0^{th} cell at frequency f can be expressed as:

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

where $H^{(i,f)} \in \mathbb{C}^{1 \times 7}$, $i=0, 1, \dots, 18$, denotes the channel matrix between the DRUs in the i -th cell and the user in the central (0^{th}) cell, $x^{(i,f)} = [x_0^{(i,f)}, x_1^{(i,f)}, \dots, x_6^{(i,f)}]^T \in \mathbb{C}^{7 \times 1}$, $i=0, 1, \dots, 18$ is the transmitted signal vector of the DRUs in the i -th cell, $n(f) \in \mathbb{C}^{1 \times 1}$ denotes the white noise vector with distribution $\text{CN}(0, \sigma_n^2 I_1)$.

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The distributed antenna power constraint is considered, we have

$$E[|x_n^{(i,f)}|^2] \leq P_n^{(i,f)}, n=0,1,\dots,6, i=0,1,\dots,18, \quad (2)$$

where in DAS-SFR,

$$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=1, 2, \dots, 7, 9, 11, 13, 15, 17),$$

$$x_n^{(i,F_2)}=0, P_n^{(i,F_2)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=0, 2, 4, 6, 7, 8, 10, 11, 12, 14, 15, 16, 18),$$

$$x_n^{(i,F_3)}=0, P_n^{(i,F_3)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=0, 1, 3, 5, 8, 9, 10, 12, 13, 14, 16, 17, 18),$$

in DAS-HFR3 (frequency reuse factor 3),

$$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=1, 2, \dots, 7, 9, 11, 13, 15, 17),$$

$$x_n^{(i,F_2)}=0, P_n^{(i,F_2)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=0, 2, 4, 6, 7, 8, 10, 11, 12, 14, 15, 16, 18),$$

$$x_n^{(i,F_3)}=0, P_n^{(i,F_3)}=0 \text{ when } (n=1, 2, \dots, 6 \text{ and } i=0, 1, 3, 5, 8, 9, 10, 12, 13, 14, 16, 17, 18),$$

in DAS-HFR1 (frequency reuse factor 1),

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

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

$$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0 \text{ when } (n=0, 1, \dots, 6 \text{ and } i=1, 2, \dots, 7, 9, 11, 13, 15, 17) \text{ or } (n=1, 2, \dots, 6 \text{ and } i=0, 8, 10, 12, 14, 16, 18),$$

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

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

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

$$x_n^{(i,f)}=0, P_n^{(i,f)}=0 \text{ when } (n=1, \dots, 6 \text{ and } i=0, 1, \dots, 18 \text{ and } f=F_1, F_2, F_3) \text{ where } P_n^{(i,f)} \text{ denotes the power constraint of the } n\text{-th DRU in the } i\text{-th cell.}$$

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

$$H^{(i,f)} = H_w^{(i,f)} L^{(i,f)} \quad (3)$$

$$= [h_0^{(i,f)}, h_1^{(i,f)}, \dots, h_6^{(i,f)}] \cdot \text{diag}\{l_0^{(i,f)}, l_1^{(i,f)}, \dots, l_6^{(i,f)}\}$$

where $H_w^{(i,f)}$ and $L^{(i,f)}$ 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 0^{th} cell, respectively. $\{h_j^{(i,f)} | j=0, 1, \dots, 6; i=0, 1, \dots, 18; f=F_1, F_2, F_3\}$ are independent and identically distribute (i.i.d) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\{l_j^{(i,f)} | j=0, 1, \dots, 6; i=0, 1, \dots, 18; f=F_1, F_2, F_3\}$ can be modeled as)

$$l_n^{(i,f)} = \sqrt{D_n^{(i)} \gamma X_n^{(i,f)}}, n=0,1,\dots,6, i=0,1,\dots,18 \quad (4)$$

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

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

where σ_X is the shadowing standard deviation and

$$\lambda = \frac{\ln 10}{10}.$$

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:

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

The variance of N is derived by Central Limit Theorem as

$$\begin{aligned} \text{Var}(N^{(f)}) &= \left[\sum_{i=1}^{18} \sum_{n=0}^6 [l_n^{(i,f)}]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2 \right] I_1 \\ &= [\sigma^{(f)}]^2 I_1 \end{aligned} \quad (7)$$

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

$$y^{(f)} = H_w^{(0,f)} L^{(0,f)} x^{(0,f)} + N^{(f)} \quad (8)$$

Achievable Capacity of Distributed Antenna Network

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

$$C^{(f)} = E_{H_w^{(0,f)}} \left[\log_2 \det \left(I_1 + \frac{1}{[\sigma^{(f)}]^2} (H_w^{(0,f)} L^{(0,f)}) P^{(0,f)} (H_w^{(0,f)} L^{(0,f)})^H \right) \right] \quad (9)$$

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

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

where

$$\gamma_f = \frac{1}{[\sigma^{(f)}]^2} \sum_{i=0}^6 |h_i^{(0,f)}|^2 [l_i^{(0,f)}]^2 P_i^{(0,f)}$$

is a weighted chi-squared distributed random variable with p.d.f given by

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

where

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

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

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

$f = F_1, F_2, F_3$

where Ei(t) is the exponential integral function

$$\text{Ei}(t) = -\int_{-x}^{\infty} e^{-t} / t dt$$

and can be easily calculated with popular numerical tools such as MATLAB and MAPLE.

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

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

$f = F_1, F_2, F_3$

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

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

Analytical and Simulation Results

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} .

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.

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.

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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.

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.

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.

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.

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, αR) region and the exterior area is located in the (αR , R) region.

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.

Note that

$$N_{interior} = \alpha^2 N_{users},$$

$$N_{exterior} = (1 - \alpha^2) N_{users}, \quad (15)$$

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.

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

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

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

tech $\in$

$$\left\{ \begin{array}{l} \text{DAS} - \text{SFR} - \text{SC1}, \text{DAS} - \text{SFR} - \text{SC2}, \text{DAS} - \text{SFR} - \text{SC3}, \\ \text{DAS} - \text{HFR3}, \text{Con} - \text{HFR3}, \text{DAS} - \text{HFR1}, \text{Con} - \text{HFR1} \end{array} \right\}$$

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.

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.

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.

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.

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 .

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.

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.

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.

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

$$C_m^{(f)} = W_{RB}^{(f)} \log(1 + \text{SINR}_m^{(f)})_{f=F_1, F_2, F_3} \quad (16)$$

where, $W_{RB}^{(f)}$ is the bandwidth of RBs assigned to a UE and $\text{SINR}_m^{(f)}$ 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

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

where M is the number of UEs in a group.

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.

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.

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

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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.

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.

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

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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.

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.

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	$\frac{N_{RB(F_2)}}{\alpha^2 N_{users}}$	$\frac{N_{RB(F_3)}}{\alpha^2 N_{users}}$	$\frac{N_{RB(F_1)}}{(1 - \alpha^2) N_{users}}$	0	0
$\frac{N_{RB(F)}^{DAS-HFR3}}{N_{RB(F)}^{Con-HFR3}}$	$\frac{N_{RB(F_1)}}{N_{users}}$	0	0	$\frac{N_{RB(F_1)}}{N_{users}}$	0	0
$\frac{N_{RB(F)}^{DAS-HFR1}}{N_{RB(F)}^{Con-HFR1}}$	$\frac{N_{RB(F_1)}}{N_{users}}$	$\frac{N_{RB(F_2)}}{N_{users}}$	$\frac{N_{RB(F_3)}}{N_{users}}$	$\frac{N_{RB(F_1)}}{N_{users}}$	$\frac{N_{RB(F_2)}}{N_{users}}$	$\frac{N_{RB(F_3)}}{N_{users}}$

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.

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

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	$128.1 + 37.6 \log_{10}(R(\text{km}))$

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TABLE 2-continued

Simulation Parameters	
Parameters	Value
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:

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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.

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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.

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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.

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Related U.S. Application Data

continuation of application No. 14/800,515, filed on Jul. 15, 2015, now Pat. No. 9,419,837, which is a continuation of application No. 14/260,145, filed on Apr. 23, 2014, now Pat. No. 9,137,078, which is a continuation of application No. 13/211,247, filed on Aug. 16, 2011, now Pat. No. 8,737,300.

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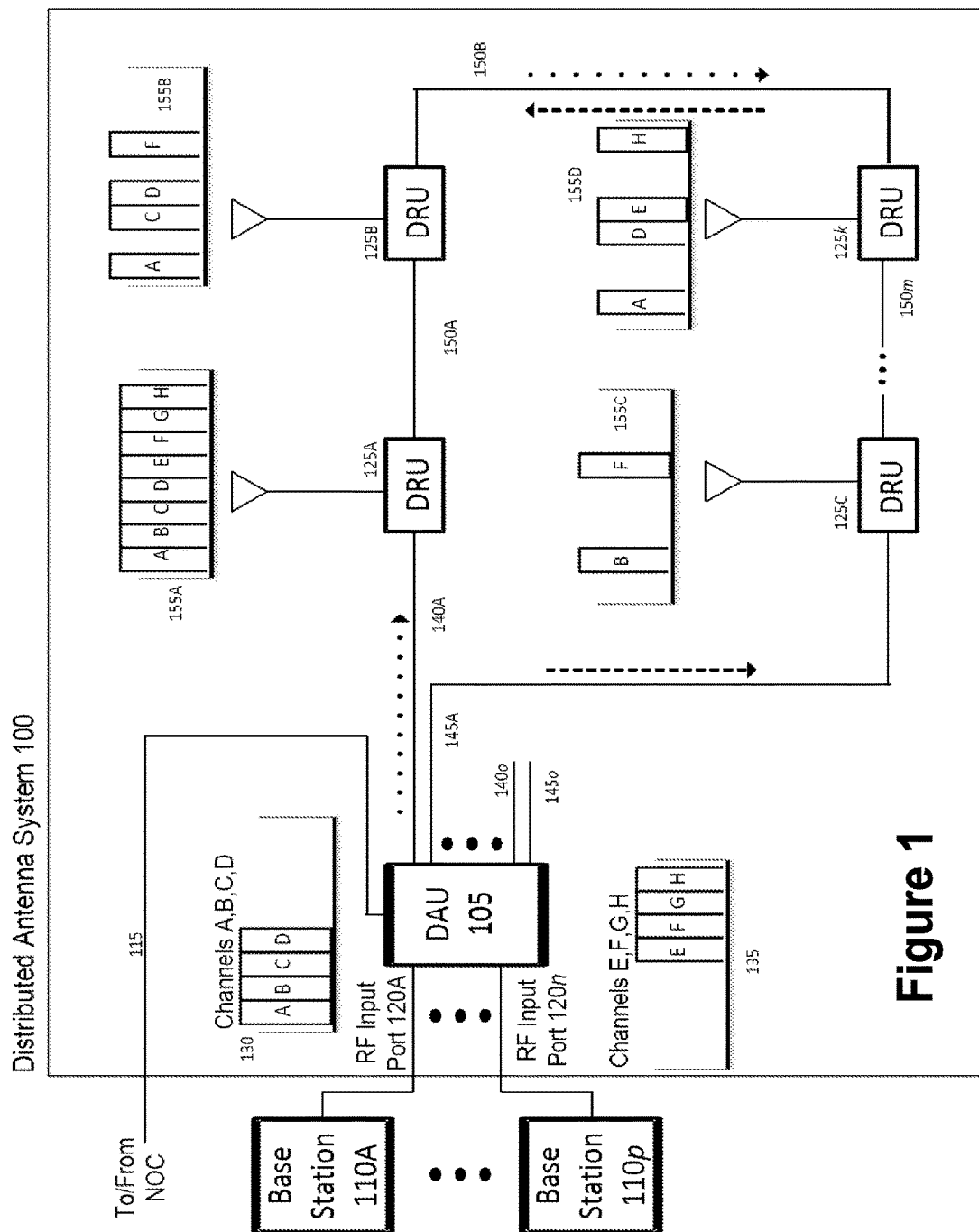
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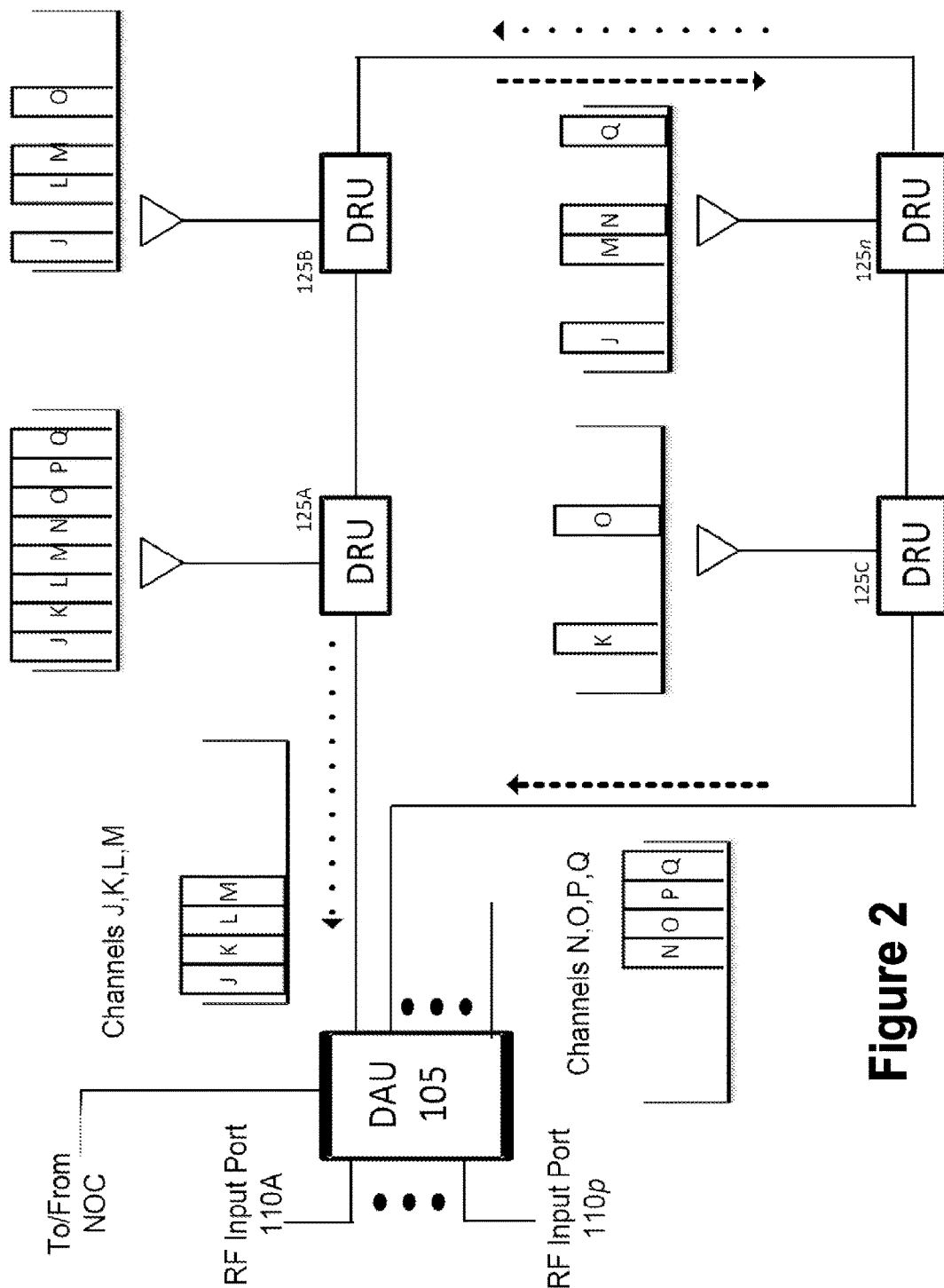


Figure 2

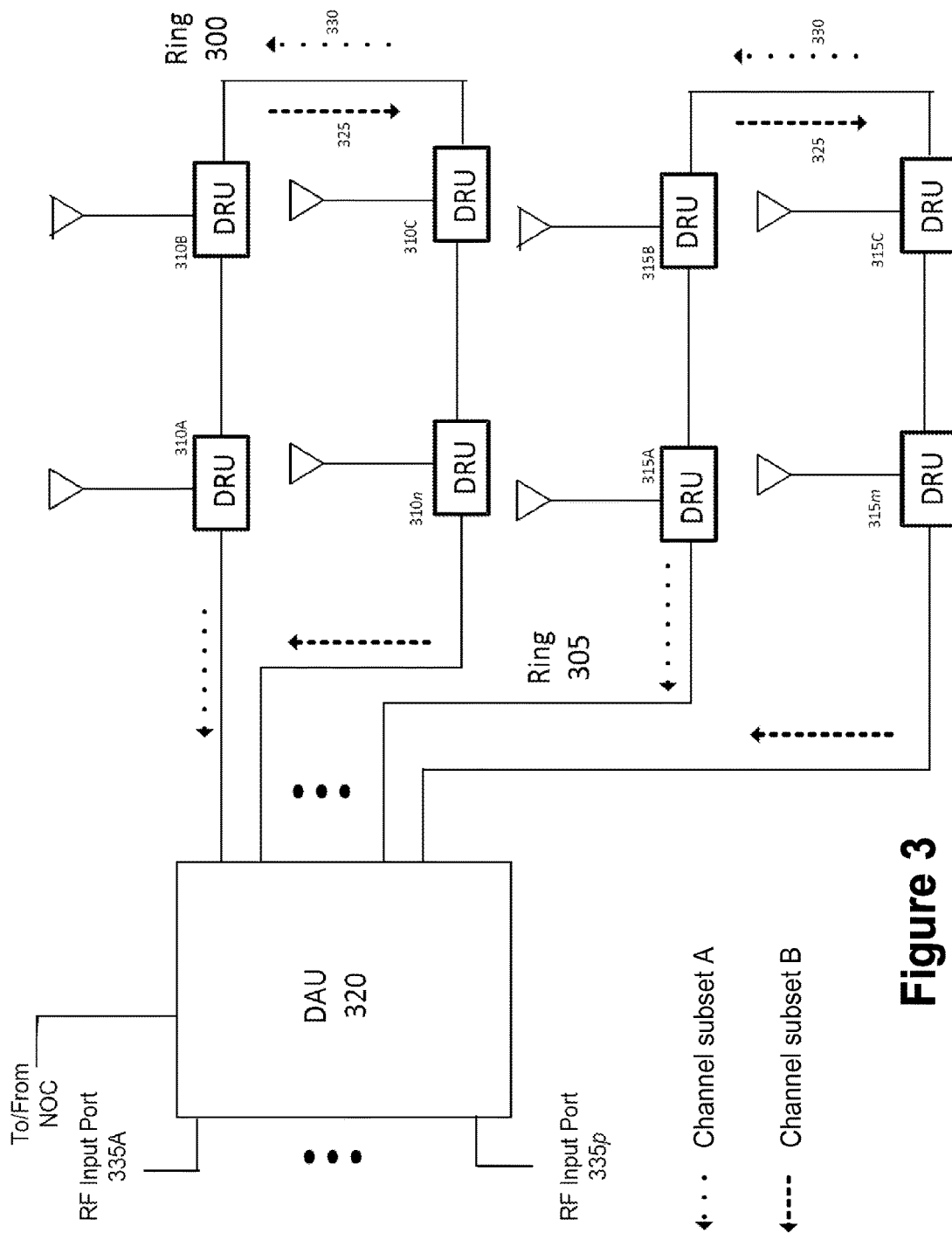


Figure 3

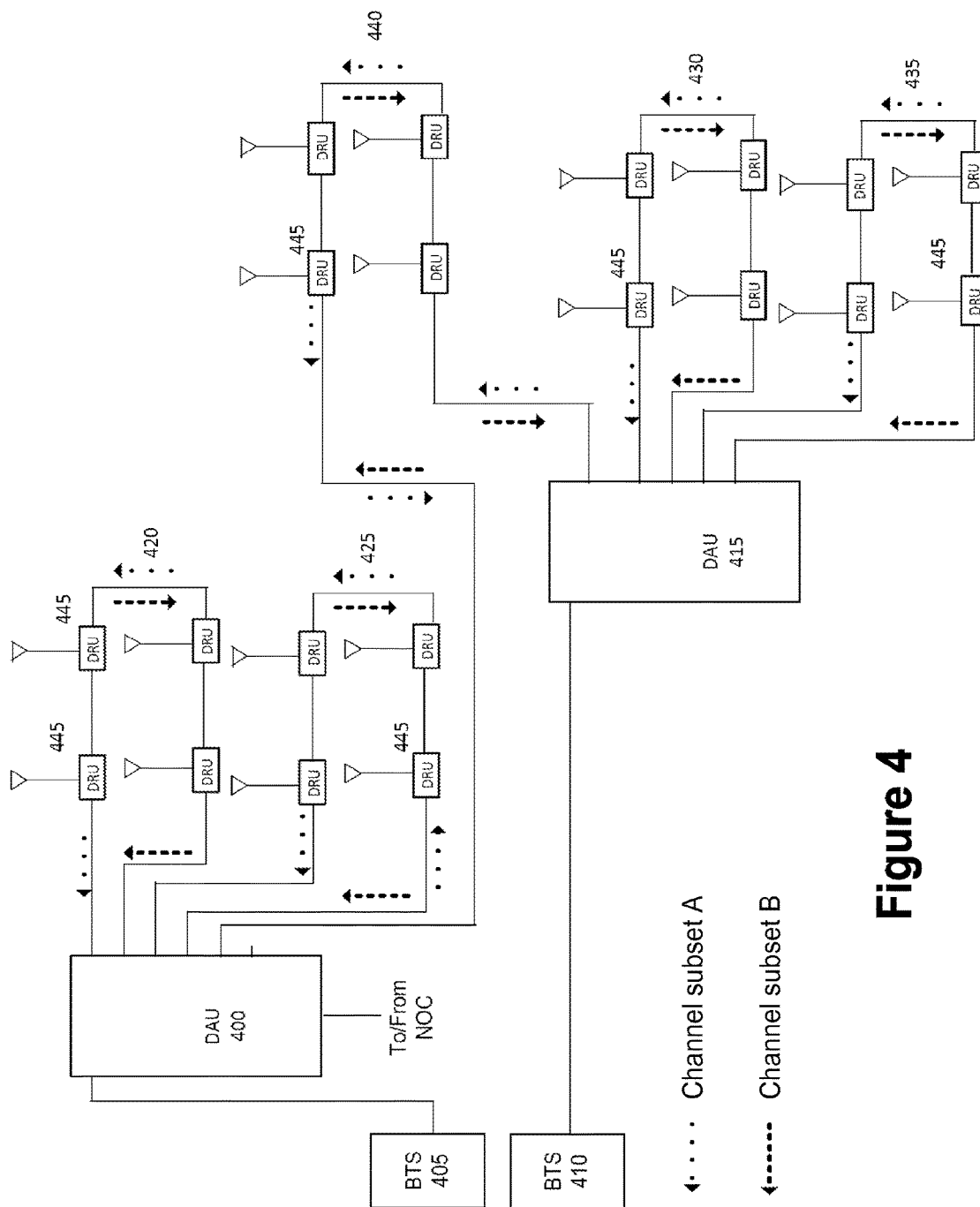


Figure 4

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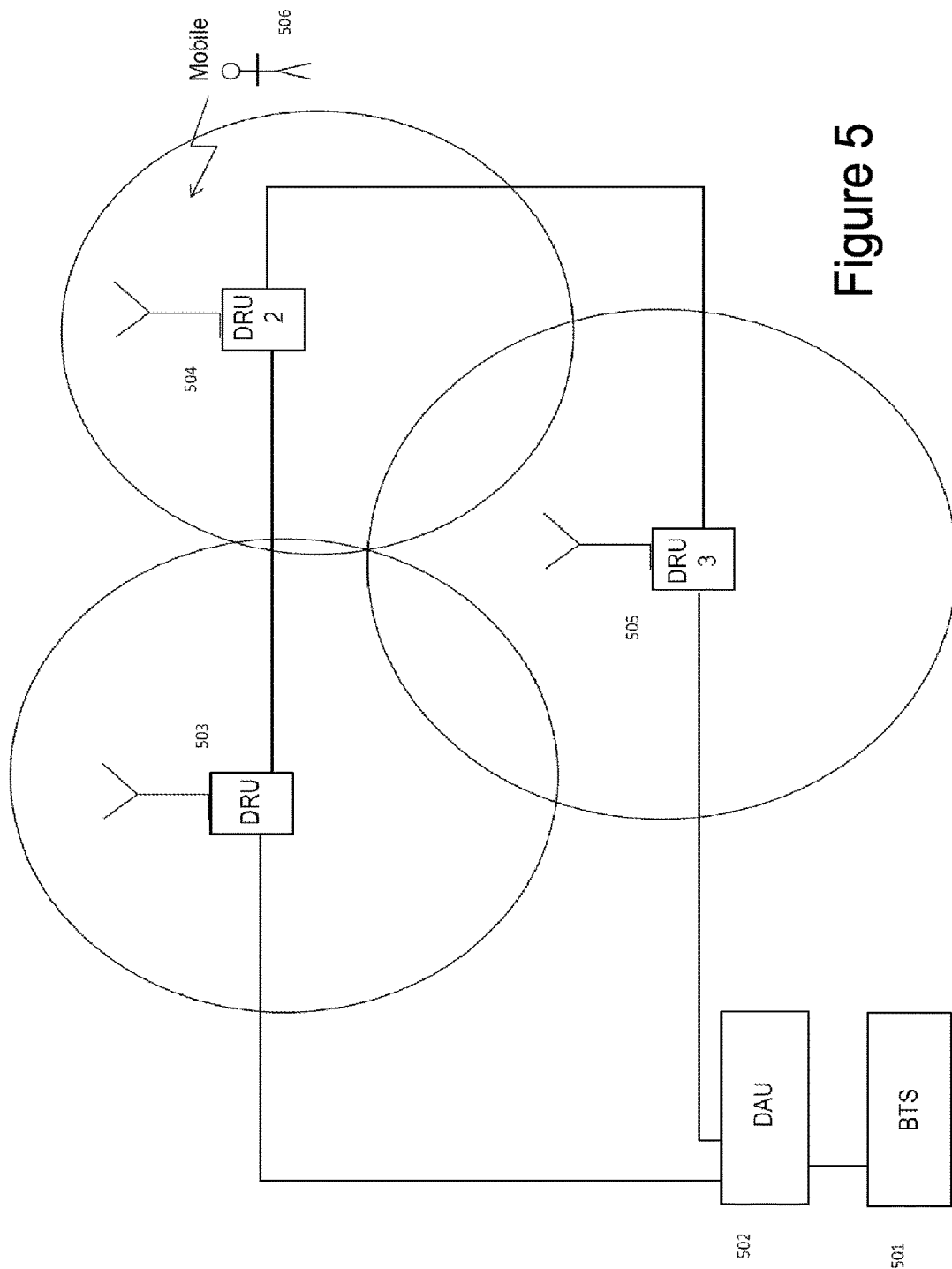


Figure 5

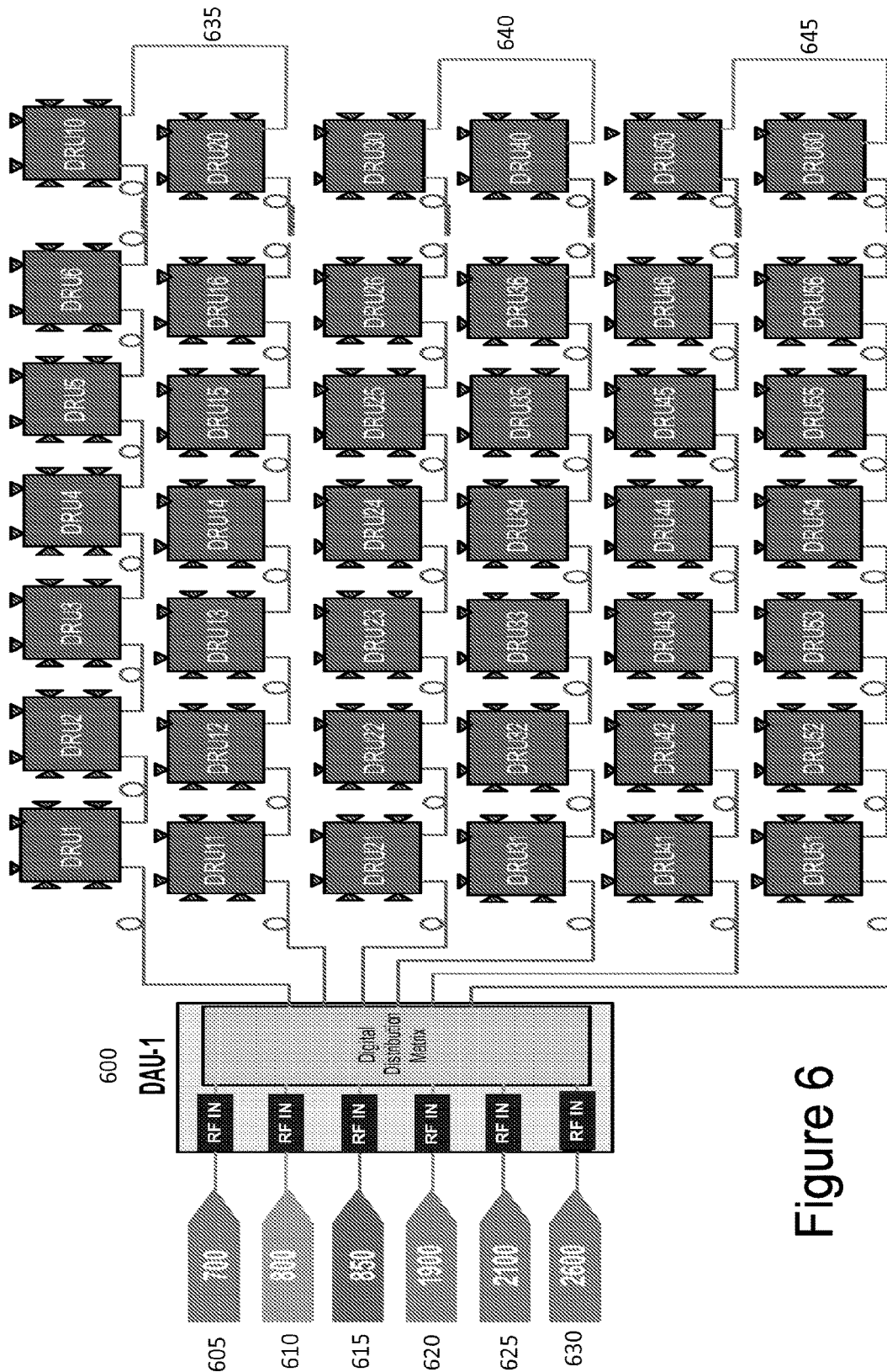


Figure 6

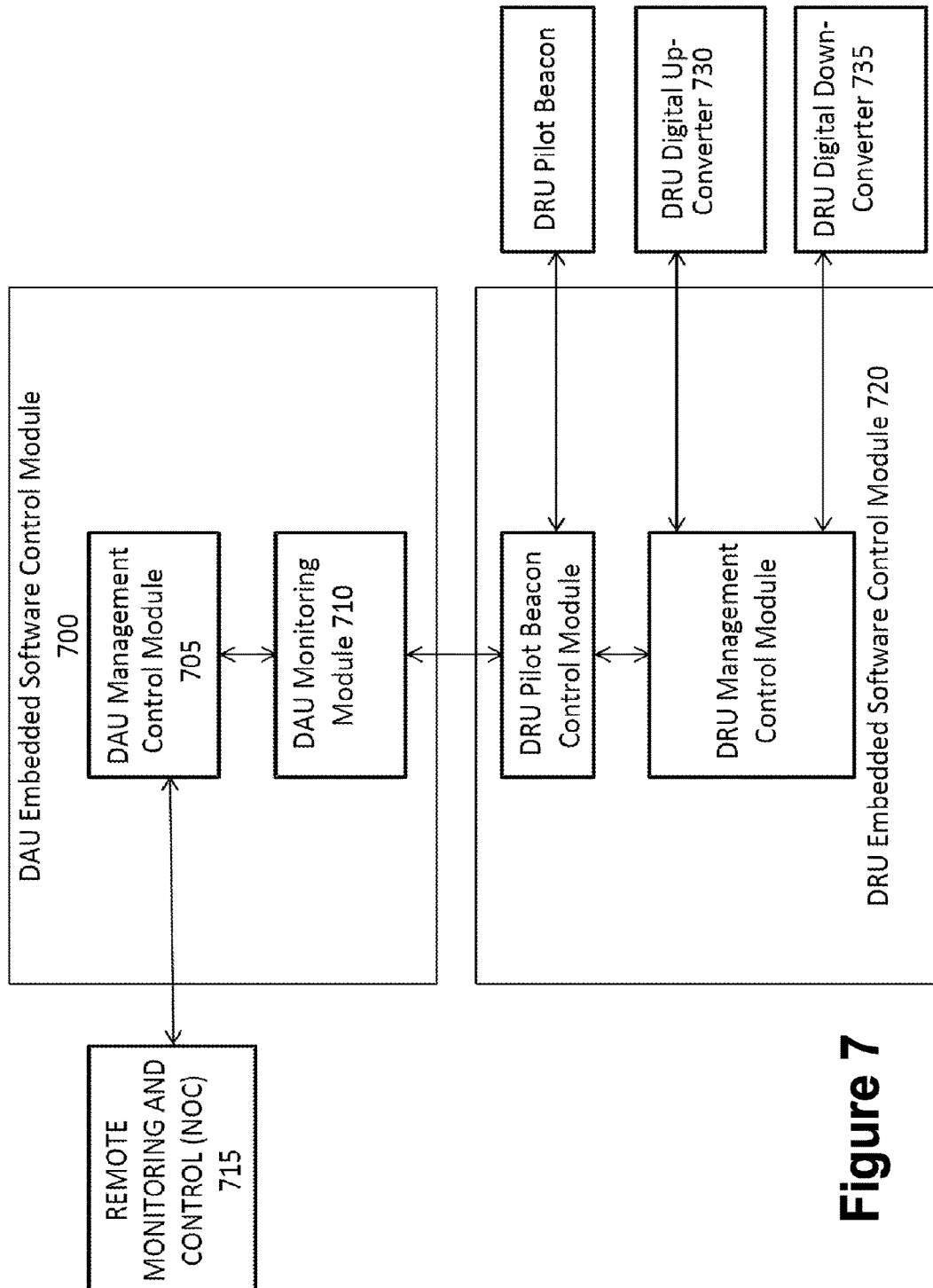
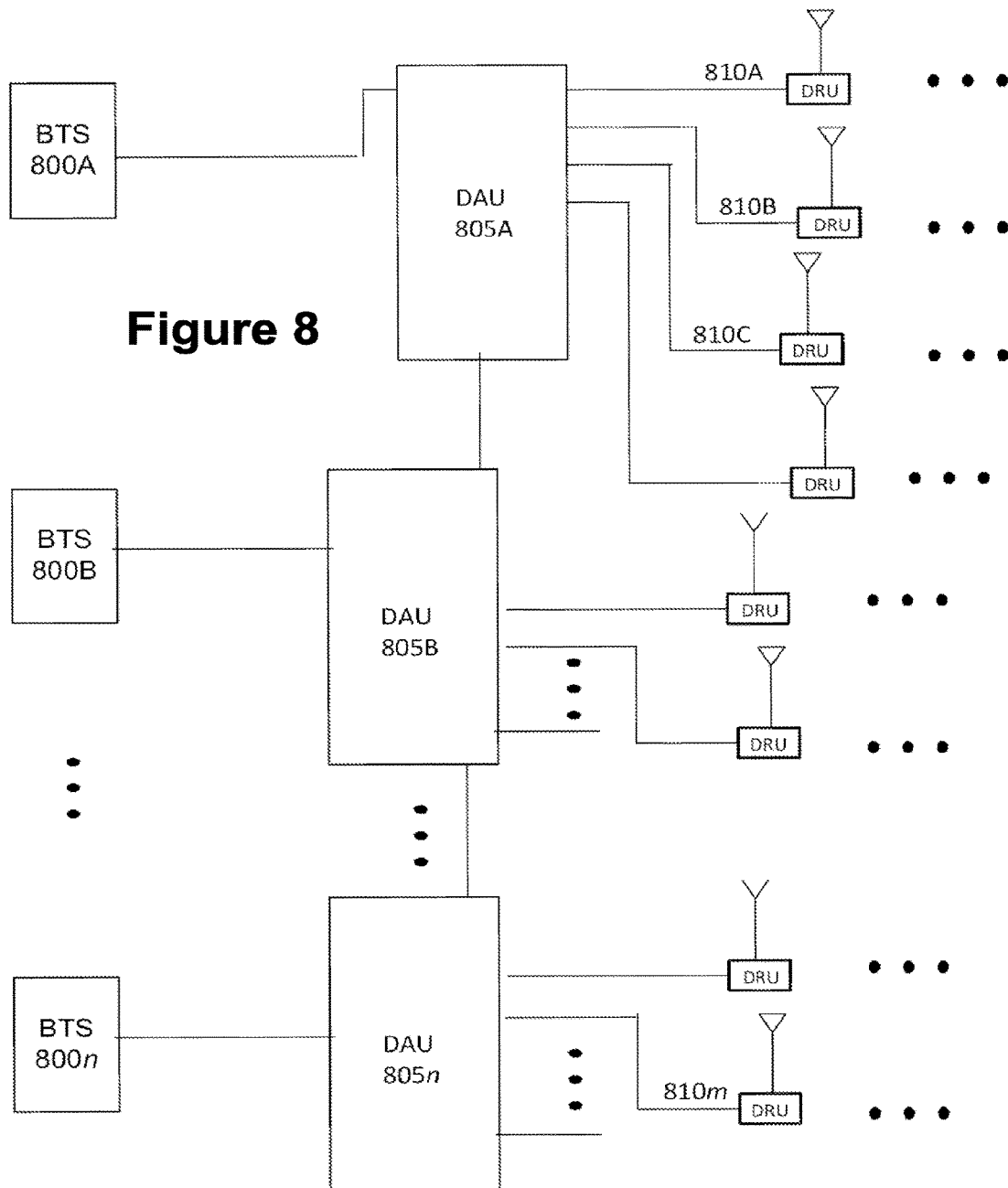


Figure 7



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DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 15/223,819, filed Jul. 29, 2016; which is a continuation of U.S. patent application Ser. No. 14/800,515, filed Jul. 15, 2015, now U.S. Pat. No. 9,419,837; which is a continuation of U.S. patent application Ser. No. 14/260,145, filed Apr. 23, 2014, now U.S. Pat. No. 9,137,078; which is a continuation of U.S. patent application Ser. No. 13/211,247, filed Aug. 16, 2011, now U.S. Pat. No. 8,737,300; which claims the benefit of U.S. Provisional Patent Application No. 61/439,940, filed Feb. 7, 2011, the disclosures of which are hereby incorporated by reference for all purposes.

FIELD OF THE INVENTION

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 one or more remotely monitored and controlled digital access units configured to assign particular packet transmissions to selected ones of a plurality of remote units, which can in some embodiments be configured in a daisy-chained rings.

BACKGROUND OF THE INVENTION

Wireless and mobile network operators face the continuing challenge of building networks that effectively manage high data-traffic growth rates. Mobility and an increased level of multimedia content for end users requires end-to-end network adaptations that support both new services and the increased demand for broadband and flat-rate Internet access. One of the most difficult challenges faced by network operators is maximizing the capacity of their DAS networks while ensuring cost-effective DAS deployments and at the same time providing a very high degree of DAS remote unit availability.

In order to provide DAS network capacity which is high enough to meet short-term needs of network subscribers in specific locations yet also avoid costly and inefficient deployment of radio resources, DAS network planners prefer to employ DAS architectures and solutions which provide a high degree of dynamic flexibility. Therefore, it would be advantageous for wireless network operators to employ a DAS solution which has a high degree of flexibility to implement dynamic rearrangements based on ever-changing network conditions and subscriber needs. Also, the more future-proof a DAS deployment can be, generally the lower its life cycle cost.

DAS network planners and system integrators employ a wide range of innovative approaches for helping to ensure that a particular DAS deployment is as cost-effective as possible. The types of costs considered by network planners and integrators include DAS deployment or DAS installation cost, as well as operational costs including maintenance costs, emergency restoration costs and network re-arrangement costs. Rearrangement costs are particularly significant for indoor DAS applications, due to frequent changes in building use and facility needs changes. Therefore, it would be advantageous to employ DAS systems and methods which are based on as few DAS transport facilities as

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possible to minimize installation and/or lease costs and have self-healing capabilities to avoid the need for costly emergency restoration services.

In order to obtain a high degree of DAS remote unit availability, two primary conditions must be satisfied. First, the DAS remote unit itself must be inherently reliable. Second, the transport media e.g., optical fiber, must be very reliable. It is well known that electronic and/or optical connections themselves are a significant root cause of failure or reduced availability in a DAS network. Companies who maintain outdoor DAS networks have reported that a failure of outside plant optical fiber facilities is not as rare as would be desirable. Therefore, it would be advantageous to employ systems and methods which offer higher redundancy and/or self-healing features in the event of failure of a transport media connection.

SUMMARY OF THE INVENTION

The present invention substantially achieves the advantages and benefits discussed above and overcomes the limitations of the prior art discussed above by providing a distributed antenna system responsive to one or more base stations and having at least one but in some embodiments a plurality of Digital Access Units ("DAU's"), each operating to control the packet traffic of an associated plurality of Digital Remote Units ("DRU's"). In embodiments employing multiple DAU's, the DAU's can be daisy-chained linearly or in a ring configuration. Likewise, depending upon the implementation, the DRU's associated with a given DAU can be configured in either a linear or ring Daisy chain configuration.

The data received from the base stations is down-converted, digitized and converted to baseband with the DAU. The data streams are then I/Q mapped and framed and independently serialized, such that multiple data streams are available in parallel from the DAU. In at least some embodiments, the DAU communicates with the associated DRU's via an optical transport arrangement. It will be appreciated by those skilled in the art that, using the present invention, it is possible to configure a distributed antenna system having n base stations, each providing m RF outputs for transmission by one or more associated DAU's to o DRU's, where the only limits are imposed by the technical performance specifications of the particular DAS, such as delay.

By the use of a ring configuration for connecting, in at least some embodiments, the DRU's and/or the DAU's, fault tolerance is built into the system, with resulting high availability. In single DAU embodiments, each DRU is accessible through two paths, and therefore remains available even in the event of a line break. In multi-DAU embodiments, where the DAU's are linearly daisy-chained, each DRU is accessible from multiple DRU's such that even some DAU failures will not prevent system operation. In embodiments employing a ring connection for the DAU's, multiple paths exist to each DAU, and thus provide an additional level of fault tolerance as well as dynamic load balancing and resource management as discussed in greater detail hereinafter.

Thus, the configuration of the advanced system architecture of the present invention provides a high degree of flexibility to manage, control, enhance and facilitate the radio resource efficiency, usage, availability, and overall performance of the distributed wireless network. The present invention enables specialized applications and enhancements including Flexible Simulcast, automatic traffic load-balancing, network and radio resource optimization,

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network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, radio frequency carrier placement, traffic monitoring, traffic tagging, and indoor location determination using pilot beacons. The present invention can also serve multiple operators, multi-mode radios (modulation-independent) and multi-frequency bands per operator to increase the efficiency and traffic capacity of the operators' wireless networks.

Further the present invention provides a high degree of dynamic flexibility, supports dynamic re-arrangements, and provides a low life cycle cost. This advanced system architecture enables deployment of DAS networks using fewer DAS transport facilities to reduce costs, while providing self-healing features. The present invention also offers redundancy and enhanced system availability.

It is an object of the present invention to provide Flexible Simulcast capabilities, as disclosed in U.S. Provisional Application Ser. No. 61/382,836, entitled "Remotely Reconfigurable Distributed Antenna System and Methods," filed Sep. 14, 2010, incorporated herein by reference, in a high-availability ring configuration using, for example, optical fiber transport. As discussed above, the ring configuration insures that a break in any optical fiber cable will not shut down the daisy-chained network, because the downlink and uplink signals can be rerouted around the cable break to the respective DRUs.

It is a further object of the present invention to balance the bidirectional data rate on the optical fibers so as to increase the maximum achievable data rate during operation on the ring network of DRUs.

It is a further object of the present invention to provide higher transport network capacity in the event the data transport is asymmetrical between the downlink and uplink, as is typically the case for mobile broadband networks.

It is a further object of the present invention to provide an adaptive and automatic control for optimizing the transport media capacity on the ring.

It is a further object of the present invention to provide a method of summing co-channel users' uplink signals in the DRU daisy chain.

Applications of the present invention are suitable to be employed with distributed base stations, distributed antenna systems, distributed repeaters, mobile equipment and wireless terminals, portable wireless devices, and other wireless communication systems such as microwave and satellite communications. The present invention is also field upgradable through a link such as an Ethernet connection to a remote computing center.

Appendix I is a glossary of terms used herein, including acronyms.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram according to one embodiment of the invention showing the basic structure and an example of a unidirectional, channelized downlink transport, one ring scenario based on having one DAU and four DRUs.

FIG. 2 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a unidirectional, channelized uplink transport, one ring scenario based on having one DAU and four DRUs.

FIG. 3 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an

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example of a unidirectional, channelized uplink transport, two ring scenario based on having one DAU and eight DRUs.

FIG. 4 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a unidirectional channelized uplink or downlink transport. This example of a five ring scenario comprises two DAUs and twenty DRUs. FIG. 4 provides an example of a daisy chain ring network.

FIG. 5 illustrates an embodiment of a cellular network system employing multiple DRUs according to the present invention.

FIG. 6 illustrates an embodiment of a multi-band system employing six different services operating in different frequency channels with multiple DRUs according to the present invention.

FIG. 7 illustrates in block diagram form the interaction between the DAU embedded software control module and the DRU embedded software control module.

FIG. 8 illustrates in block diagram form an embodiment of a DAS according to an aspect of the invention, including daisy-chained DAU's.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a novel Reconfigurable Distributed Antenna System that provides a high degree of flexibility to manage, control, re-configure, enhance and facilitate the radio resource efficiency, usage and overall performance of the distributed wireless network. FIG. 1 illustrates an embodiment of the Distributed Antenna System **100** that provides an example of a unidirectional, channelized downlink transport in accordance with the present invention. In FIGS. 1-4, a dotted line denotes a distinct subset of uplink and downlink channels identified as "A." A dashed line denotes a distinct subset of uplink and downlink channels identified as "B." The subset of uplink and downlink channels in A do not include those of B and vice versa. The system employs a Digital Access Unit functionality **105** (hereinafter "DAU"). The DAU **105** serves as an interface between associated base stations (BTS) **110A-B** and a plurality of digital remote units (DRU) **125A-n**, although only four DRU's are shown in FIG. 1. In the present description, "DRU" will be used interchangeably with Remote Radio Head Unit, or "RRU", because of the similarity of the functions discussed herein, although those skilled in the art will recognize that a DRU communicates with a DAU, whereas an RRU communicates with a base station. In addition, those skilled in the art will recognize that a DAU is monitored and controlled by a remote network operations center ("NOC"), as indicated at bidirectional link **115** in FIG. 1. Such links are typically Ethernet connections or external modems, but can be any form of link suitable for remote monitoring and control. The NOC has the capability to remotely configure the DAU parameter settings which in turn configures the DRU's parameter settings. The NOC can request information from the DAUs. The DAUs can subsequently request information from the DRUs. The information requested includes but is not limited to uplink power, downlink power, optical error rate, gain settings, active carriers, etc.

For the downlink (DL) path, RF input signals **120A** through **120n** are received at the DAU **105** from one or more base station units (BTS) indicated at **110A** through **110n**. The RF input signals are separately down-converted, digitized, and converted to baseband (using a Digital Down-

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Converter) by the DAU. Data streams are then I/Q mapped and framed and specific parallel data streams are then independently serialized and translated to optical signals using pluggable SFP modules, again by the DAU 105. The independently serialized, parallel data streams are then delivered to different DRU's 125A-125k, typically over optical fiber cable arranged, in at least some embodiments, in a ring configuration indicated at connection pairs 140A-145A, or, in other embodiments, a daisy chain configuration. In addition, each DAU can support a plurality of rings with associated DRU's, where the additional rings are indicated by fiber optic pairs up through 140o-145o. It will be appreciated by those skilled in the art that the number of RF inputs, DAU's and DRU's and rings is limited only by network performance factors, such as delay. In addition, as discussed in connection with FIG. 4 herein, the DAS can be further extended by using a ring or daisy-chain of DAU's, each of which supports an arrangement of DRU's and rings as shown in FIG. 1.

One function of the DAU 105 is to determine the direction in which downlinked channels are propagated around the ring. As just one example, the embodiment shown in FIG. 1 is configured to have downlink channels A, B, C and D propagate in a first direction, for example clockwise, and channels E, F, G, and H propagate in the counter direction, although it will be understood that the number of channels propagating in each direction need not be equal, nor adjacent, nor sequential. Likewise, the number of channels received at each DRU is assigned by the DAU and need not be equal, adjacent or sequential, but instead will typically be any configuration that optimizes network utilization.

Referring next to FIG. 2, an embodiment of an uplink (UL) path in accordance with the invention can be better appreciated. Channels received at the antenna associated with each DRU are converted into optical signals by each DRU 125A-125k. Optical signals received from the DRU's are de-serialized and de-framed by the DAU 105, and are also up-converted digitally using a Digital Up-Converter implemented within the DAU 105. Each data stream is then independently converted to the analog domain and up-converted to the appropriate RF frequency band, still within the DAU 105 in the illustrated implementation, although this functionality can be separate. The RF signals are then delivered to the appropriate one of a plurality of BTS' 110A-110p. As with the arrangement shown in FIG. 1, the direction of propagation of each channel is controlled by the DAU, with some channels propagating in a clockwise direction and others in a counterclockwise direction. Also as discussed in connection with FIG. 1, while adjacent channels are shown as propagating in the same direction in FIG. 2, this is not required and any channel can be selected to propagate in either direction.

Referring again to FIG. 1, it will be appreciated by those skilled in the art that, in some implementations of a DAS, more than one carrier can exist in each channel, and, as such, a DRU may receive a channel comprising a signal containing two or more carriers, or a wireless operator may have more than one RF carrier per channel allocated to a single base station. This is referred to as a "composite signal". The manner in which a composite downlink signal is managed by the present invention can be better understood with reference to FIG. 1. In such instances, the DAU will receive a composite downlink input signal 130 from, e.g., a first base station 110A belonging to one wireless operator, enters the DAU 105 at the RF input port 120A. Composite signal 130 comprises carriers A-D. A second composite downlink input signal from e.g., a pth base station 110p belonging to the

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same wireless operator enters DAM at the DAU1 RF input port 120n. Composite signal 135 comprises carriers E-H. The functionality of the DAU 105, and DRU's 125A-125k, respectively, are explained in detail in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010, the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

One optical output of DAU 105 is fed to DRU 125A, via bidirectional optical cable 140A. A second optical output of DAU 105 is fed via bidirectional optical cable 145A to DRU3. Similarly, bidirectional optical cables 150, 155 and 160 connect DRU's 125A-n in a ring configuration, such that DRU 125A connects to DRU 125B via cable 150A, DRU 125B connects to DRU 125n via cable 15013, and DRU 125k connects to DRU 125C, or the kth-1 DRU, via cable 150m. This connection facilitates networking of DAU 105, which means that all of Carriers A-H are available within DAU 105 to transport data to DRU's 125A-k depending on software settings within the networked DAU system. Depending upon the embodiment, the software settings within DRU 125A are configured either manually or automatically, such that carriers A-H are present in the downlink output signal 155A at the antenna port of DRU 125A. The presence of all eight carriers means that DRU 125A is potentially able to access the full capacity of both base stations feeding DAU 105. A possible application for DRU125A is a cafeteria in an enterprise building during the lunch hour where a large number of wireless subscribers are gathered.

DRU 125B is fed by a second optical port of DRU 125A via bidirectional optical cable 150A. The optical cable 150A performs the function of daisy chaining DRU 125A with DRU12513. As with DRU 125A, the software settings within DRU 125B are configured either manually or automatically such that Carriers A, C, D and F are present in downlink output signal 155E at the antenna port of DRU 125B. The capacity of DRU 125B is set to a much lower value than DRU 125A by virtue of its specific channel settings as controlled by DAU 105. The individual Digital Remote Units have integrated frequency selective DUCs and DDCs with gain control for each carrier. The DAU's can remotely turn on and off the individual carriers via the gain control parameters.

In a similar manner as described previously for DRU 125A, the software settings within DRU 125C are configured either manually or automatically such that Carriers B and F are present in downlink output signal 155C at the antenna port of DRU 125C. Compared to the downlink signal 155B at the antenna port of DRU 12513, the capacity of DRU 125C, which is also configured via its software settings, is much less than the capacity of DRU 125B. DRU 125n is fed by the optical cable 150m connected to the second optical port of the nth-1 DRU, shown for simplicity in FIG. 1 as DRU 125C. The software settings within DRU 125n are configured either manually or automatically such that carriers A, D, E and H are present in downlink output signal 155D at the antenna port of DRU 125n. Typically, the capacity of DRU 125n is set to a much lower value than DRU 125A, however, the relative capacity settings of each of DRU's 125A-n can be adjusted dynamically to meet the capacity needs within the coverage zones determined by the physical positions of antennas connected to those DRU's. As noted above, the ring connection is completed by interconnecting DRU 125B and DRU 125n through optical cable 150B. The ring configuration insures that any optical cable breaks will not shut down the daisy chained network. The

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downlink and uplink signals will be rerouted around the cable break to the respective DRUs.

The present invention facilitates conversion and transport of several discrete relatively narrow RF bandwidths. This approach allows conversion of only those multiple specific relatively narrow bandwidths which carry useful or specific information. This approach also allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and allows transport of more individual operators' band segments over the optical fiber. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 together with U.S. Provisional Application Ser. No. 61/382,836, entitled "Remotely Reconfigurable Distributed Antenna System and Methods", filed Sep. 14, 2010, both assigned to the assignee of the present invention, and also referring to FIG. 1 of the instant patent application, Digital Up Converters located within the DRU can be dynamically reconfigured as the result of commands from the NOC to transport from the DAU input to any specific DRU output any specific narrow frequency band or bands, RF carriers or RF channels which are available at the respective RF input port of either DAU. This capability is illustrated in FIG. 1 where only specific frequency bands or RF carriers appear at the output of a given DRU. More specifically, through commands received from the NOC, the FPGA's in the DAU and one or more of the associated DRU's can be reprogrammed or reconfigured to convert and transport only the desired narrow bandwidths.

A related capability of the present invention is that not only can the Digital Up Converters located within each DRU be configured to transport any specific narrow frequency band from the DAU input to any specific DRU output, but also the Digital Up Converters within each DRU can be configured to transport any specific time slot or time slots of each carrier from the DAU input to any specific DRU output. The carriers and time slots are monitored by the DAU by filtering the signals and performing power detection of the individual time slots, which information can be conveyed to the NOC as desired. Then, as with the Digital Up Converters, the Field Programmable Gate Arrays (FPGA) in the DAU or DRU can be dynamically reconfigured by commands received from the NOC in a manner analogous to software programmability. The DAU detects which carriers and corresponding time slots are active. This information is relayed to the individual DRUs via the management control and monitoring protocol software. This information is then used, as appropriate, by the DRUs for turning off and on individual carriers and their corresponding time slots.

Data transport between the Base Station and the subscribers is typically asymmetrical, whereby the downlink data rate is higher than the uplink rate. The ring network configuration of Daisy Chained DRUs can exploit this data rate asymmetry to maximize the data transport on the optical fibers **150A-150m**.

The present invention balances the bidirectional data rate on the optical fibers so as to increase the maximum achievable data rate on the ring network of DRUs. The individual downlink channels are transmitted in a unidirectional sense along the ring network. Referring to FIG. 1, downlink channels A, B, C, and D are transmitted in a clockwise sense around the ring of DRU's **125A-k**. On the other hand, downlink channels E, F, G and H are transmitted in a counterclockwise sense around the ring of DRUs. Referring to FIG. 2, the uplink channels J, K, L and M are transmitted in a counterclockwise sense whereas uplink channels N, O,

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P and Q are transmitted in a clockwise sense around the ring of DRUs. If the downlink and uplink data rates were the same, there would be no advantage in the transport mechanism. However, if the data transport is asymmetrical between the downlink and uplink then a significant advantage can be gained. For example, for a factor of two difference between the downlink and uplink data rates, a 4/3 factor increase in data transport can be achieved. The larger the asymmetry between the downlink and uplink data rates, the larger will be the increase in data transport using the unidirectional channel transport mechanism around the ring.

Referring again to FIG. 1, a further embodiment in accordance with another aspect of the present invention may be better understood. In the event that there is a significant change in asymmetry between the downlink and uplink data rates and/or if there is a change in channel complement at the BTS, the Management Control module [discussed in connection with FIG. 7 herein] which is typically comprised within each DAU is able to automatically and adaptively re-allocate data transport resources on the clockwise direction of the ring and on the counter-clockwise direction of the ring to maximize the overall transport capacity. As stated previously, the larger the degree of asymmetry between uplink and downlink data rates for a particular DAU, the higher the increase in data transport using the unidirectional channel transport mechanism around the ring. If there is more than one DAU present, in an embodiment one DAU is designated a Master DAU by the NOC, and the Management Control module located in the Master DAU makes decisions to optimize the overall transport capacity. In the event the master DAU fails, the NOC can designate another DAU as master. Alternatively, any suitable failover algorithm can be implemented.

Referring to FIG. 3, an alternative embodiment of the present invention wherein a single DAU controls a plurality of rings, each comprising a plurality of daisy-chained DRU's, can be better understood. In FIG. 3, two daisy-chained rings, indicated at **300** and **305**, are shown although the number of rings could be greater and is determined mainly as a matter of design preference up to limits imposed by network performance. The rings each link a plurality of DRU's **310A-n** and **315A-m**, to a single DAU **320**. The directional flow of the data transport is shown as the dashed lines **325** and dotted lines **330**. The downlink channels available from the plurality of DRU's are divided into two subsets which flow in opposite directions around the two daisy-chained rings. The uplink channels are transported in a similar fashion. The channels are grouped into the two subsets so as to maximize the data transport to and from the DRUs. The DAU in turn communicates with one or more BTS's via RF Ports **335A p**.

Heuristic algorithms may be used to allocate RF channel data in a Dual-ring DAS. For FIG. 3, there are two fibre rings **R1, R2** (clockwise and counter clockwise) and a set **T** of $n \geq 2$ independent RF channels K_i , $1 \leq i \leq n$ (including uplink and downlink). A channel K_i requires a bandwidth of $b(K_i)$ to transport on a fibre ring. A time-bounded algorithm exists which obtains a schedule having the optimal bandwidth allocation (i.e. the maximum aggregate bandwidth of each ring is as small as possible). A large number of advanced heuristic algorithms have been developed to solve such scheduling optimization problems. Some examples are genetic algorithm, evolutionary algorithm, greedy search, Tabu search, harmony search, simulated annealing, ant colony optimization, etc. For purposes of simplicity and

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clarity, a simple heuristic algorithm for two rings is described here, although the number of rings is not limited to two.

The algorithm begins by sorting the channels K_i decreasingly by bandwidth $b(K_i)$. Then it schedules the channel in such a way that each channel is assigned to the ring which has the smaller aggregate bandwidth. The formal description of the algorithm follows.

Input: $T = \text{set of } n \text{ independent channels } K_i \text{ with required bandwidth } b(K_i), 1 \leq i \leq n$.

Output: L_1, L_2 and D_1, D_2 . L_j is the set of channels schedule on ring R_j , and D_j is the maximum aggregate bandwidth of ring R_j , $D_j = D_j - (\sum b(K_i), K_i \in L_j), 1 \leq j \leq 2$.

ALGORITHM (T, L, D)

Step 1 (initialize K_i and D_1, D_2) Sort K_i such that $b(K_i) \geq b(K_{i+1}), 1 \leq i \leq n-1$. $D_1 \leftarrow 0, D_2 \leftarrow 0$.

Step 2 (Schedule a channel)

For $i=1$ to n , step 1 do

If $D_1 \leq D_2$, then [assign K_i onto $L_1, D_1 \leftarrow D_1 + b(K_i)$].

else [assign K_i onto $L_2, D_2 \leftarrow D_2 + b(K_i)$].

Referring next to FIG. 4, a still further an alternative embodiment of the present invention may be understood. The arrangement illustrated in FIG. 1 comprised downlink signals from two separate base stations belonging to the same wireless operator entering the DAU 105 at input ports 110A and 110P, respectively. In the embodiment of FIG. 4, a first composite signal enters a first DAU 400 at that DAU's RF input port from a base station 405, and a second composite downlink input signal from, e.g., a second base station 410 belonging to a different wireless operator enters DAU 415 at that second DAU's RF input port. DAU 400 directly supports two rings 420 and 425, DAU 415 directly supports two rings 430 and 435, and a ring 440 is shared between DAU 400 and DAU 405. Each of the rings comprises daisy-chained DRU's generally indicated at 445 and connected via, for example, fiber optic links, as discussed in connection with FIG. 1. It will be noted that channels A are transported in the opposite sense as channels B. The downlink channels in subset A are transported counterclockwise around each ring, whereas the channels in subset B are transported in a clockwise sense around each ring. In this embodiment, signals belonging to both the first operator and the second operator are converted and transported to the DRU's 445 on ring 440 because DAU 400 and DAU 405 are daisy-chained through the fiber optic cable 440. This embodiment provides an example of a neutral host wireless system, where multiple wireless operators share a common infrastructure comprised of DAU 400, DAU 415, and DRU's 445. All the previously mentioned features and advantages accrue to each of the two wireless operators. It will further be appreciated that, while FIG. 4 illustrates only two DAU's linked in daisy-chain style, it is possible to daisy chain a larger plurality of DAU's, and the daisy-chained DAU's can also be configured in a ring configuration similar to the manner in which the DRU's are connected. This arranged is illustrated in FIG. 8, below.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and again referring to FIG. 1 of the instant patent application, the Digital Up Converters present in the DRU's of the present invention can be programmed to process various signal formats and modulation types including FDMA, CDMA, TDMA, OFDMA and others. Also, the Digital Up Converters present in the respective DRUs can be programmed to operate with signals to be transmitted within various frequency bands subject to the capabilities and limitations of

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the system architecture disclosed in U.S. Provisional Application Ser. No. 61/374,593, mentioned above. In one embodiment of the present invention where a wideband CDMA signal is present within, e.g., the bandwidth corresponding to a first carrier at the input port to DAU 105, the transmitted signal at the antenna ports of DRU 125A, DRU 1256 and DRUk will be a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to that first carrier at the input port to DAU 105.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, again identified above, and also referring to FIG. 1 of the instant patent application, it is to be understood that the Digital Up Converters present in the respective DRUs can be programmed to transmit any desired composite signal format to each of the respective DRU antenna ports. As an example, the Digital Up Converters present in DRU 125A and DRU 125B can be dynamically software-reconfigured as described previously so that the signal present at the antenna port of DRU 125A would correspond to the spectral profile shown in FIG. 1 as 155A and also that the signal present at the antenna port of DRU 125B would correspond to the spectral profile shown in FIG. 1 as 155B. The application for such a dynamic re-arrangement of DRU capacity would be e.g., if a company meeting were suddenly convened in the area of the enterprise corresponding to the coverage area of DRU 125B.

Referring again to FIG. 2, another embodiment of the Distributed Antenna System of the present invention can be better understood. As disclosed in the aforementioned U.S. Provisional Application Ser. No. 61/374,593, and also as shown in FIG. 2, the optical ring transport mechanism can be implemented with regard to uplink signals. As discussed previously with regard to downlink signals and by referring to FIG. 1, the uplink system shown in FIG. 2 is mainly comprised of DAU 105, together with DRU's 125A-125k. In a manner similar to the downlink operation explained by referring to FIG. 1, the operation of the uplink system shown in FIG. 2 can be understood as follows.

The Digital Down Converters present in each of DRU's 125A-k are dynamically software-configured as described previously so that uplink signals of the appropriate desired signal format(s) present at the receive antenna ports of the respective DRU's 125A-125k are selected based on the desired uplink band(s) to be processed and filtered, converted and transported to the appropriate uplink output port of DAU 105. The DAU and DRUs frame the individual data packets corresponding to their respective radio signature using the Common Public Radio Interface (CPRI) standard. Other Interface standards are applicable provided they uniquely identify data packets with respective DRUs. Header information is transmitted along with the data packet which identifies the DRU and DAU that corresponds to the individual data packet.

In one example for the embodiment shown in FIG. 2, DRU's 125A and 125C are configured to receive uplink signals within the Channel K bandwidth, whereas DRU 1256 and DRU 125n are both configured to reject uplink signals within the Channel K bandwidth. When DRU 125C receives a strong enough signal at its receive antenna port within the Channel K bandwidth to be properly filtered and processed, the Digital Down Converters within DRU 125C facilitate processing and conversion. Similarly, when DRU 125A receives a strong enough signal at its receive antenna port within the Channel K bandwidth to be properly filtered and processed, the Digital Down Converters within DRU 125A facilitate processing and conversion. The signals from

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DRU 125A and DRU 125C are combined based on the active signal combining algorithm, and are fed to the base station connected to the uplink output port of DAU 105. The term simulcast is frequently used to describe the operation of DRU125A and DRU 125C with regard to uplink and downlink signals within Channel K bandwidth. The term Flexible Simulcast refers to the fact that the present invention supports dynamic and/or manual rearrangement of which specific DRU are involved in the signal combining process for each Channel bandwidth.

Referring still to FIG. 2, the Digital Down Converters present in DRU 125A are configured to receive and process signals within Channel J-Q bandwidths. The Digital Down Converters present in DRU 1256 are configured to receive and process signals within Channel J, L, M and O bandwidths. The Digital Down Converters present in DRU 125C are configured to receive and process signals within Channel K and O bandwidths. The Digital Down Converters present in DRU 125n are configured to receive and process signals within Channel J, M, N and Q bandwidths. The respective high-speed digital signals resulting from processing performed within each of the four DRU are routed to the DAU. As described previously, the uplink signals from the four DRUs are combined within the respective DAU corresponding to each base station.

In summary, the Reconfigurable Distributed Antenna System of the present invention described herein efficiently conserves resources and reduces costs. The reconfigurable system is adaptive or manually field-programmable, since the algorithms can be adjusted like software in the digital processor at any time.

Referring next to FIG. 5, an alternative embodiment of the present invention may be better understood. FIG. 5 provides a daisy chain example of a distributed antenna system (DAS). Each DRU has a coverage radius that can be adjusted based on the power transmission from that particular remote unit. The DAU controls the various DRU's transmission power and can optimize the overall coverage zone. In the illustrated embodiment, DAU 502, again under the control of a NOC (not shown), is associated with a base station 501 and in turn interfaces with three DRU's 503, 504 and 505. A user 506 with a mobile device is provided relatively uniform coverage throughout the area covered by the three DRU's.

Referring next to FIG. 6, a still further alternative embodiment may be better appreciated. FIG. 6 shows an embodiment of a multi-band system illustrating one DAU supporting up to six different services operating at different frequency bands, with three optical rings of DRU's 1-60. The input frequency bands 605-630 (here denoted as six frequency bands at 700, 800, 850, 1900, 2100 and 2600 MHz) are input into the DAU 600 from the BTS's (not shown). The DAU includes, among other functionalities discussed herein, an RF IN portion for each band, and a digital distribution matrix for distributing the frequency bands to a plurality of DRU's, indicated as DRU1-DRU60, daisy-chained along three separate rings 635, 640 and 645 for achieving the desired coverage. The frequency bands are transported to either all or a subset of DRUs. The particular number of frequency bands, DAU's, DRU's and rings is exemplary only, and can, in practice, be any number appropriate to the performance capabilities and needs of the network.

Referring next to FIG. 7 that illustrates embedded software control modules, the software embedded in the DAU and DRU, which controls the operation of key functions of these devices, can be better understood. In particular, the

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DAU embedded software control module 700 comprises a DAU Management Control Module 705 and a DAU monitoring module 710. The DAU Management Control Module 705 communicates with the NOC 715, and also the DAU monitoring module 710. One such key function is determining and/or setting the appropriate amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular DRU or group of DRUs to meet desired capacity and throughput objectives. As noted previously, the NOC 715 monitors the DAS operation and sends commands to the DAU's for configuring various functions of the DRU's as well as the DAU, in at least some embodiments.

The DAU Monitoring module, in addition to other functions, detects which carriers and corresponding time slots are active for each DRU. The DAU Management Control module communicates with the DRU Embedded Software Control module 720 over a fiber optic link control channel via a control protocol. In an embodiment, the control protocol comprises headers together with packets of data, such that both control information and data are transmitted to the DRU's together as a message. DRU functions or features that the header would control in the DRU are typically implementation specific and can include, among other things, measuring uplink and downlink power, measuring gain of uplink and downlink, and monitoring alarms in the DRU.

In turn, the DRU Management Control module 725 within the DRU Embedded Software Control Module sets the individual parameters of all the DRU Digital Up-Converters 730 to enable or disable specific radio resources from being transmitted by a particular DRU or group of DRUs, and also sets the individual parameters of all the DRU Digital Down-Converters 735 to enable or disable specific radio resources from being transmitted by a particular DRU or group of DRUs. In addition, the DRU Embedded Software Control Module comprises a DRU Pilot Beacon Control Module 740, which communicates with a DRU Pilot Beacon 745.

Referring next to FIG. 8, an embodiment of a daisy-chained configuration of DAU's is illustrated, together with a daisy-chained configuration of DRU's. In an embodiment, a plurality of base stations 800A-800n are each associated with one of DAU's 805A-n. The DAU's are daisy-chained, and each DAU communicates with one or more daisy-chains 810A-810m of DRU's which may or may not be arranged in a ring configuration. It will be appreciated that the DAU's can also be configured in a ring configuration, as discussed above.

An algorithm operating within the DAU Monitoring module which detects which carriers and corresponding time slots for each carrier are active for each DRU provides information to the DAU Management Control module to help identify when, e.g., a particular downlink carrier is loaded by a percentage greater than a predetermined threshold whose value is communicated to the DAU Management Control module by the DAU's Remote Monitoring and Control function 715. If that occurs, the DAU Management Control module can adaptively modify the system configuration to begin to deploy, typically although not necessarily slowly, additional radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular DRU which need those radio resources within its coverage area. At the same time, usually the DAU Management Control module adaptively modifies the system configuration to begin to remove, again typically slowly, certain radio resources (such as RF carriers, CDMA codes or TDMA time

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slots) for use by a particular DRU where that DRU no longer needs those radio resources within its coverage area.

Although the present invention has been described with reference to the preferred embodiments, it will be understood that the invention is not limited to the details described thereof. Various substitutions and modifications have been suggested in the foregoing description, and others will occur to those of ordinary skill in the art. Therefore, all such substitutions and modifications are intended to be embraced within the scope of the invention as defined in the appended claims.

GLOSSARY OF TERMS

ACLR Adjacent Channel Leakage Ratio
ACPR Adjacent Channel Power Ratio
ADC Analog to Digital Converter
AQDM Analog Quadrature Demodulator
AQM Analog Quadrature Modulator
AQDMC Analog Quadrature Demodulator Corrector
AQMC Analog Quadrature Modulator Corrector
BPF Bandpass Filter
BTS Base Transceiver System or Base Station
CDMA Code Division Multiple Access
CFR Crest Factor Reduction
DAC Digital to Analog Converter
DAU Digital Access Unit
DET Detector
DHMPA Digital Hybrid Mode Power Amplifier
DDC Digital Down Converter
DNC Down Converter
DPA Doherty Power Amplifier
DQDM Digital Quadrature Demodulator
DQM Digital Quadrature Modulator
DSP Digital Signal Processing
DUC Digital Up Converter
EER Envelope Elimination and Restoration
EF Envelope Following
ET Envelope Tracking
EVM Error Vector Magnitude
FFLPA Feedforward Linear Power Amplifier
FIR Finite Impulse Response
FPGA Field-Programmable Gate Array
GSM Global System for Mobile communications
I-Q In-phase/Quadrature
IF Intermediate Frequency
LINC Linear Amplification using Nonlinear Components
LO Local Oscillator
LPF Low Pass Filter
MCPA Multi-Carrier Power Amplifier
MDS Multi-Directional Search
OFDM Orthogonal Frequency Division Multiplexing
PA Power Amplifier
PAPR Peak-to-Average Power Ratio
PD Digital Baseband Predistortion
PLL Phase Locked Loop
PN Pseudo-Noise
QAM Quadrature Amplitude Modulation
QPSK Quadrature Phase Shift Keying
RF Radio Frequency
RRH Remote Radio Head
RRU Remote Radio Head Unit
SAW Surface Acoustic Wave Filter
UMTS Universal Mobile Telecommunications System
UPC Up Converter
WCDMA Wideband Code Division Multiple Access
WLAN Wireless Local Area Network

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What is claimed is:

1. A system for transporting wireless communications, comprising:

a baseband unit;
a plurality of signal sources, including at least a first signal source and a second signal source;
a plurality of remote units, including at least a first remote unit and a second remote unit;
wherein the baseband unit comprises a plurality of interfaces to communicatively couple the baseband unit to the plurality of signal sources;
wherein the baseband unit is configured to receive a plurality of radio resources from the first signal source and the second signal source;

wherein the baseband unit is configured to send a digital representation of a first set of radio resources to the first remote unit at a first point in time, the first set of radio resources for transmission at an antenna of the first remote unit;

wherein the baseband unit is configured to send a digital representation of a second set of radio resources to the first remote unit at a second point in time, the second set of radio resources for transmission at the antenna of the first remote unit;

wherein a number of radio resources in the first set of radio resources is different from a number of radio resources in the second set of radio resources; and
wherein the baseband unit is configured to receive digital signals from each of the plurality of remote units.

2. The system of claim 1 wherein the baseband unit is configured to packetize each digital representation of a radio resource.

3. The system of claim 1 wherein the digital representation of the first set of radio resources includes destination information identifying the first remote unit and the digital representation of the second set of radio resources includes destination information identifying the first remote unit.

4. The system of claim 1 wherein the first set of radio resources is a subset of the plurality of radio resources and includes at least some radio resources from the first signal source and at least some radio resources from the second signal source.

5. The system of claim 1 wherein the baseband unit and at least one of the plurality of signal sources are part of a baseband controller.

6. The system of claim 1 wherein the baseband unit further comprises at least one interface to communicatively couple the baseband unit to one or more additional baseband units.

7. The system of claim 6 wherein the one or more additional baseband units includes a plurality of additional baseband units, and the baseband unit is connected to at least a first one of the plurality of additional baseband units through a direct connection and at least a second one of the plurality of additional baseband units through an indirect connection.

8. A baseband controller for use in the transport of wireless communications, comprising:

a plurality of interfaces to communicatively couple a baseband unit to a plurality of signal sources, including at least a first signal source and a second signal source;
at least one interface to communicatively couple the baseband unit to a plurality of remote units, including at least a first remote unit;

wherein the baseband unit is configured to receive a plurality of radio resources from the first signal source and the second signal source;

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wherein the baseband unit is configured to send digital representations of a first set of radio resources to the first remote unit at a first point in time, the first set of radio resources for transmission at an antenna of the first remote unit;

wherein the baseband unit is configured to send digital representations of a second set of radio resources to the first remote unit at a second point in time, the second set of radio resources for transmission at the antenna of the first remote unit; and

wherein a number of radio resources in the first set of radio resources is different from a number of radio resources in the second set of radio resources.

9. The baseband controller of claim 8 wherein the baseband unit is configured to packetize each digital representation of a radio resource.

10. The baseband controller of claim 8 wherein the digital representation of the first set of radio resources includes destination information identifying the first remote unit and the digital representation of the second set of radio resources includes destination information identifying the first remote unit.

11. The baseband controller of claim 8 wherein the first set of radio resources is a subset of the plurality of radio resources and includes at least some radio resources from the first signal source and at least some radio resources from the second signal source.

12. The baseband controller of claim 8 wherein the baseband unit further comprises at least one interface to communicatively couple the baseband unit to one or more additional baseband units.

13. The baseband controller of claim 8 wherein the plurality of radio resources include a first composite signal from the first signal source and a second composite signal from the second signal source, and the baseband unit is configured to form the digital representation of the first set of radio resources from a first subset of the first composite signal and a second subset of the second composite signal.

14. A method for providing digital signals in a Distributed Antenna System (DAS), comprising:

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receiving at a baseband unit, from a plurality of signal sources including at least a first signal source and a second signal source, a plurality of radio resources; transmitting from the baseband unit, at a first point in time, a digital representation of a first set of radio resources to a first remote unit, the first set of radio resources for transmission at an antenna of the first remote unit;

transmitting from the baseband unit, at a second point in time, a digital representation of a second set of radio resources to the first remote unit, the second set of radio resources for transmission at the antenna of the first remote unit;

wherein a number of radio resources in the first set of radio resources is different from a number of radio resources in the second set of radio resources.

15. The method of claim 14 wherein the digital representation of the first set of radio resources includes destination information identifying the first remote unit and the digital representation of the second set of radio resources includes destination information identifying the second remote unit.

16. The method of claim 14 wherein the first set of radio resources is a subset of the plurality of radio resources and includes at least some radio resources from the first signal source and at least some radio resources from the second signal source.

17. The method of claim 14 further comprising receiving at the baseband unit, from at least one additional baseband unit, a second plurality of radio resources.

18. The method of claim 14 wherein the plurality of radio resources include a first composite signal from the first signal source and a second composite signal from the second signal source, the method further comprising forming, at the baseband unit, the digital representation of the first set of radio resources from a first subset of the first composite signal and a second subset of the second composite signal.

19. The method of claim 14 further comprising packetizing, at the baseband unit, at least a subset of the plurality of radio resources.

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(54) **REMOTELY RECONFIGURABLE
DISTRIBUTED ANTENNA SYSTEM AND
METHODS**

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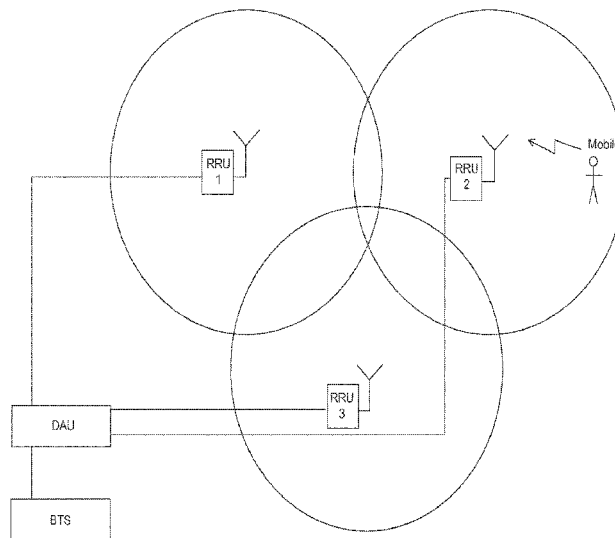
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(57) **ABSTRACT**

The present disclosure is a novel utility of a software defined radio (SDR) based Distributed Antenna System (DAS) that is field reconfigurable and support multi-modulation schemes (modulation-independent), multi-carriers, multi-frequency bands and multi-channels. The present disclosure enables a high degree of flexibility to manage, control, enhance, facilitate the usage and performance of a distributed wireless network such as flexible simulcast, automatic traffic load-balancing, network and radio resource optimization, network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, frequency carrier placement, traffic monitoring, traffic tagging, pilot beacon, etc.

20 Claims, 7 Drawing Sheets



Indoor Localization System of GSM and LTE

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continuation of application No. 16/737,419, filed on Jan. 8, 2020, which is a continuation of application No. 16/175,520, filed on Oct. 30, 2018, now Pat. No. 10,701,695, which is a continuation of application No. 15/391,408, filed on Dec. 27, 2016, now Pat. No. 10,159,074, which is a continuation of application No. 14/949,405, filed on Nov. 23, 2015, now Pat. No. 9,531,473, which is a continuation of application No. 14/169,719, filed on Jan. 31, 2014, now Pat. No. 9,419,714, which is a continuation of application No. 13/211,243, filed on Aug. 16, 2011, now Pat. No. 8,682,338.

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H03F 3/24; H03F 2200/204; H03F 2201/3224; H03F 2201/3233; H04Q 2213/1301

See application file for complete search history.

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* cited by examiner

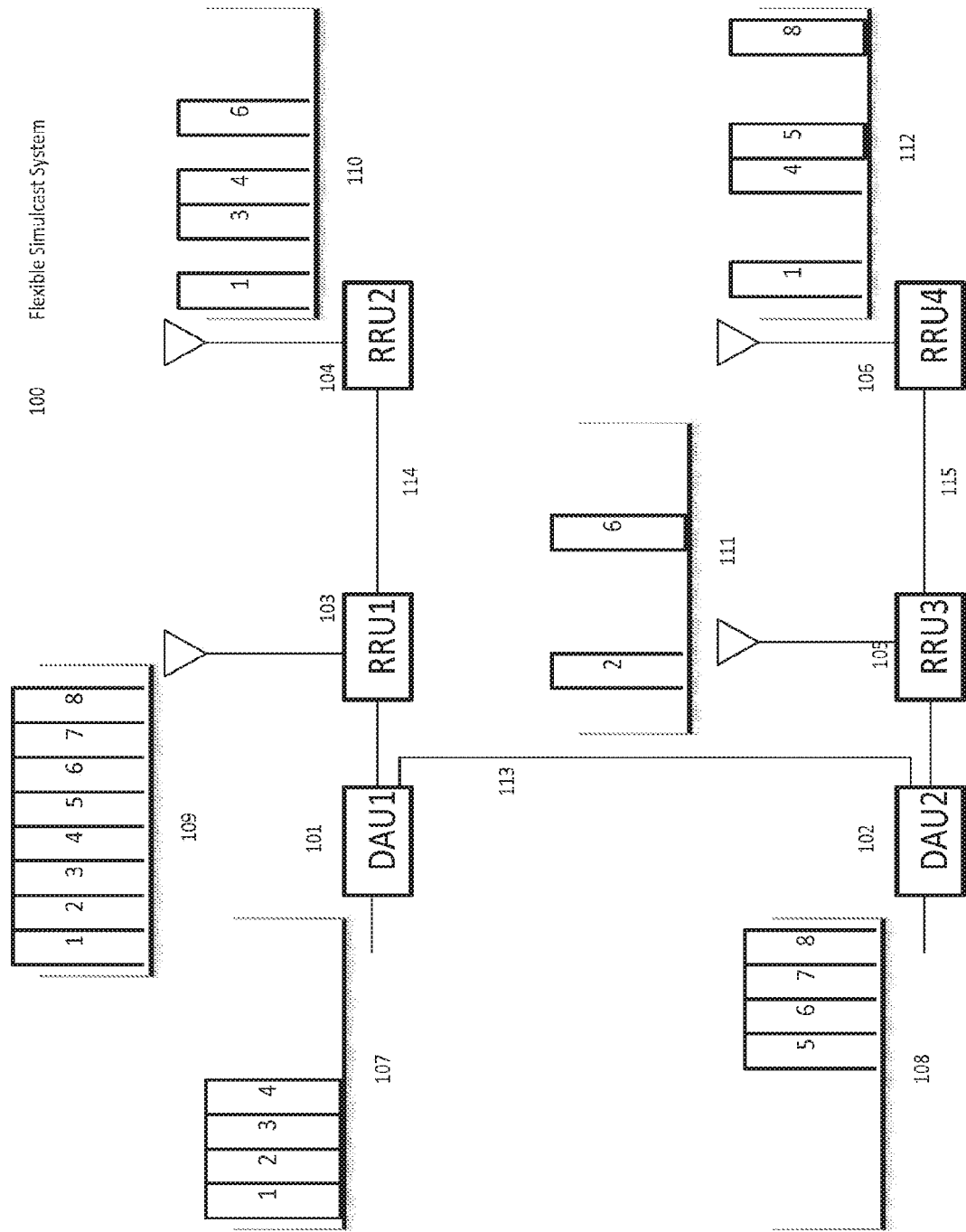


Figure 1: Flexible Simulcast Downlink Example

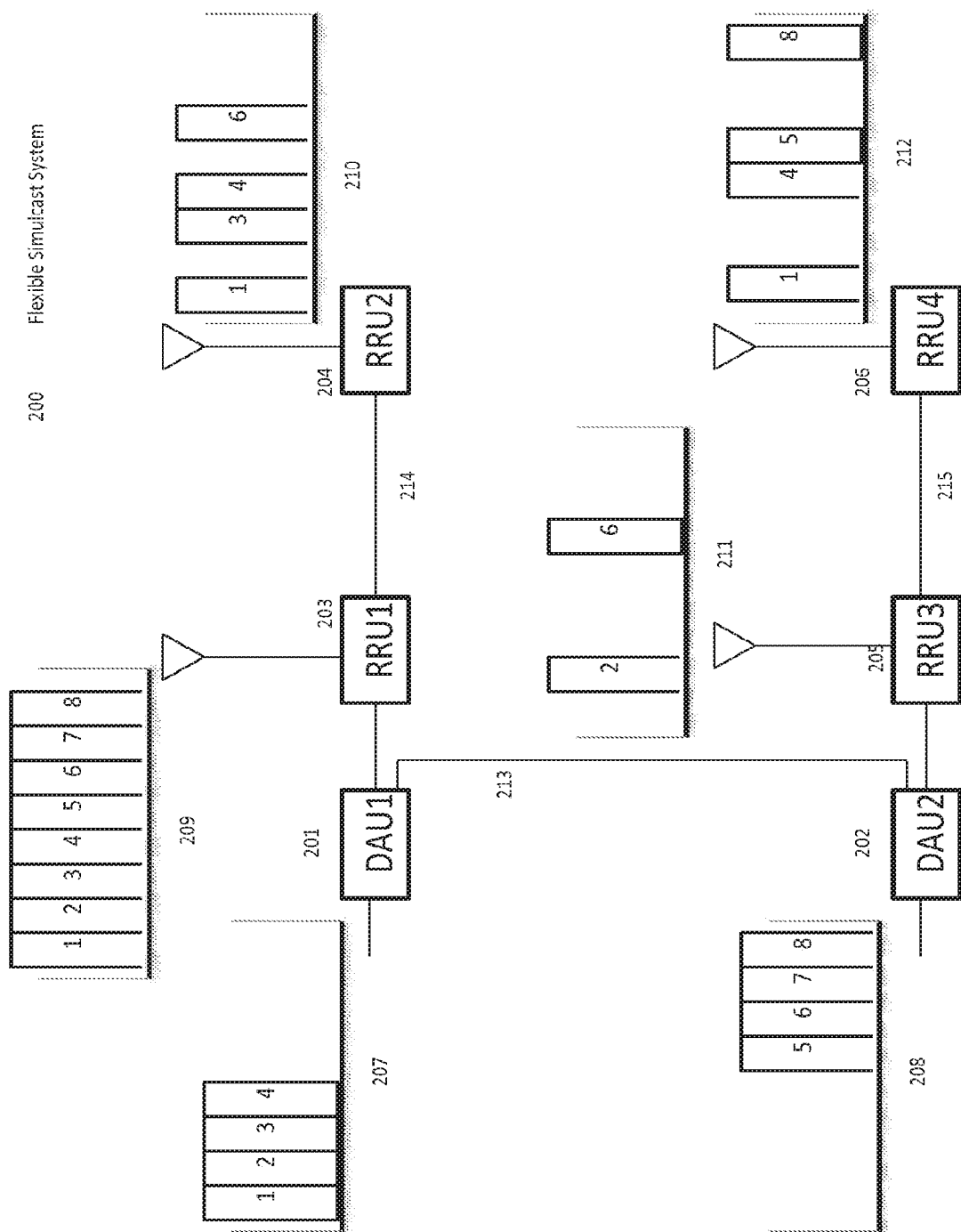


Figure 2: Flexible Simulcast Uplink Example

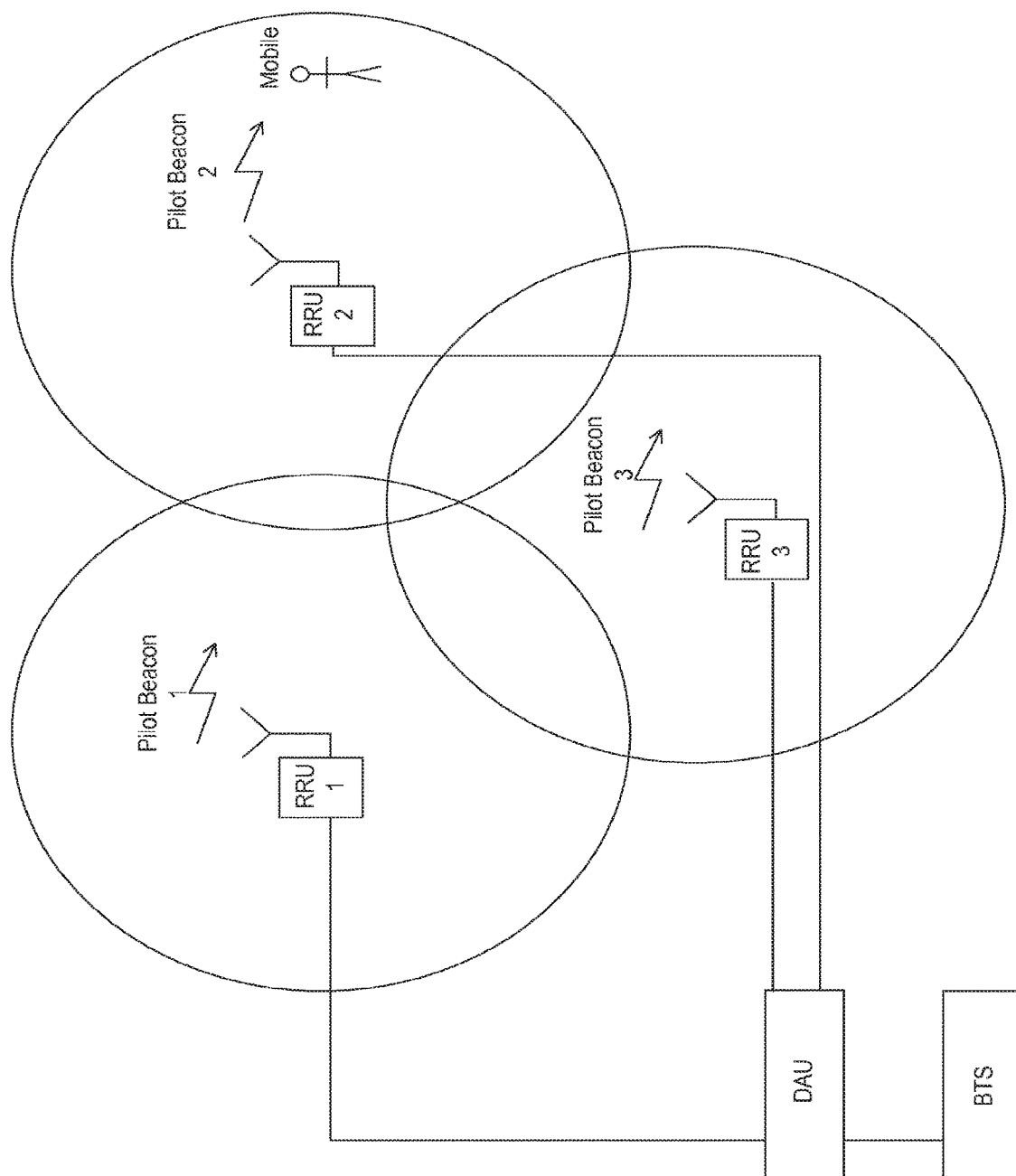


Figure 3 Pilot Beacon Indoor Localization System for CDMA and WCDMA

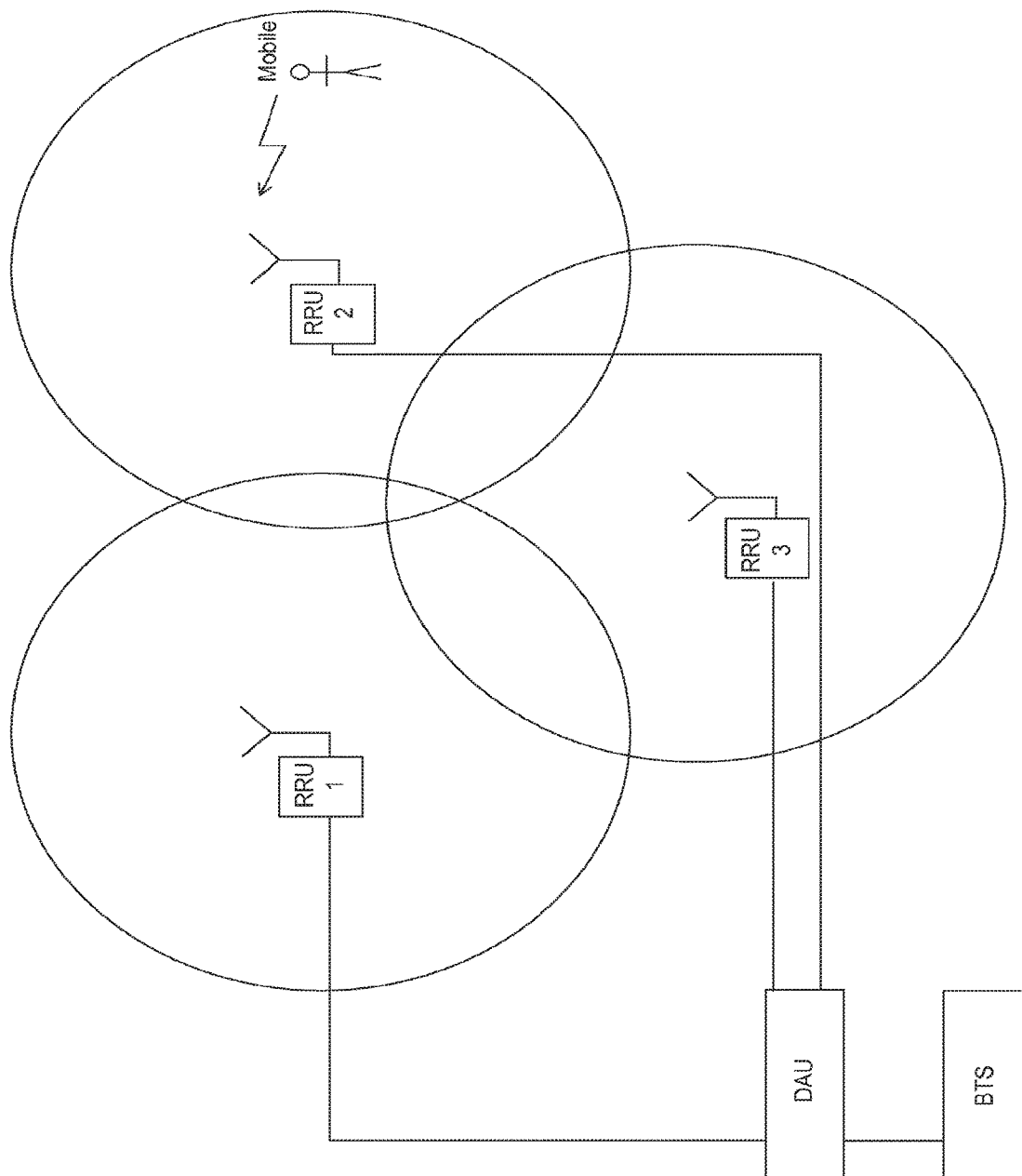


Figure 4 Indoor Localization System of GSM and LTE

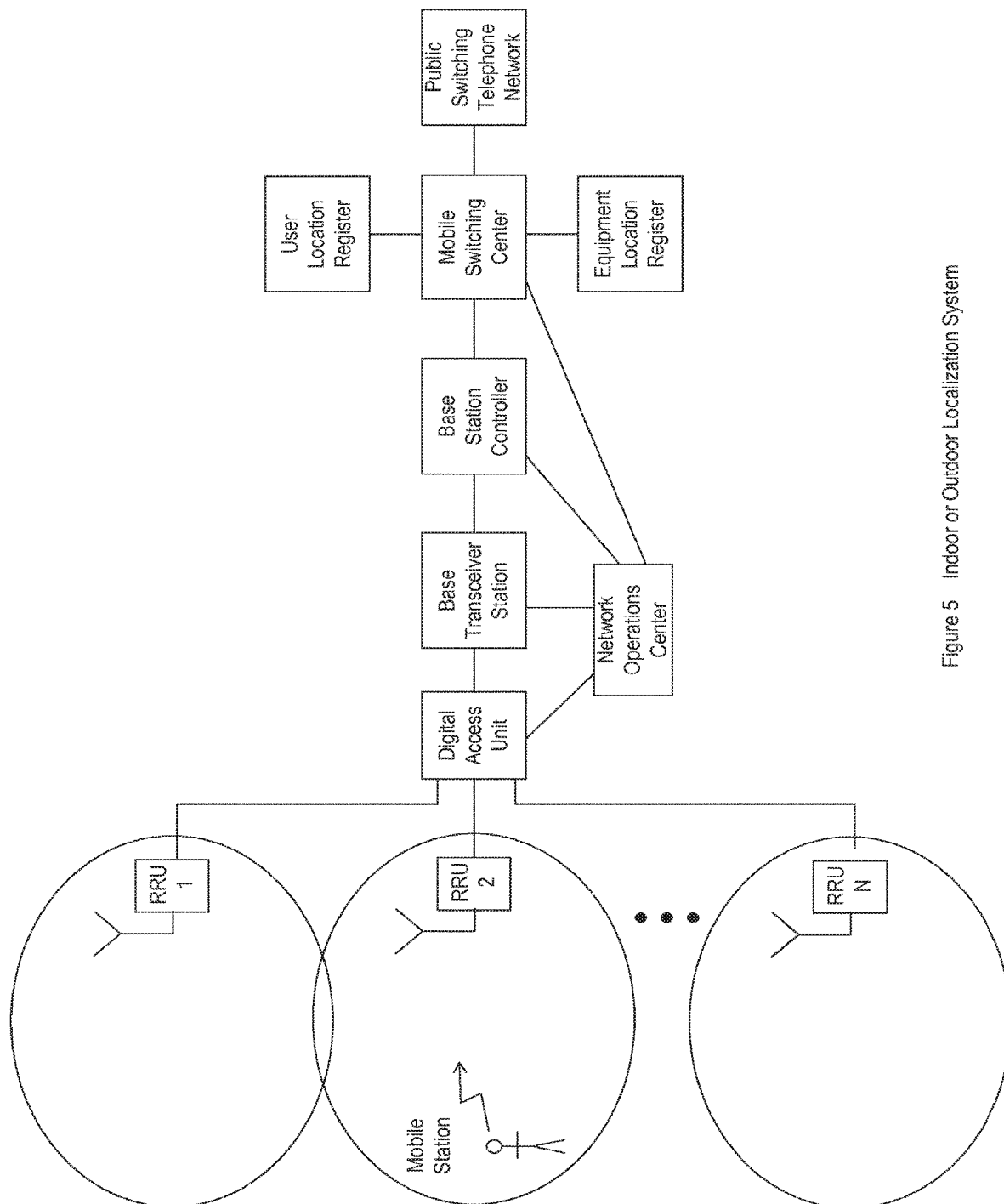


Figure 5 Indoor or Outdoor Localization System

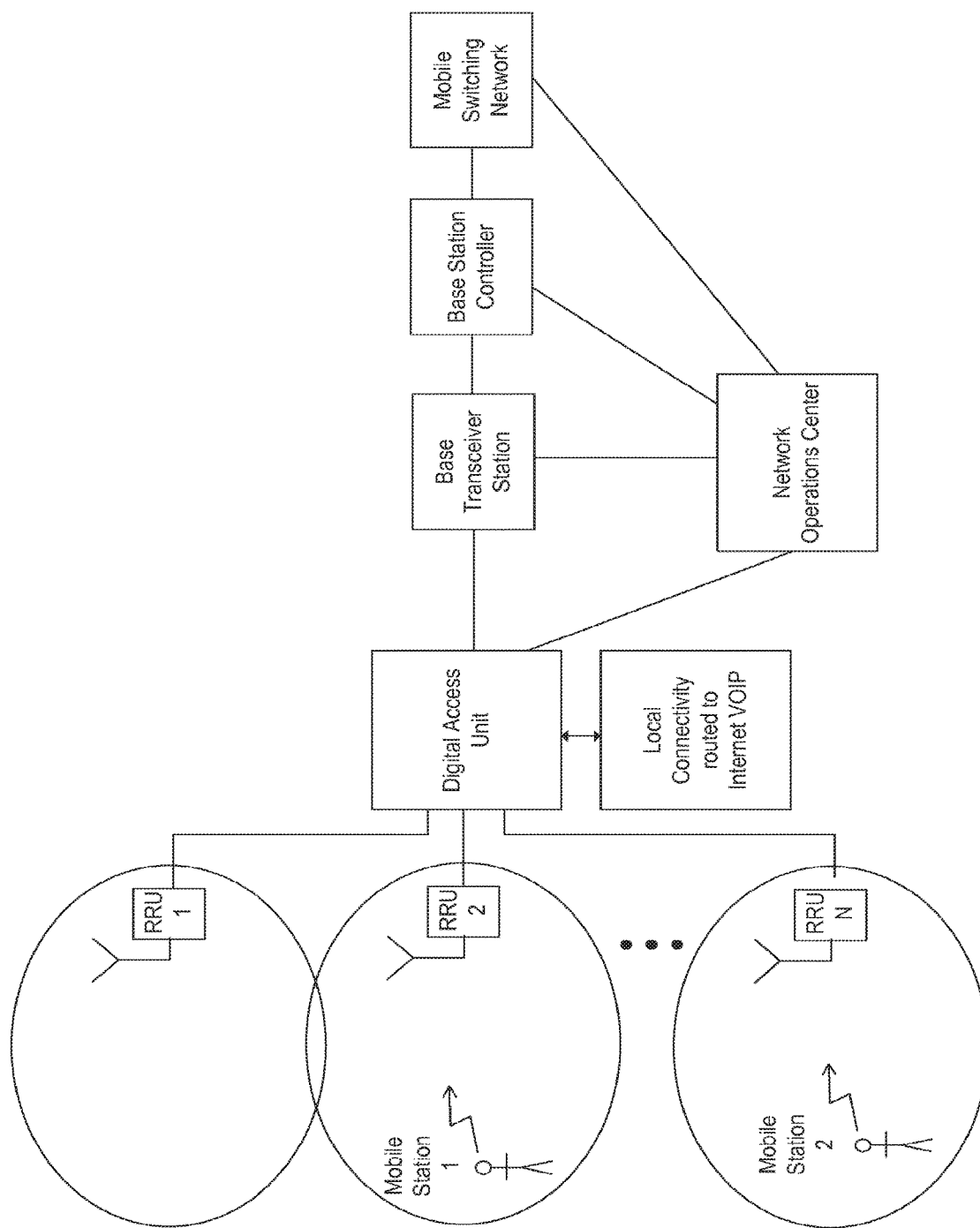


Figure 6 Local Connectivity

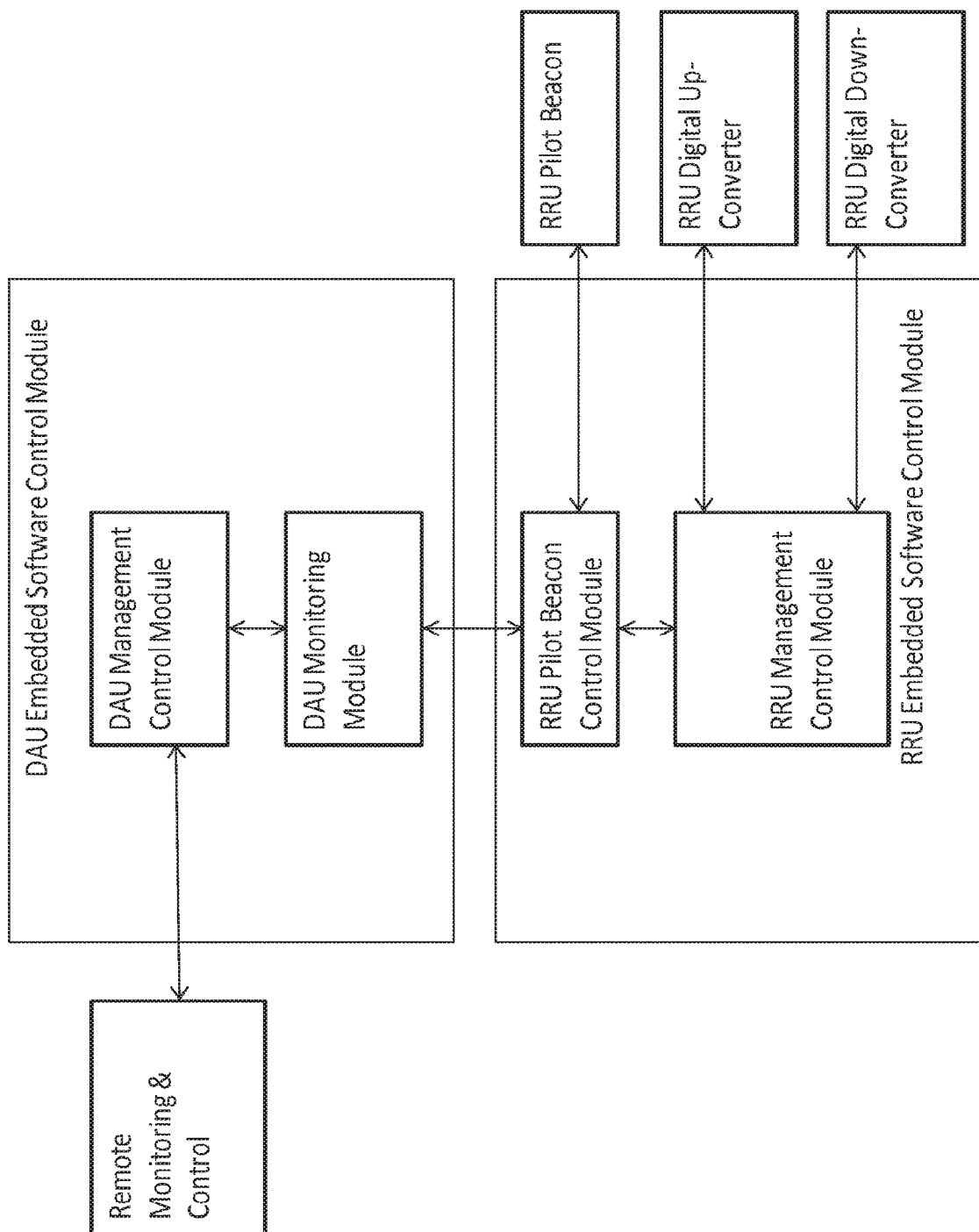


Figure 7: Embedded Software Control Modules

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**REMOTELY RECONFIGURABLE
DISTRIBUTED ANTENNA SYSTEM AND
METHODS**

**CROSS-REFERENCES TO RELATED
APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 16/868,748, filed May 7, 2020, which is a continuation of U.S. patent application Ser. No. 16/737,419, filed Jan. 8, 2020, which is a continuation of U.S. patent application Ser. No. 16/175,520, filed Oct. 30, 2018, now U.S. Pat. No. 10,701,695, which is a continuation of U.S. patent application Ser. No. 15/391,408, filed Dec. 27, 2016, now U.S. Pat. No. 10,159,074, which is a continuation of U.S. patent application Ser. No. 14/949,405, filed Nov. 23, 2015, now U.S. Pat. No. 9,531,473; which is a continuation of U.S. patent application Ser. No. 14/169,719, filed Jan. 31, 2014, now U.S. Pat. No. 9,419,714; which is a continuation of U.S. patent application Ser. No. 13/211,243, filed Aug. 16, 2011, now U.S. Pat. No. 8,682,338; which claims the benefit of U.S. Patent Application No. 61/382,836, filed Sep. 14, 2010; the disclosures of which are hereby incorporated by reference for all purposes

FIELD OF THE INVENTION

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 software defined radio (SDR).

BACKGROUND OF THE INVENTION

Wireless and mobile network operators face the continuing challenge of building networks that effectively manage high data-traffic growth rates. Mobility and an increased level of multimedia content for end users requires end-to-end network adaptations that support both new services and the increased demand for broadband and flat-rate Internet access. One of the most difficult challenges faced by network operators is caused by the physical movements of subscribers from one location to another, and particularly when wireless subscribers congregate in large numbers at one location. A notable example is a business enterprise facility during lunchtime, when a large number of wireless subscribers visit a cafeteria location in the building. At that time, a large number of subscribers have moved away from their offices and usual work areas. It's likely that during lunchtime there are many locations throughout the facility where there are very few subscribers. If the indoor wireless network resources were properly sized during the design process for subscriber loading as it is during normal working hours when subscribers are in their normal work areas, it is very likely that the lunchtime scenario will present some unexpected challenges with regard to available wireless capacity and data throughput.

To accommodate this variation in subscriber loading, there are several candidate prior art approaches.

One approach is to deploy many low-power high-capacity base stations throughout the facility. The quantity of base stations is determined based on the coverage of each base station and the total space to be covered. Each of these base stations is provisioned with enough radio resources, i.e., capacity and broadband data throughput to accommodate the maximum subscriber loading which occurs during the

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course of the workday and work week. Although this approach typically yields a high quality of service, the notable disadvantage of this approach is that during a major part of the time many of the base stations' capacity is being wasted. Since a typical indoor wireless network deployment involves capital and operational costs which are assessed on a per-subscriber basis for each base station, the typically high total life cycle cost for a given enterprise facility is far from optimal.

10 A second candidate approach involves deployment of a DAS along with a centralized group of base stations dedicated to the DAS. A conventional DAS deployment falls into one of two categories. The first type of DAS is "fixed", where the system configuration doesn't change based on time of day or other information about usage. The remote units associated with the DAS are set up during the design process so that a particular block of base station radio resources is thought to be enough to serve each small group of DAS remote units. A notable disadvantage of this approach is that most enterprises seem to undergo frequent re-arrangements and re-organizations of various groups within the enterprise. Therefore, it's highly likely that the initial setup will need to be changed from time to time, requiring deployment of additional staff and contract resources with appropriate levels of expertise regarding wireless networks.

25 The second type of DAS is equipped with a type of network switch which allows the location and quantity of DAS remote units associated with any particular centralized base station to be changed manually. Although this approach would seem to allow dynamic reconfiguration based on the needs of the enterprise or based on time of day, it frequently requires deployment of additional staff resources for real-time management of the network. Another issue is that it's not always correct or best to make the same DAS remote unit configuration changes back and forth on each day of the week at the same times of day. Frequently it is difficult or impractical for an enterprise IT manager to monitor the subscriber loading on each base station. And it is almost certain that the enterprise IT manager has no practical way to determine the loading at a given time of day for each DAS remote unit; they can only guess.

35 Another major limitation of prior art DAS deployments is related to their installation, commissioning and optimization process. Some challenging issues which must be overcome include selecting remote unit antenna locations to ensure proper coverage while minimizing downlink interference from outdoor macro cell sites, minimizing uplink interference to outdoor macro cell sites, and ensuring proper intra-system handovers while indoors and while moving from outdoors to indoors (and vice-versa). The process of performing such deployment optimization is frequently characterized as trial-and-error and as such, the results may not be consistent with a high quality of service.

50 A major limitation of prior art DAS equipment employing digital transmission links such as optical fiber or wired Ethernet is the fact that the prior-art RF-to-digital conversion techniques utilize an approach whereby the system converts a single broad RF bandwidth of e.g., 10 to 25 MHz to digital. Therefore all the signals, whether weak or strong, desired or undesired, contained within that broad bandwidth are converted to digital, whether those signals are desired or not. This approach frequently leads to inefficiencies within the DAS which limit the DAS network capacity. It would be preferable to employ an alternative approach yielding greater efficiencies and improved flexibility, particularly for neutral host applications.

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In 2008 the FCC further clarified its E-911 requirements with regard to Phase 2 accuracy for mobile wireless networks. The information required in Phase 2 is the mobile phone number and the physical location, within a few dozen yards, from which the call was made. The Canadian government is reportedly considering enacting similar requirements. Also the FCC is eager to see US mobile network operators provide positioning services with enhanced accuracy for E-911 for indoor subscribers. There is a reported effort within the FCC to try to mandate Phase 2 accuracy indoors, within the next 2 years.

Many wireless networks employ mobile and fixed broadband wireless terminals which employ GPS-based E-911 location services. It has been demonstrated that GPS signals from satellites outdoors don't propagate well into the indoor space. Therefore an alternative, more robust E-911 location determination approach is required for indoors, particularly if the FCC requirements are changed to be more stringent.

Several US operators have expressed concern about how they can practically and cost-effectively obtain these enhanced location accuracy capabilities. Operators are very eager to identify a cost-effective approach which can be deployed indoors for enhanced location accuracy.

One proposed approach toward indoor location accuracy enhancement for CDMA networks would employ a separate unit known as a CDMA Pilot Beacon. A notable disadvantage of this approach for an indoor OAS application is that since the CDMA Pilot Beacon unit is a separate and dedicated device and not integrated within the OAS, it would likely be costly to deploy. The Pilot Beacon approach for CDMA networks employs a Pilot Beacon with a unique PN code (in that area) which effectively divides a particular CDMA network coverage area (e.g., indoors) into multiple small zones (which each correspond to the coverage area of a low-power Pilot Beacon). Each Pilot Beacon's location, PN code and RF Power level are known by the network. Each Pilot Beacon must be synchronized to the CDMA network, via GPS or local base station connection. A variable delay setting permits each Pilot Beacon to have the appropriate system timing to permit triangulation and/or Cell ID position determination. One optional but potentially costly enhancement to this approach would employ a Wireless Modem for each Pilot Beacon to provide remote Alarms, Control and Monitoring of each CDMA Pilot Beacon. No known solution for indoor location accuracy enhancement has been publicly proposed for WCDMA networks.

One candidate technically-proven approach toward indoor location accuracy enhancement for GSM networks would employ a separate unit known as a Location Measurement Unit or LMU. A notable disadvantage of this approach for an indoor DAS application is that, since the LMU is a separate and dedicated device and not integrated within the DAS, it is costly to deploy. Each LMU requires a backhaul facility to a central server which analyzes the LMU measurements. The LMU backhaul cost adds to the total cost of deploying the enhanced accuracy E-911 solution for GSM networks. Despite the availability of the already technically-proven LMU approach, it has not been widely deployed in conjunction with indoor DAS.

Based on the prior art approaches described herein, it is apparent that a highly efficient, easily deployed and dynamically reconfigurable wireless network is not achievable with prior art systems and capabilities.

BRIEF SUMMARY OF THE INVENTION

The present invention substantially overcomes the limitations of the prior art discussed above. The advanced

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system architecture of the present invention provides a high degree of flexibility to manage, control, enhance and facilitate radio resource efficiency, usage and overall performance of the distributed wireless network. This advanced system architecture enables specialized applications and enhancements including flexible simulcast, automatic traffic load-balancing, network and radio resource optimization, network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, radio frequency carrier placement, traffic monitoring, traffic tagging, and indoor location determination using pilot beacons. The present invention can also serve multiple operators, multi-mode radios (modulation-independent) and multi-frequency bands per operator to increase the efficiency and traffic capacity of the operators' wireless networks.

Accordingly, it is an object of the present invention to provide a capability for Flexible Simulcast. With Flexible Simulcast, the amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs by each RRU Access Module can be set via software control as described hereinafter to meet desired capacity and throughput objectives or wireless subscriber needs. To achieve these and other objects, an aspect of the present invention employs software-programmable frequency selective Digital Up-Converters (DUCs) and Digital Down-Converters (DDCs). A software-defined Remote Radio Head architecture is used for cost-effective optimization of the radio performance. Frequency selective DDCs and DUCs at the Remote Radio Head enable a high signal to noise ratio (SNR) which maximize the throughput data rate. An embodiment shown in FIG. 1 depicts a basic structure and provides an example of a Flexible Simulcast downlink transport scenario. FIG. 2 depicts an embodiment of a basic structure of a Flexible Simulcast uplink transport scenario.

It is a further object of the present invention to facilitate conversion and transport of several discrete relatively narrow RF bandwidths. In another aspect of the invention, an embodiment converts only that plurality of specific, relatively narrow bandwidths that carry useful information. Thus, this aspect of the present invention allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and facilitates transport of more operators' band segments over the optical fiber. To achieve the above result, the present invention utilizes frequency-selective filtering at the Remote Radio Head which enhances the system performance. In some embodiments of this aspect of the invention, noise reduction via frequency-selective filtering at the Remote Radio Head is utilized for maximizing the SNR and consequently maximizing the data throughput. It is a further object of the present invention to provide CDMA and WCDMA indoor location accuracy enhancement. In an aspect of the present invention, an embodiment provides enhanced location accuracy performance by employing pilot beacons. FIG. 3 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU). The Remote Radio Heads have a unique beacon that is distinct and identifies that particular indoor cell. The mobile user will use the beacon information to assist in the localization to a particular cell.

It is a further object of the present invention to enhance GSM and LTE indoor location accuracy. In another aspect, an embodiment of the present invention provides localization of a user based on the radio signature of the mobile device. FIG. 4 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central

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Digital Access Unit (DAU). In accordance with the invention, each Remote Radio Head provides unique header information on data received by that Remote Radio Head. The system of the invention uses this header information in conjunction with the mobile user's radio signature to localize the user to a particular cell. It is a further object of the present invention to re-route local traffic to Internet VOIP, Wi-Fi or WiMAX. In this aspect of the invention, an embodiment determines the radio signatures of the individual users within a DAU or Island of DAUs and uses this information to identify if the users are located within the coverage area associated with a specific DAU or Island of DAUs. The DAUs track the radio signatures of all the active users within its network and record a running data base containing information pertaining to them. One embodiment of the present invention is for the Network Operations Center (NOC) to inform the DAU that, e.g., two specific users are collocated within the same DAU or Island of DAUs, as depicted in FIG. 6. The DAUs then reroute the users to Internet VOIP, Wi-Fi or WiMAX as appropriate. Another embodiment of the present invention is to determine the Internet Protocol (IP) addresses of the individual users' Wi-Fi connections. If the individual users' IP addresses are within the same DAU or Island of DAUs, the data call for these users is rerouted over the internal network.

Applications of the present invention are suitable to be employed with distributed base stations, distributed antenna systems, distributed repeaters, mobile equipment and wireless terminals, portable wireless devices, and other wireless communication systems such as microwave and satellite communications. The present invention is also field upgradable through a link such as an Ethernet connection to a remote computing center.

Appendix I is a glossary of terms used herein, including acronyms.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram according to one embodiment of the invention showing the basic structure and an example of a Flexible Simulcast downlink transport scenario based on having 2 DAU and 4 DRU.

FIG. 2 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a Flexible Simulcast uplink transport scenario based on having 2 DAU and 4 DRU.

FIG. 3 shows an embodiment of an indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU).

FIG. 4 shows an embodiment of an indoor system in accordance with the invention which employs multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU).

FIG. 5 illustrates an embodiment of a cellular network system employing multiple Remote Radio Heads according to the present invention.

FIG. 6 is a depiction of local connectivity according to one embodiment of the present invention.

FIG. 7 illustrates an embodiment of the basic structure of the embedded software control modules which manage key functions of the DAU and RRU, in accordance with the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention is a novel Reconfigurable Distributed Antenna System that provides a high degree of flexibility to manage, control, re-configure, enhance and facilitate the radio resource efficiency, usage and overall performance of the distributed wireless network. An embodiment of the Reconfigurable Distributed Antenna System in accordance with the present invention is shown in FIG. 1. The Flexible Simulcast System **100** can be used to explain the operation of Flexible Simulcast with regard to downlink signals. The system employs a Digital Access Unit functionality (hereinafter "DAU"). The DAU serves as an interface to the base station (BTS). The DAU is (at one end) connected to the BTS, and on the other side connected to multiple RRUs. For the downlink (DL) path, RF signals received from the BTS are separately down-converted, digitized, and converted to baseband (using a Digital Down-Converter). Data streams are then I/Q mapped and framed. Specific parallel data streams are then independently serialized and translated to optical signals using pluggable SFP modules, and delivered to different RRUs over optical fiber cable. For the uplink (UL) path optical signals received from RRUs are deserialized, deframed, and up-converted digitally using a Digital Up-Converter. Data streams are then independently converted to the analog domain and up-converted to the appropriate RF frequency band. The RF signal is then delivered to the BTS. An embodiment of the system is mainly comprised of DAU1 indicated at **101**, RRU1 indicated at **103**, RRU2 indicated at **104**, DAU2 indicated at **102**, RRU3 indicated at **105**, and RRU4 indicated at **106**. A composite downlink input signal **107** from, e.g., a base station belonging to one wireless operator enters DAU1 at the DAU1 RF input port. Composite signal **107** is comprised of Carriers 1-4. A second composite downlink input signal from e.g., a second base station belonging to the same wireless operator enters DAU2 at the DAU2 RF input port. Composite signal **108** is comprised of Carriers 5-8. The functionality of DAU1, DAU2, RRU1, RRU2, RRU3 and RRU4 are explained in detail by U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and attached hereto as an appendix. One optical output of DAU1 is fed to RRU1. A second optical output of DAU1 is fed via bidirectional optical cable **113** to DAU2. This connection facilitates networking of DAU1 and DAU2, which means that all of Carriers 1-8 are available within DAU1 and DAU2 to transport to RRU1, RRU2, RRU3 and RRU4 depending on software settings within the networked DAU system comprised of DAU1 and DAU2. The software settings within RRU1 are configured either manually or automatically such that Carriers 1-8 are present in the downlink output signal **109** at the antenna port of RRU1. The presence of all 8 carriers means that RRU1 is potentially able to access the full capacity of both base stations feeding DAU1 and DAU2. A possible application for RRU1 is in a wireless distribution system is e.g., a cafeteria in an enterprise building during the lunch hour where a large number of wireless subscribers are gathered. RRU2 is fed by a second optical port of RRU1 via bidirectional optical cable **114** to RRU2. Optical cable **114** performs the function of daisy chaining RRU2 with RRU1. The software settings within RRU2 are configured either manually or automatically such that Carriers 1, 3, 4 and 6 are present in downlink output signal **110** at the antenna port of RRU2. The capacity of RRU2 is set to a much lower value than RRU1 by virtue of

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its specific Digital Up Converter settings. The individual Remote Radio Units have integrated frequency selective DUCs and DDCs with gain control for each carrier. The DAUs can remotely turn on and off the individual carriers via the gain control parameters.

In a similar manner as described previously for RRU1, the software settings within RRU3 are configured either manually or automatically such that Carriers 2 and 6 are present in downlink output signal **111** at the antenna port of RRU3. Compared to the downlink signal **110** at the antenna port of RRU2, the capacity of RRU3 which is configured via the software settings of RRU3 is much less than the capacity of RRU2. RRU4 is fed by a second optical port of RRU3 via bidirectional optical cable **115** to RRU4. Optical cable **115** performs the function of daisy chaining RRU4 with RRU3. The software settings within RRU4 are configured either manually or automatically such that Carriers 1, 4, 5 and 8 are present in downlink output signal **112** at the antenna port of RRU4. The capacity of RRU4 is set to a much lower value than RRU1. The relative capacity settings of RRU1, RRU2, RRU3 and RRU4 can be adjusted dynamically as discussed in connection with FIG. 7 to meet the capacity needs within the coverage zones determined by the physical positions of antennas connected to RRU1, RRU2, RRU3 and RRU4 respectively.

The present invention facilitates conversion and transport of several discrete relatively narrow RF bandwidths. This approach allows conversion of only those multiple specific relatively narrow bandwidths which carry useful or specific information. This approach also allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and allows transport of more individual operators' band segments over the optical fiber. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, Digital Up Converters located within the RRU which are dynamically software-programmable as discussed hereinafter can be re-configured to transport from the DAU input to any specific RRU output any specific narrow frequency band or bands, RF carriers or RF channels which are available at the respective RF input port of either DAU. This capability is illustrated in FIG. 1 where only specific frequency bands or RF carriers appear at the output of a given RRU.

A related capability of the present invention is that not only can the Digital Up Converters located within each RRU be configured to transport any specific narrow frequency band from the DAU input to any specific RRU output, but also the Digital Up Converters within each RRU can be configured to transport any specific time slot or time slots of each carrier from the DAU input to any specific RRU output. The DAU detects which carriers and corresponding time slots are active. This information is relayed to the individual RRUs via the management control and monitoring protocol software discussed hereinafter. This information is then used, as appropriate, by the RRUs for turning off and on individual carriers and their corresponding time slots.

Referring to FIG. 1 of the instant patent application, an alternative embodiment of the present invention may be described as follows. In a previous description of FIG. 1, a previous embodiment involved having downlink signals from two separate base stations belonging to the same wireless operator enter DAU1 and DAU2 input ports respectively. In an alternative embodiment, a second composite downlink input signal from e.g., a second base station belonging to a different wireless operator enters DAU2 at the

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DAU2 RF input port. In this embodiment, signals belonging to both the first operator and the second operator are converted and transported to RRU1, RRU2, RRU3 and RRU4 respectively. This embodiment provides an example of a neutral host wireless system, where multiple wireless operators share a common infrastructure comprised of DAU1, DAU2, RRU1, RRU2, RRU3 and RRU4. All the previously mentioned features and advantages accrue to each of the two wireless operators.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, the Digital Up Converters present in the RRU can be programmed to process various signal formats and modulation types including FDMA, CDMA, TDMA, OFDMA and others. Also, the Digital Up Converters present in the respective RRUs can be programmed to operate with signals to be transmitted within various frequency bands subject to the capabilities and limitations of the system architecture disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010. In one embodiment of the present invention where a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1, the transmitted signal at the antenna ports of RRU1, RRU2 and RRU4 will be a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to carrier 1 at the input port to DAU1.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also referring to FIG. 1 of the instant patent application, it is understood that the Digital Up Converters present in the respective RRUs can be programmed to transmit any desired composite signal format to each of the respective RRU antenna ports. As an example, the Digital Up Converters present in RRU1 and RRU2 can be dynamically software-reconfigured as described previously so that the signal present at the antenna port of RRU1 would correspond to the spectral profile shown in FIG. 1 as **110**, and also that the signal present at the antenna port of RRU2 would correspond to the spectral profile shown in FIG. 1 as **109**. The application for such a dynamic rearrangement of RRU capacity would be e.g., if a company meeting were suddenly convened in the area of the enterprise corresponding to the coverage area of RRU2. Although the description of some embodiments in the instant application refers to base station signals **107** and **108** as being on different frequencies, the system and method of the present invention readily supports configurations where one or more of the carriers which are part of base station signals **107** and **108** and are identical frequencies, since the base station signals are digitized, packetized, routed and switched to the desired RRU.

Another embodiment of the Distributed Antenna System in accordance with the present invention is shown in FIG. 2. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and also as shown in FIG. 2 the Flexible Simulcast System **200** can be used to explain the operation of Flexible Simulcast with regard to uplink signals. As discussed previously with regard to downlink signals and by referring to FIG. 1, the uplink system shown in FIG. 2 is mainly comprised of DAU1 indicated at **201**, RRU1 indicated at **203**, RRU2 indicated at **204**, DAU2 indicated at **202**, RRU3 indicated at **205**, and

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RRU4 indicated at 206. In a manner similar to the downlink operation explained by referring to FIG. 1, the operation of the uplink system shown in FIG. 2 can be understood as follows.

The Digital Down Converters present in each of RRU1, RRU2, RRU3 and RRU4 are dynamically software-configured as described previously so that uplink signals of the appropriate desired signal format(s) present at the receive antenna ports of the respective RRU1, RRU2, RRU3 and RRU4 are selected based on the desired uplink band(s) to be processed and filtered, converted and transported to the appropriate uplink output port of either DAU1 or DAU2. The DAUs and RRUs frame the individual data packets corresponding to their respective radio signature using the Common Public Interface Standard (CPRI). Other Interface standards are applicable provided they uniquely identify data packets with respective RRUs. Header information is transmitted along with the data packet which identifies the RRU and DAU that corresponds to the individual data packet.

In one example for the embodiment shown in FIG. 2, RRU1 and RRU3 are configured to receive uplink signals within the Carrier 2 bandwidth, whereas RRU2 and RRU4 are both configured to reject uplink signals within the Carrier 2 bandwidth. When RRU3 receives a strong enough signal at its receive antenna port within the Carrier 2 bandwidth to be properly filtered and processed, the Digital Down Converters within RRU3 facilitate processing and conversion. Similarly, when RRU1 receives a strong enough signal at its receive antenna port within the Carrier 2 bandwidth to be properly filtered and processed, the Digital Down Converters within RRU1 facilitate processing and conversion. The signals from RRU1 and RRU3 are combined based on the active signal combining algorithm, and are fed to the base station connected to the uplink output port of DAU1. The term simulcast is frequently used to describe the operation of RRU1 and RRU3 with regard to uplink and downlink signals within Carrier 2 bandwidth. The term Flexible Simulcast refers to the fact that the present invention supports dynamic and/or manual rearrangement of which specific RRU are involved in the signal combining process for each Carrier bandwidth.

Referring to FIG. 2, the Digital Down Converters present in RRU1 are configured to receive and process signals within Carrier 1-8 bandwidths. The Digital Down Converters present in RRU2 are configured to receive and process signals within Carrier 1, 3, 4 and 6 bandwidths. The Digital Down Converters present in RRU3 are configured to receive and process signals within Carrier 2 and 6 bandwidths. The Digital Down Converters present in RRU4 are configured to receive and process signals within Carrier 1, 4, 5 and 8 bandwidths. The respective high-speed digital signals resulting from processing performed within each of the four RRU are routed to the two DAUs. As described previously, the uplink signals from the four RRUs are combined within the respective DAU corresponding to each base station.

An aspect of the present invention includes an integrated Pilot Beacon function within the each RRU. In an embodiment, each RRU comprises a unique software programmable Pilot Beacon as discussed hereinafter. This approach is intended for use in CDMA and/or WCDMA indoor DAS networks. A very similar approach can be effective for indoor location accuracy enhancement for other types of networks such as LTE and WiMAX. Because each RRU is already controlled and monitored via the DAUs which comprise the network, there is no need for costly deploy-

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ment of additional dedicated wireless modems for remote monitoring and control of pilot beacons.

An RRU-integrated Pilot Beacon approach is employed for both CDMA and WCDMA networks. Each operational pilot beacon function within an RRU employs a unique PN code (in that area) which effectively divides the WCDMA or CDMA indoor network coverage area into multiple small "zones" (which each correspond to the coverage area of a low-power Pilot Beacon). Each Pilot Beacon's location, PN code and RF Power level are known by the network. Each Pilot Beacon is synchronized to the WCDMA or CDMA network, via its connection to the DAU.

Unlike the transmit signal from a base station which is "dynamic", the Pilot Beacon transmit signal will be effectively "static" and its downlink messages will not change over time based on network conditions.

For a WCDMA network, in Idle mode each mobile subscriber terminal is able to perform Pilot Signal measurements of downlink signals transmitted by base stations and Pilot Beacons. When the WCDMA mobile subscriber terminal transitions to Active mode, it reports to the serving cell all its Pilot Signal measurements for base stations and for Pilot Beacons. For CDMA networks, the operation is very similar. For some RRU deployed in an indoor network, the RRU can be provisioned as either a Pilot Beacon or to serve mobile subscribers in a particular operator bandwidth, but not both.

For a WCDMA network, existing inherent capabilities of the globally-standardized networks are employed. The WCDMA mobile subscriber terminal is able to measure the strongest CPICH RSCP (Pilot Signal Code Power) in either Idle mode or any of several active modes. Also, measurements of CPICH Ec/No by the mobile subscriber terminal in either Idle mode or any of several active modes are possible. As a result, the mobile subscriber terminal reports all available RSCP and Ec/No measurements via the serving base station (whether indoor or outdoor) to the network. Based on that information, the most likely mobile subscriber terminal location is calculated and/or determined. For CDMA networks, the operation is very similar to the process described herein.

A previously described embodiment of the present invention referring to FIG. 1 involved having a wideband CDMA signal present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. In the previously described embodiment, the transmitted signal at the antenna ports of RRU1, RRU2 and RRU4 is a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to carrier 1 at the input port to DAU1. An alternative embodiment of the present invention is one where a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. However, in the alternative embodiment the transmitted signal at the antenna port of RRU1 differs slightly from the previous embodiment. In the alternative embodiment, a wideband CDMA signal is present within e.g., the bandwidth corresponding to carrier 1 at the input port to DAU1. The transmitted signal from RRU1 is a combination of the wideband CDMA signal which was present at the input port to DAU1, along with a specialized WCDMA pilot beacon signal. The WCDMA pilot beacon signal is intentionally set well below the level of the base station pilot signal.

A further alternative embodiment can be explained referring to FIG. 1 which applies in the case where CDMA signals are generated by the base station connected to the input port of DAU1. In this further alternative embodiment

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of the present invention, the transmitted signal at the antenna port of RRU1 is a combination of the CDMA signal which was present at the input port to DAU1, along with a specialized CDMA pilot beacon signal. The CDMA pilot beacon signal is intentionally set well below the level of the base station pilot signal.

An embodiment of the present invention provides enhanced accuracy for determining location of indoor wireless subscribers. FIG. 4 depicts a typical indoor system employing multiple Remote Radio Head Units (RRUs) and a central Digital Access Unit (DAU). Each Remote Radio Head provides a unique header information on data received by that Remote Radio Head. This header information in conjunction with the mobile user's radio signature are used to localize the user to a particular cell. The DAU signal processing can identify the individual carriers and their corresponding time slots. A header is included with each data packet that uniquely identifies the corresponding RRU. The DAU can detect the carrier frequency and the corresponding time slot associated with the individual RRUs. The DAU has a running data base that identifies each carrier frequency and time slot with a respective RRU. The carrier frequency and time slot is the radio signature that uniquely identifies the GSM user.

The DAU communicates with a Network Operation Center (NOC) via a Ethernet connection or an external modem, as depicted in FIG. 5. Once a E911 call is initiated the Mobile Switching Center (MSC) in conjunction with the NOC can identify the corresponding BaseTransceiver Station (BTS) where the user has placed the call. The user can be localized within a BTS cell. The NOC then makes a request to the individual DAUs to determine if the E911 radio signature is active in their indoor cell. The DAU checks its data base for the active carrier frequency and time slot. If that radio signature is active in the DAU, then that DAU will provide the NOC with the location information of the corresponding RRU.

A further embodiment of the present invention includes LTE to provide enhanced accuracy for determining the location of indoor wireless subscribers. GSM uses individual carriers and time slots to distinguish users whereas LTE uses multiple carriers and time slot information to distinguish users. The DAU can simultaneously detect multiple carriers and their corresponding time slots to uniquely identify the LTE user. The DAU has a running data base that identifies the carrier frequencies and time slot radio signature for the respective RRU. This information can be retrieved from the NOC once a request is made to the DAU.

Referring next to FIG. 7, the DAU embedded software control module and RRU embedded software control module can be better understood in connection with the operation of key functions of the DAU and RRU. One such key function is determining and/or setting the appropriate amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs to meet desired capacity and throughput objectives. The DAU embedded software control module comprises a DAU Monitoring module that detects which carriers and corresponding time slots are active for each RRU. The DAU embedded software control module also comprises a DAU Management Control module which communicates with the RRU over a fiber optic link control channel via a control protocol with the RRU Management Control module. In turn, the RRU Management Control module sets the individual parameters of all the RRU Digital Up-Converters to enable or disable specific radio resources from being transmitted by a particular RRU or group of

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RRUs, and also sets the individual parameters of all the RRU Digital Down-Converters to enable or disable specific uplink radio resources from being processed by a particular RRU or group of RRUs.

In an embodiment, an algorithm operating within the DAU Monitoring module, that detects which carriers and corresponding time slots for each carrier are active for each RRU, provides information to the DAU Management Control module to help identify when, e.g., a particular downlink carrier is loaded by a percentage greater than a predetermined threshold whose value is communicated to the DAU Management Control module by the DAU's Remote Monitoring and Control function. If that occurs, the DAU Management Control module adaptively modifies the system configuration to slowly begin to deploy additional radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular RRU which need those radio resources within its coverage area. At the same time, in at least some embodiments the DAU Management Control module adaptively modifies the system configuration to slowly begin to remove certain radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular RRU which no longer needs those radio resources within its coverage area. Another such key function of the DAU embedded software control module and RRU embedded software control module is determining and/or setting and/or analyzing the appropriate transmission parameters and monitoring parameters for the integrated Pilot Beacon function contained within each RRU. These Pilot Beacon transmission and monitoring parameters include Beacon Enable/Disable, Beacon Carrier Frequencies, Beacon Transmit Power, Beacon PN Code, Beacon Downlink BCH Message Content, Beacon Alarm, Beacon Delay Setting and Beacon Delay Adjustment Resolution. The RRU Pilot Beacon Control module communicates with the pilot beacon generator function in the RRU to set and monitor the pilot beacon parameters as listed herein.

In summary, the Reconfigurable Distributed Antenna System of the present invention described herein efficiently conserves resources and reduces costs. The reconfigurable system is adaptive or manually field-programmable, since the algorithms can be adjusted like software in the digital processor at any time.

Although the present invention has been described with reference to the preferred embodiments, it will be understood that the invention is not limited to the details described thereof. Various substitutions and modifications have been suggested in the foregoing description, and others will occur to those of ordinary skill in the art. Therefore, all such substitutions and modifications are intended to be embraced within the scope of the invention as defined in the appended claims.

APPENDIX I

Glossary of Terms

ACLR Adjacent Channel Leakage Ratio
ACPR Adjacent Channel Power Ratio
ADC Analog to Digital Converter
AQDM Analog Quadrature Demodulator
AQM Analog Quadrature Modulator
AQDMC Analog Quadrature Demodulator Corrector
AQMC Analogy Quadrature Modulator Corrector
BPF Bandpass Filter
BTS Base Transceiver System or Base Station
CDMA Code Division Multiple Access

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CFR Crest Factor Reduction
 DAC Digital to Analog Converter
 DAU Digital Access Unit
 DET Detector
 DHMPA Digital Hybrid mode Power Amplifier
 DDC Digital Down Converter
 DNC Down Converter
 DPA Doherty Power Amplifier
 DQDM Digital Quadrature Demodulator
 DQM Digital Quadrature Modulator
 DSP Digital Signal Processing
 DUC Digital Up Converter
 EER Envelope Elimination and Restoration
 EF Envelope Following
 ET Envelope Tracking
 EVM Error Vector Magnitude
 FFLPA Feedforward Linear Power Amplifier
 FIR Finite Impulse Response
 FPGA Field-Programmable Gate Array
 GSM Global System for Mobile Communications
 I-Q In-phase/Quadrature
 IF Intermediate Frequency
 LINC Linear Amplification Using Nonlinear Components
 LO Local Oscillator
 LPF Low Pass Filter
 MCPA Multi-Carrier Power Amplifier
 MDS Multi-Directional Search
 OFDM Orthogonal Frequency Division Multiplexing
 PA Power Amplifier
 PARR Peak-to-Average Power Ratio
 PD Digital Baseband Predistortion
 PLL Phase Locked Loop
 PN Pseudo-Noise
 QAM Quadrature Amplitude Modulation
 QPSK Quadrature Phase Shift Keying
 RF Radio Frequency
 RRH Remote Radio Head
 RRU Remote Radio head Unit
 SAW Surface Acoustic Wave Filter
 UMTS Universal Mobile Telecommunications System
 UPC Up Converter
 WCDMA Wideband Code Division Multiple Access
 WLAN Wireless Local Area Network

What is claimed is:

1. A wireless system comprising:

one or more central nodes that receive a number of a plurality of radio resources from an operator hub that enables wireless communications and that provides the plurality of radio resources to a radio access network using the Common Public Radio Interface (CPRI) protocol; and

a plurality of wireless access points that is coupled to the one or more central nodes and distributes one or more wireless signals to one or more wireless subscribers, the plurality of wireless access points including at least a first access point and a second access point,

wherein one or more central nodes assigns a first subset of the number of the plurality of radio resources to the first access point and a second subset of the number of the plurality of radio resources to the second access point, the first subset including more radio resources than the second subset, and

wherein, in response to a change in need of a number of wireless subscribers coupled to the second access point and which of the second subset is loaded beyond a

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threshold, the one or more central nodes assign additional radio resources of the plurality of radio resources to the second access point.

2. The wireless system of claim 1, wherein the change in need is determined based on a change in capacity needed by the number of wireless subscribers coupled to the second access point or a change in throughput needed by the number of wireless subscribers coupled to the second access point.

3. The wireless system of claim 1, wherein the additional resources are included in the first subset prior to being assigned to the second access point, and wherein the one or more central nodes assign the additional radio resources of the plurality of radio resources to the second access point comprises removing the additional resources from the first subset assigned to the first access point.

4. The wireless system of claim 1, wherein the one or more central nodes analyze one or more transmission parameters associated with the second access point to determine the change in need.

5. The wireless system of claim 1, wherein the one or more central nodes determines the change in need by determining that at least one transmission parameter associated with the second access point is greater than a threshold.

6. The wireless system of claim 1, wherein the first access point belongs to a first sector and the second access point belongs to a second sector.

7. The wireless system of claim 1, wherein the first access point belongs to a first building and the second access point belongs to a second building.

8. The wireless system of claim 1, wherein at least one of the plurality of wireless access points enables communication between an IP device and the one or more central nodes.

9. The wireless system of claim 1, wherein at least two of the plurality of wireless access points are connected in a daisy chain manner to relay communications between at least a subset of the plurality of wireless access points.

10. The wireless system of claim 1, wherein a transmission power provided by at least one of the plurality of wireless access points is configurable via software.

11. The wireless system of claim 1, wherein the one or more one or more central nodes are coupled to a plurality of operator networks via the operator hub.

12. A method comprising:

receiving a plurality of radio resources from an operator hub that operates using a Common Public Radio Interface (CPRI) protocol;

assigning a first subset of the plurality of radio resources to a first access point included in a plurality of wireless access points and a second subset of the plurality of radio resources to a second access point included in the plurality of wireless access points, the first subset including more radio resources than the second subset; and

in response to a change in need of a number of wireless subscribers coupled to the second access point and which of the second subset is loaded beyond a threshold, assigning one or more additional radio resources of the plurality of radio resources to the second access point.

13. The method of claim 12, wherein the change in need is determined based on a change in capacity needed by the number of wireless subscribers coupled to the second access point or a change in throughput needed by the number of wireless subscribers coupled to the second access point.

14. The method of claim 12, wherein the one or more additional resources are included in the first subset prior to

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being assigned to the second access point, and wherein assigning the one or more additional radio resources comprises removing the one or more additional resources from the first subset assigned to the first access point.

15. The method of claim 12, further comprising analyzing one or more transmission parameters associated with the second access point to determine the change in need.

16. The method of claim 12, where the first access point belongs to a first sector and the second access point belongs to a second sector.

17. The method of claim 12, where the first access point belongs to a first building and the second access point belongs to a second building.

18. The method of claim 12, wherein at least one of the plurality of wireless access points enables communication between an IP device and one or more central nodes.

19. The method of claim 12, wherein at least two of the plurality of wireless access points are connected in a daisy chain manner to relay communications between at least a subset of the plurality of wireless access points.

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20. One or more non-transitory computer readable storage media storing instructions that, when executed by one or more processors, cause the one or more processors to perform the steps of:

receiving a plurality of radio resources from an operator hub that operates using a Common Public Radio Interface (CPRI) protocol;

assigning a first subset of the plurality of radio resources to a first access point included in a plurality of wireless access points and a second subset of the plurality of radio resources to a second access point included in the plurality of wireless access points, the first subset including more radio resources than the second subset; and

in response to a change in need by a number of wireless subscribers coupled to the second access point and which of the second subset is loaded beyond a threshold, assigning one or more additional radio resources of the plurality of radio resources to the second access point.

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(54) **DISTRIBUTED ANTENNA SYSTEM**

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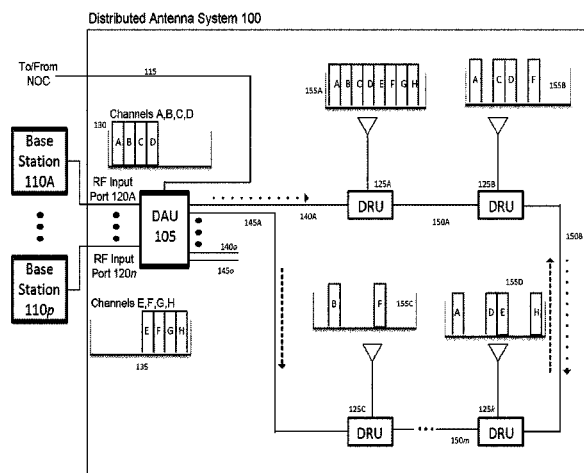
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(57) **ABSTRACT**

The present disclosure is a novel utility of a software defined radio (SDR) based Distributed Antenna System (DAS) that is field reconfigurable and support multi-modulation schemes (modulation-independent), multi-carriers, multi-frequency bands and multi-channels. The present invention enables a high degree of flexibility to manage, control, enhance, facilitate the usage and performance of a distributed wireless network such as Flexible Simulcast, automatic traffic load-balancing, network and radio resource optimization, network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, frequency carrier placement, traffic monitoring, traffic tagging, pilot beacon, etc. As a result, a DAS in accordance with the present invention can increase the efficiency and traffic capacity of the operators' wireless network.

22 Claims, 8 Drawing Sheets



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- continuation of application No. 15/223,819, filed on Jul. 29, 2016, now Pat. No. 10,080,178, which is a continuation of application No. 14/800,515, filed on Jul. 15, 2015, now Pat. No. 9,419,837, which is a continuation of application No. 14/260,145, filed on Apr. 23, 2014, now Pat. No. 9,137,078, which is a continuation of application No. 13/211,247, filed on Aug. 16, 2011, now Pat. No. 8,737,300.
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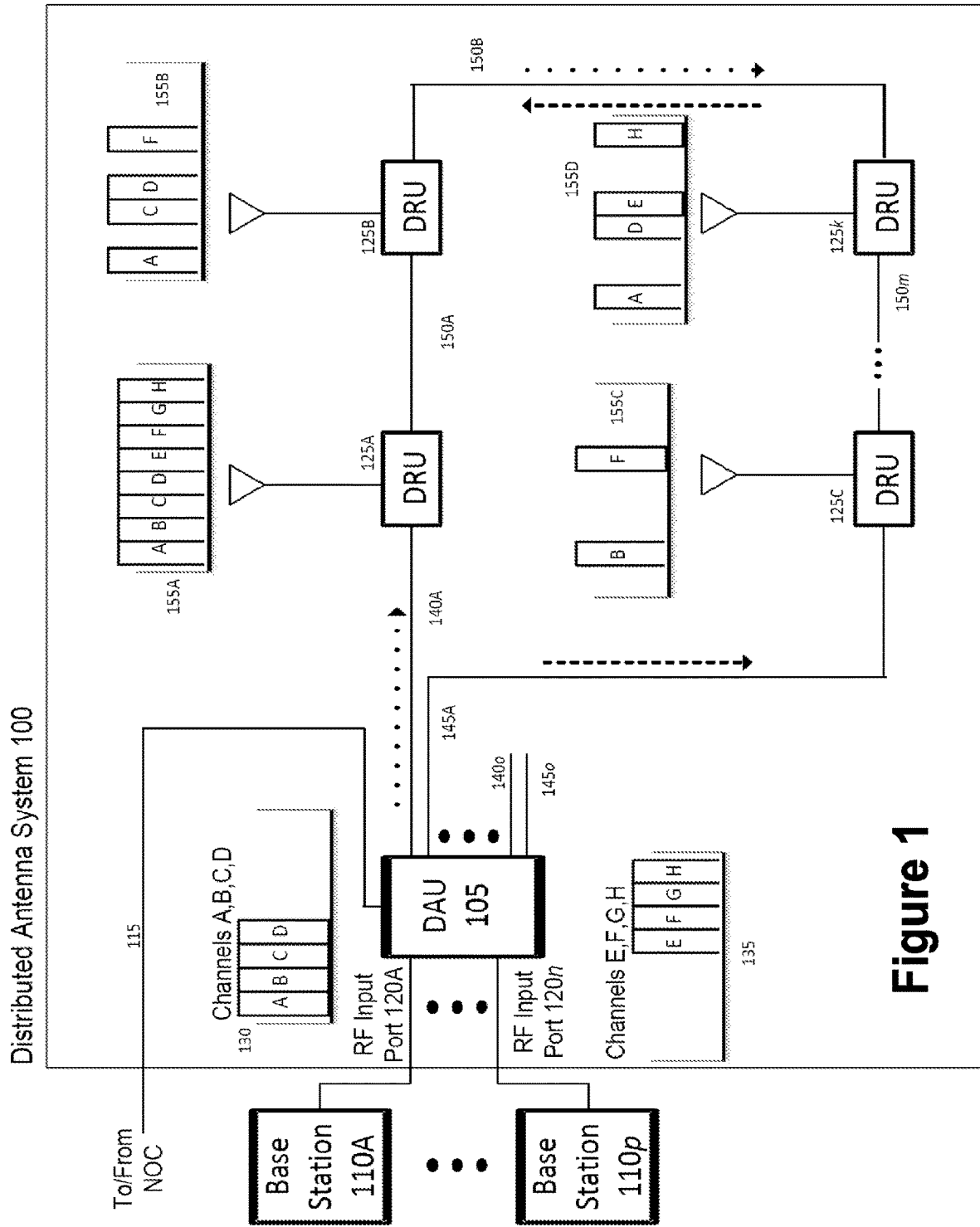
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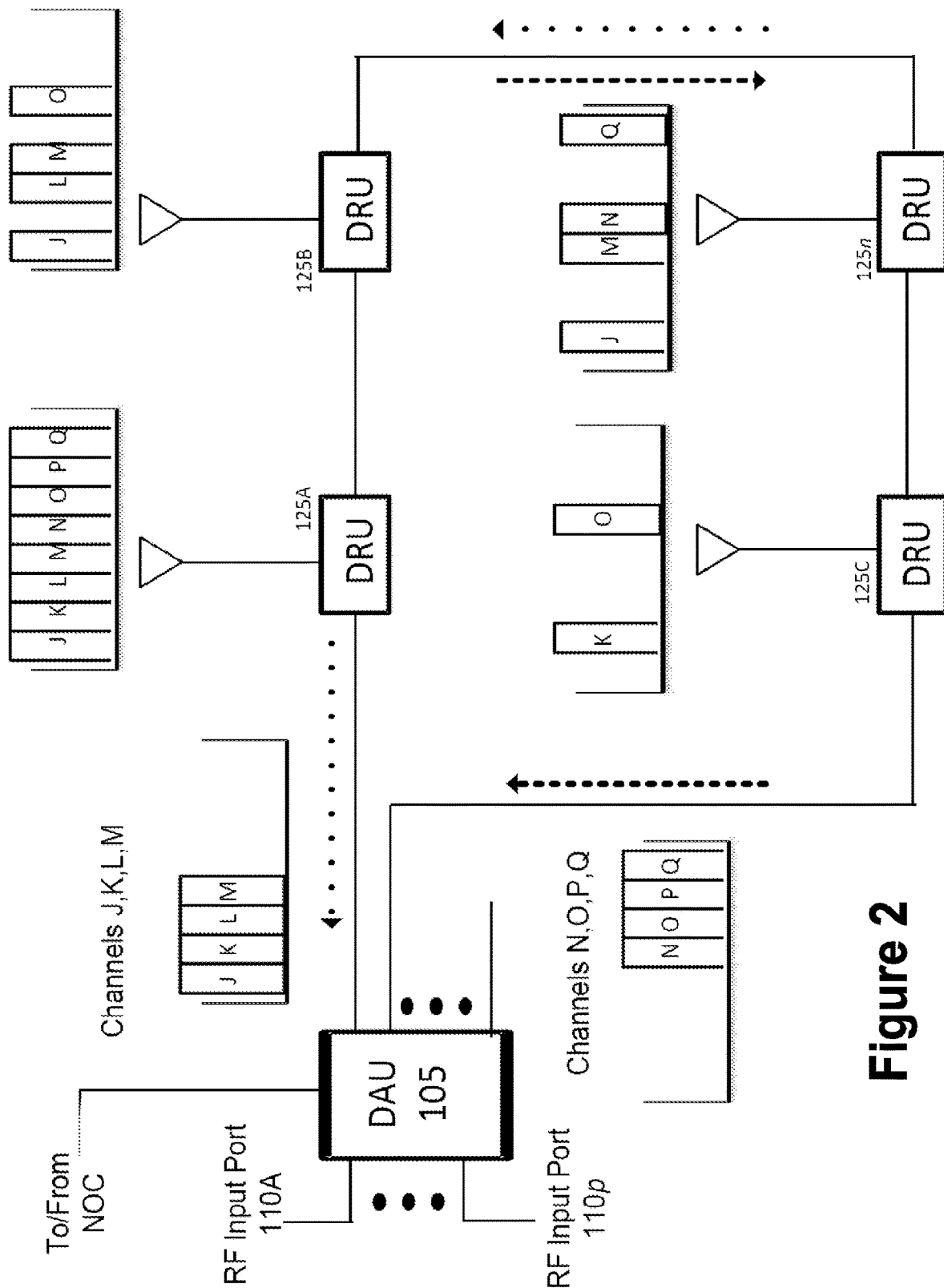


Figure 2

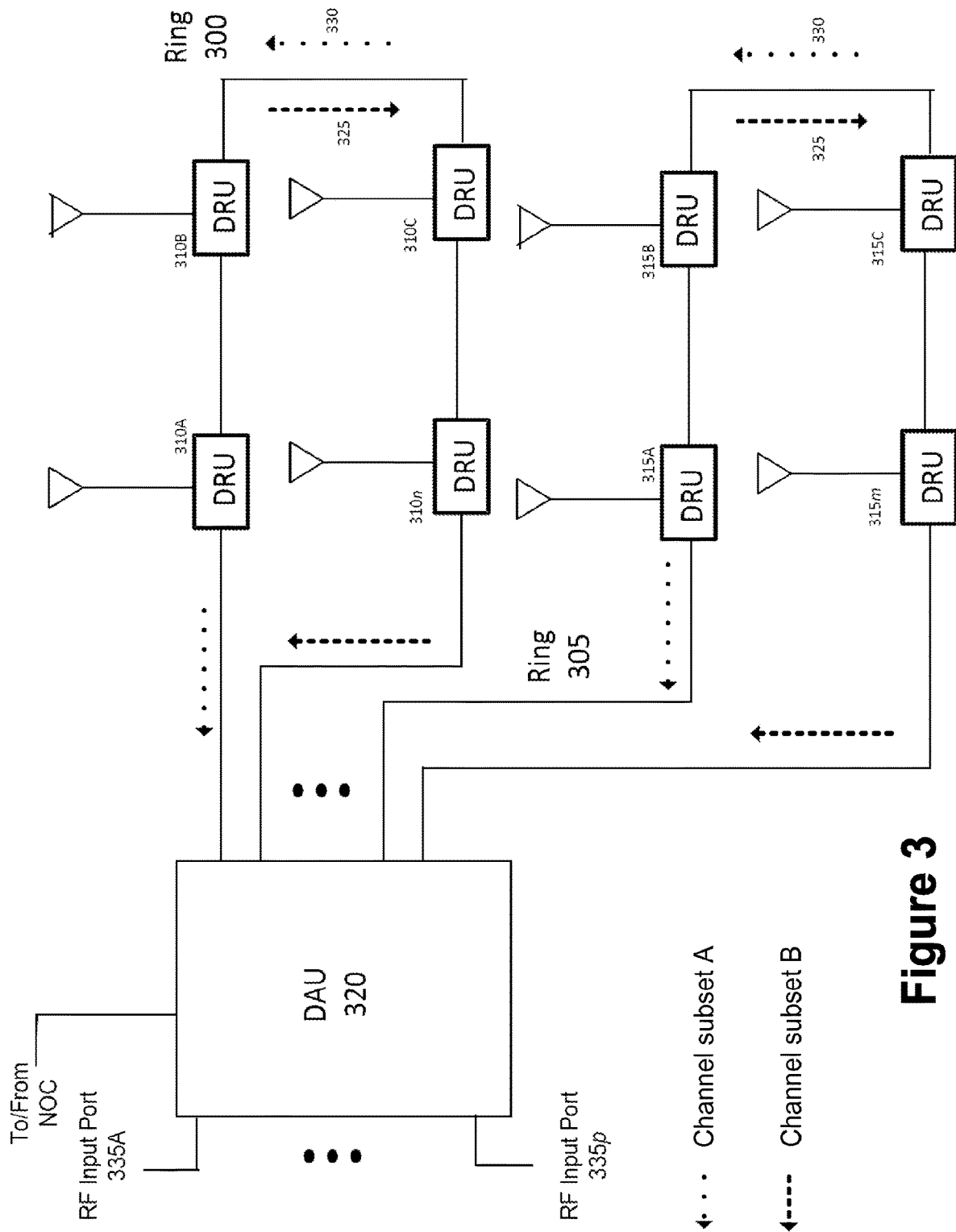


Figure 3

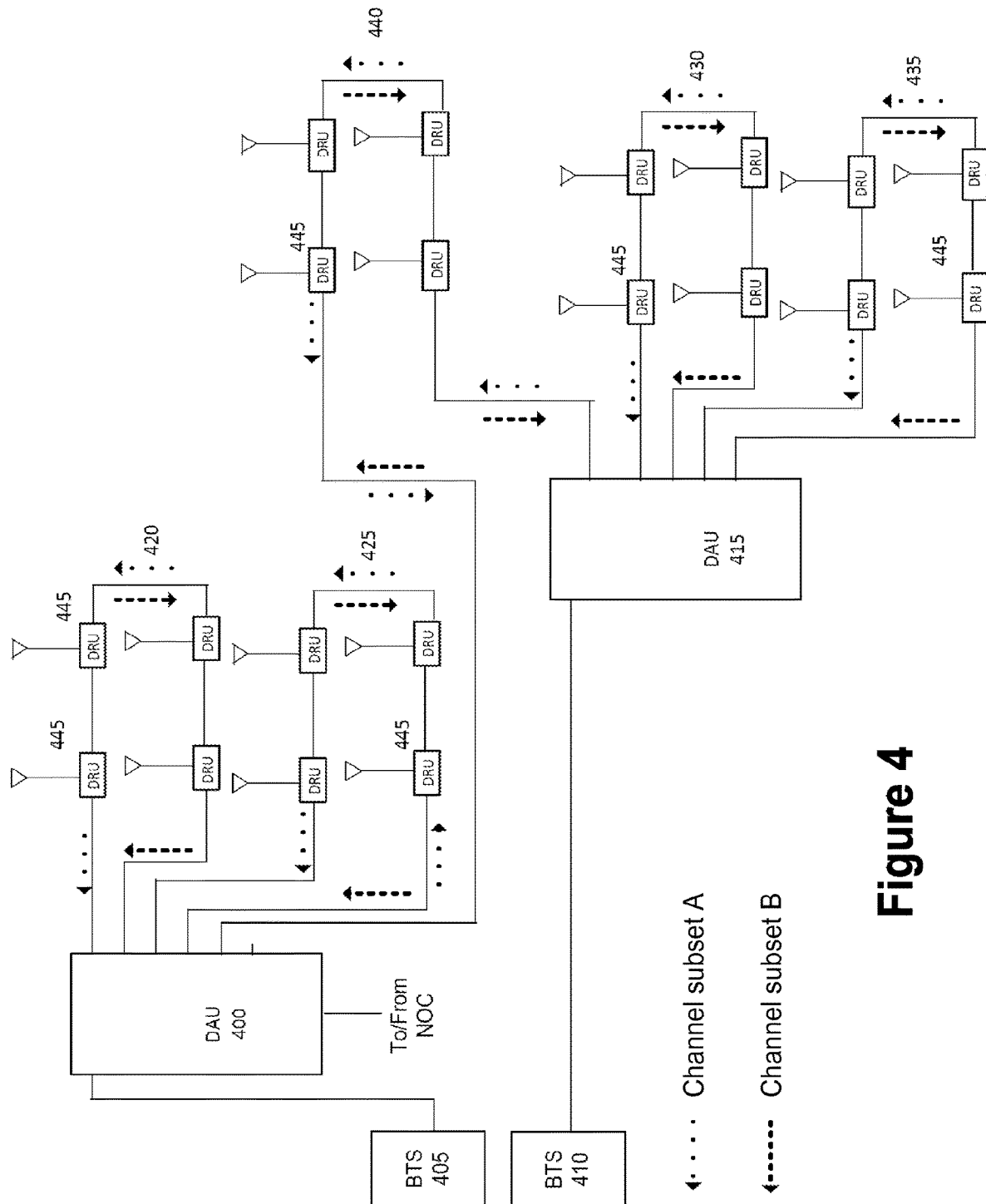


Figure 4

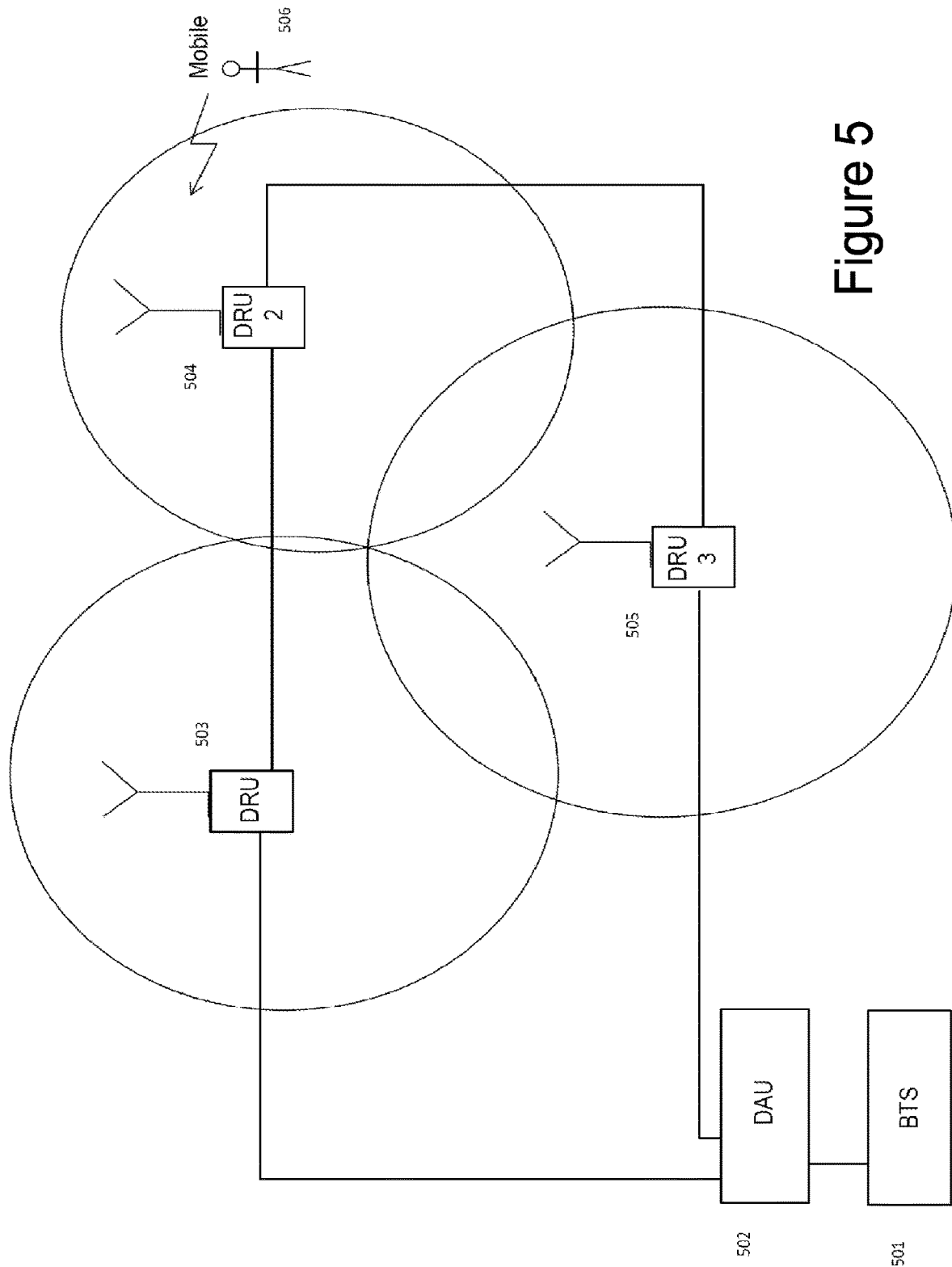


Figure 5

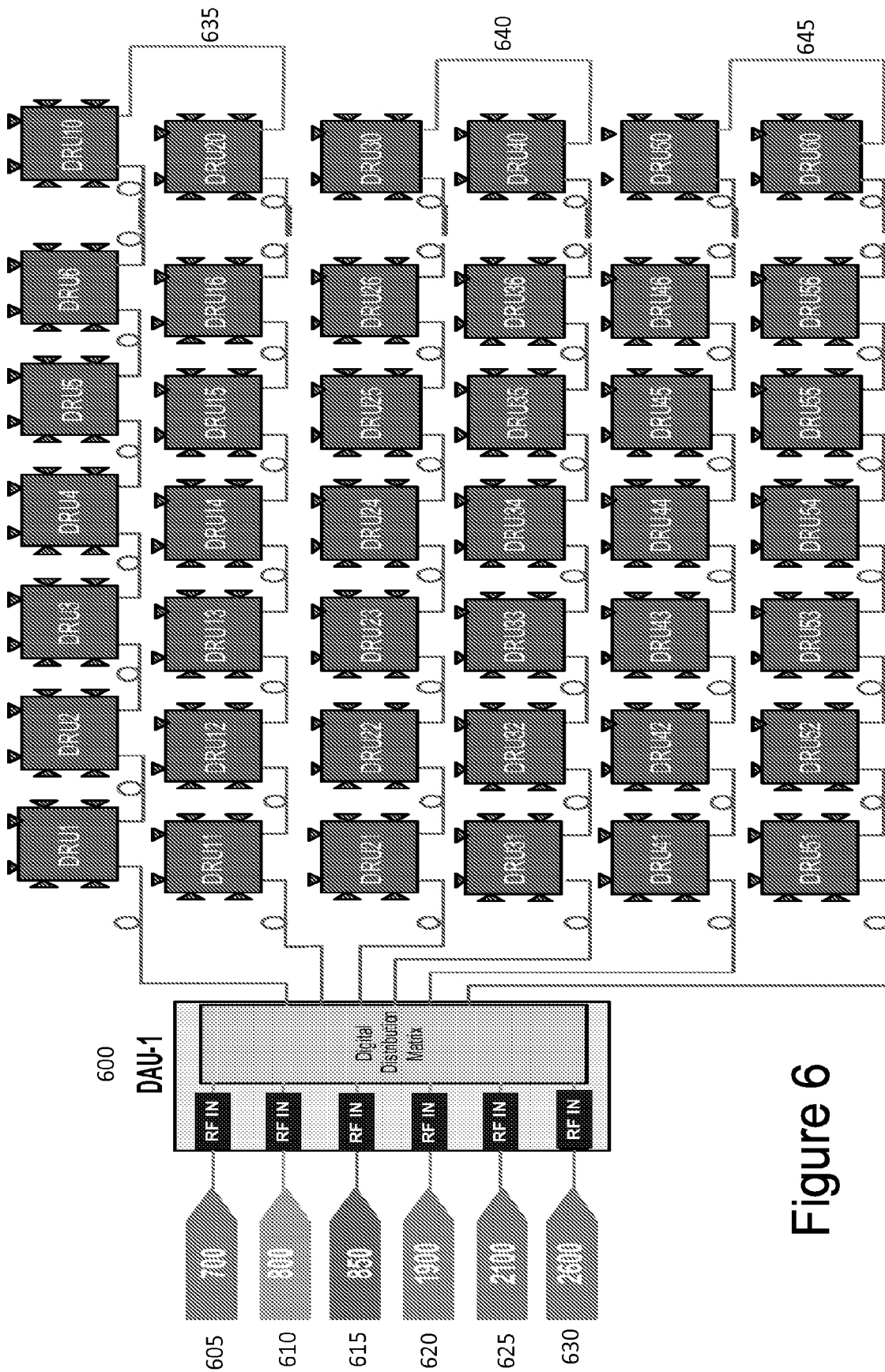


Figure 6

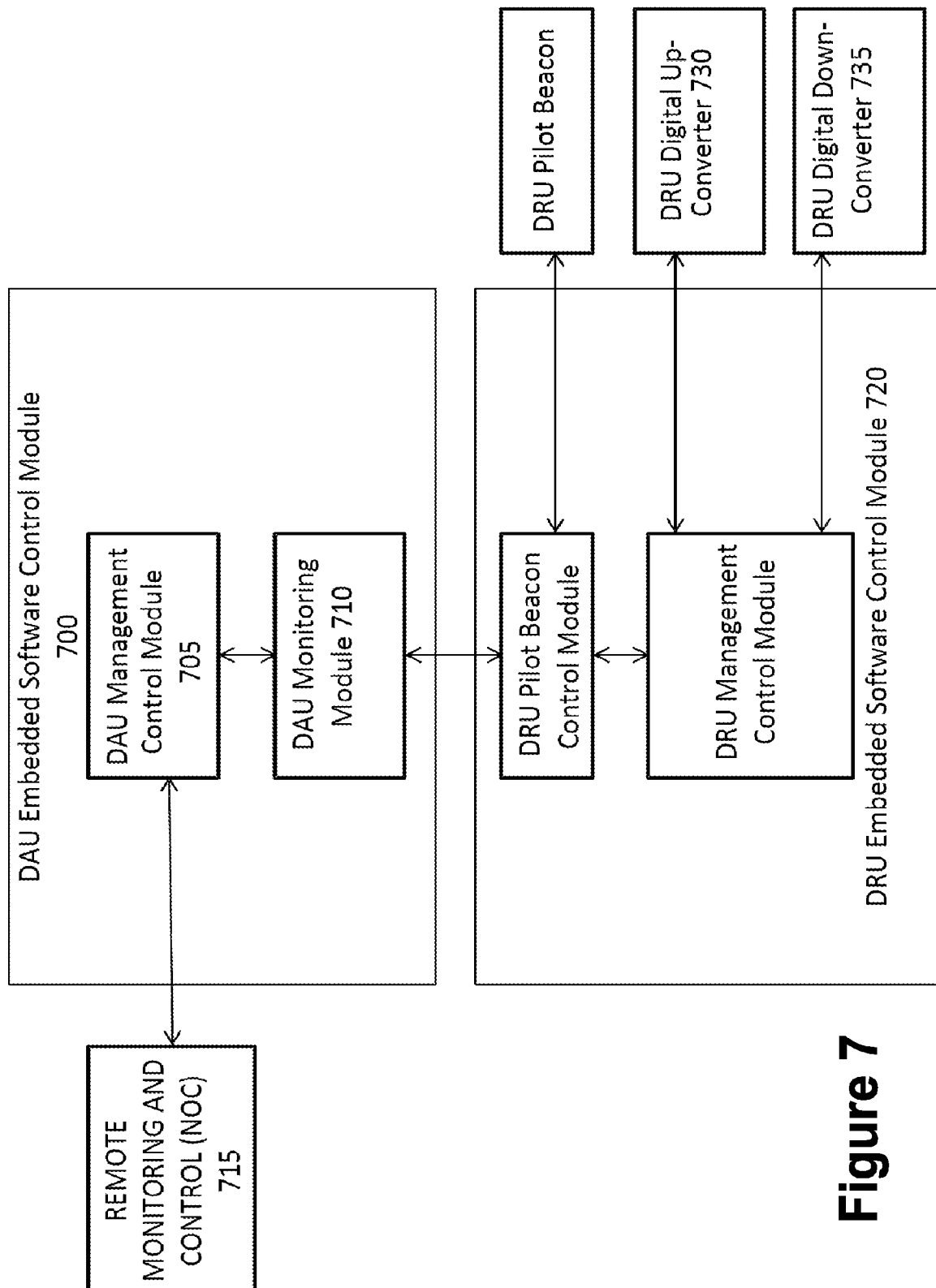
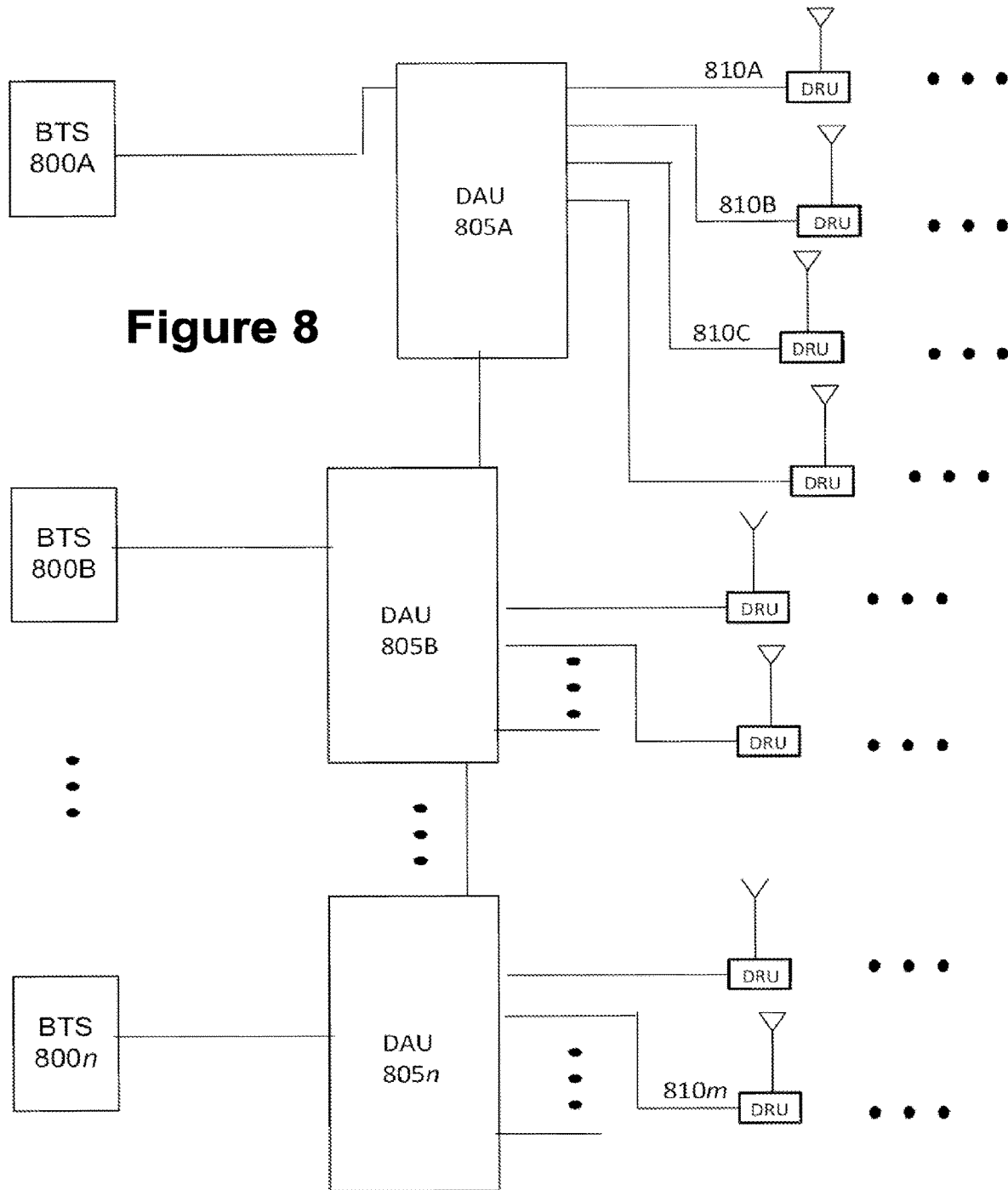


Figure 7



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DISTRIBUTED ANTENNA SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application a continuation of Ser. No. 16/059,434, filed Aug. 9, 2018; which is a continuation of U.S. patent application Ser. No. 15/223,819, filed Jul. 29, 2016, now U.S. Pat. No. 10,080,178; which is a continuation of U.S. patent application Ser. No. 14/800,515, filed Jul. 15, 2015, now U.S. Pat. No. 9,419,837; which is a continuation of U.S. patent application Ser. No. 14/260,145, filed Apr. 23, 2014, now U.S. Pat. No. 9,137,078; which is a continuation of U.S. patent application Ser. No. 13/211,247, filed Aug. 16, 2011, now U.S. Pat. No. 8,737,300; which claims the benefit of U.S. Provisional Patent Application No. 61/439,940, filed Feb. 7, 2011, the disclosures of which are hereby incorporated by reference for all purposes.

FIELD OF THE INVENTION

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 one or more remotely monitored and controlled digital access units configured to assign particular packet transmissions to selected ones of a plurality of remote units, which can in some embodiments be configured in a daisy-chained rings.

BACKGROUND OF THE INVENTION

Wireless and mobile network operators face the continuing challenge of building networks that effectively manage high data-traffic growth rates. Mobility and an increased level of multimedia content for end users requires end-to-end network adaptations that support both new services and the increased demand for broadband and flat-rate Internet access. One of the most difficult challenges faced by network operators is maximizing the capacity of their DAS networks while ensuring cost-effective DAS deployments and at the same time providing a very high degree of DAS remote unit availability.

In order to provide DAS network capacity which is high enough to meet short-term needs of network subscribers in specific locations yet also avoid costly and inefficient deployment of radio resources, DAS network planners prefer to employ DAS architectures and solutions which provide a high degree of dynamic flexibility. Therefore, it would be advantageous for wireless network operators to employ a DAS solution which has a high degree of flexibility to implement dynamic rearrangements based on ever-changing network conditions and subscriber needs. Also, the more future-proof a DAS deployment can be, generally the lower its life cycle cost.

DAS network planners and system integrators employ a wide range of innovative approaches for helping to ensure that a particular DAS deployment is as cost-effective as possible. The types of costs considered by network planners and integrators include DAS deployment or DAS installation cost, as well as operational costs including maintenance costs, emergency restoration costs and network re-arrangement costs. Rearrangement costs are particularly significant for indoor DAS applications, due to frequent changes in building use and facility needs changes. Therefore, it would be advantageous to employ DAS systems and methods

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which are based on as few DAS transport facilities as possible to minimize installation and/or lease costs and have self-healing capabilities to avoid the need for costly emergency restoration services.

5 In order to obtain a high degree of DAS remote unit availability, two primary conditions must be satisfied. First, the DAS remote unit itself must be inherently reliable. Second, the transport media e.g., optical fiber, must be very reliable. It is well known that electronic and/or optical connections themselves are a significant root cause of failure or reduced availability in a DAS network. Companies who maintain outdoor DAS networks have reported that a failure of outside plant optical fiber facilities is not as rare as would be desirable. Therefore, it would be advantageous to employ systems and methods which offer higher redundancy and/or self-healing features in the event of failure of a transport media connection.

SUMMARY OF THE INVENTION

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The present invention substantially achieves the advantages and benefits discussed above and overcomes the limitations of the prior art discussed above by providing a distributed antenna system responsive to one or more base stations and having at least one but in some embodiments a plurality of Digital Access Units ("DAU's"), each operating to control the packet traffic of an associated plurality of Digital Remote Units ("DRU's"). In embodiments employing multiple DAU's, the DAU's can be daisy-chained linearly or in a ring configuration. Likewise, depending upon the implementation, the DRU's associated with a given DAU can be configured in either a linear or ring Daisy chain configuration.

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The data received from the base stations is down-converted, digitized and converted to baseband with the DAU. The data streams are then I/Q mapped and framed and independently serialized, such that multiple data streams are available in parallel from the DAU. In at least some embodiments, the DAU communicates with the associated DRU's via an optical transport arrangement. It will be appreciated by those skilled in the art that, using the present invention, it is possible to configure a distributed antenna system having n base stations, each providing m RF outputs for transmission by one or more associated DAU's to o DRU's, where the only limits are imposed by the technical performance specifications of the particular DAS, such as delay.

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By the use of a ring configuration for connecting, in at least some embodiments, the DRU's and/or the DAU's, fault tolerance is built into the system, with resulting high availability. In single DAU embodiments, each DRU is accessible through two paths, and therefore remains available even in the event of a line break. In multi-DAU embodiments, where the DAU's are linearly daisy-chained, each DRU is accessible from multiple DRU's such that even some DAU failures will not prevent system operation. In embodiments employing a ring connection for the DAU's, multiple paths exist to each DAU, and thus provide an additional level of fault tolerance as well as dynamic load balancing and resource management as discussed in greater detail hereinafter.

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Thus, the configuration of the advanced system architecture of the present invention provides a high degree of flexibility to manage, control, enhance and facilitate the radio resource efficiency, usage, availability, and overall performance of the distributed wireless network. The present invention enables specialized applications and enhancements including Flexible Simulcast, automatic traffic load-

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balancing, network and radio resource optimization, network calibration, autonomous/assisted commissioning, carrier pooling, automatic frequency selection, radio frequency carrier placement, traffic monitoring, traffic tagging, and indoor location determination using pilot beacons. The present invention can also serve multiple operators, multi-

mode radios (modulation-independent) and multi-frequency bands per operator to increase the efficiency and traffic capacity of the operators' wireless networks.

Further the present invention provides a high degree of

dynamic flexibility, supports dynamic re-arrangements, and provides a low life cycle cost. This advanced system architecture enables deployment of DAS networks using fewer DAS transport facilities to reduce costs, while providing self-healing features. The present invention also offers redundancy and enhanced system availability.

It is an object of the present invention to provide Flexible Simulcast capabilities, as disclosed in U.S. Provisional Application Ser. No. 61/382,836, entitled "Remotely Reconfigurable Distributed Antenna System and Methods," filed Sep. 14, 2010, incorporated herein by reference, in a high-availability ring configuration using, for example, optical fiber transport. As discussed above, the ring configuration insures that a break in any optical fiber cable will not shut down the daisy-chained network, because the downlink and uplink signals can be rerouted around the cable break to the respective DRUs.

It is a further object of the present invention to balance the bidirectional data rate on the optical fibers so as to increase the maximum achievable data rate during operation on the ring network of DRUs.

It is a further object of the present invention to provide higher transport network capacity in the event the data transport is asymmetrical between the downlink and uplink, as is typically the case for mobile broadband networks.

It is a further object of the present invention to provide an adaptive and automatic control for optimizing the transport media capacity on the ring.

It is a further object of the present invention to provide a method of summing co-channel users' uplink signals in the DRU daisy chain.

Applications of the present invention are suitable to be employed with distributed base stations, distributed antenna systems, distributed repeaters, mobile equipment and wireless terminals, portable wireless devices, and other wireless communication systems such as microwave and satellite communications. The present invention is also field upgradable through a link such as an Ethernet connection to a remote computing center.

Appendix I is a glossary of terms used herein, including acronyms.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram according to one embodiment of the invention showing the basic structure and an example of a unidirectional, channelized downlink transport, one ring scenario based on having one DAU and four DRUs.

FIG. 2 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a unidirectional, channelized uplink transport, one ring scenario based on having one DAU and four DRUs.

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FIG. 3 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a unidirectional, channelized uplink transport, two ring scenario based on having one DAU and eight DRUs.

FIG. 4 is a block diagram in accordance with an embodiment of the invention showing the basic structure and an example of a unidirectional channelized uplink or downlink transport. This example of a five ring scenario comprises two DAUs and twenty DRUs. FIG. 4 provides an example of a daisy chain ring network.

FIG. 5 illustrates an embodiment of a cellular network system employing multiple DRUs according to the present invention.

FIG. 6 illustrates an embodiment of a multi-band system employing six different services operating in different frequency channels with multiple DRUs according to the present invention.

FIG. 7 illustrates in block diagram form the interaction between the DAU embedded software control module and the DRU embedded software control module.

FIG. 8 illustrates in block diagram form an embodiment of a DAS according to an aspect of the invention, including daisy-chained DAU's.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a novel Reconfigurable Distributed Antenna System that provides a high degree of flexibility to manage, control, re-configure, enhance and facilitate the radio resource efficiency, usage and overall performance of the distributed wireless network. FIG. 1 illustrates an embodiment of the Distributed Antenna System **100** that provides an example of a unidirectional, channelized downlink transport in accordance with the present invention. In FIGS. 1-4, a dotted line denotes a distinct subset of uplink and downlink channels identified as "A." A dashed line denotes a distinct subset of uplink and downlink channels identified as "B." The subset of uplink and downlink channels in A do not include those of B and vice versa. The system employs a Digital Access Unit functionality **105** (hereinafter "DAU"). The DAU **105** serves as an interface between associated base stations (BTS) **110A-B** and a plurality of digital remote units (DRU) **125A-n**, although only four DRU's are shown in FIG. 1. In the present description, "DRU" will be used interchangeably with Remote Radio Head Unit, or "RRU", because of the similarity of the functions discussed herein, although those skilled in the art will recognize that a DRU communicates with a DAU, whereas an RRU communicates with a base station. In addition, those skilled in the art will recognize that a DAU is monitored and controlled by a remote network operations center ("NOC"), as indicated at bidirectional link **115** in FIG. 1. Such links are typically Ethernet connections or external modems, but can be any form of link suitable for remote monitoring and control. The NOC has the capability to remotely configure the DAU parameter settings which in turn configures the DRU's parameter settings. The NOC can request information from the DAUs. The DAUs can subsequently request information from the DRUs. The information requested includes but is not limited to uplink power, downlink power, optical error rate, gain settings, active carriers, etc.

For the downlink (DL) path, RF input signals **120A** through **120n** are received at the DAU **105** from one or more base station units (BTS) indicated at **110A** through **110n**.

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The RF input signals are separately down-converted, digitized, and converted to baseband (using a Digital Down-Converter) by the DAU. Data streams are then I/Q mapped and framed and specific parallel data streams are then independently serialized and translated to optical signals using pluggable SFP modules, again by the DAU 105. The independently serialized, parallel data streams are then delivered to different DRU's 125A-125k, typically over optical fiber cable arranged, in at least some embodiments, in a ring configuration indicated at connection pairs 140A-145A, or, in other embodiments, a daisy chain configuration. In addition, each DAU can support a plurality of rings with associated DRU's, where the additional rings are indicated by fiber optic pairs up through 140o-145o. It will be appreciated by those skilled in the art that the number of RF inputs, DAU's and DRU's and rings is limited only by network performance factors, such as delay. In addition, as discussed in connection with FIG. 4 herein, the DAS can be further extended by using a ring or daisy-chain of DAU's, each of which supports an arrangement of DRU's and rings as shown in FIG. 1.

One function of the DAU 105 is to determine the direction in which downlinked channels are propagated around the ring. As just one example, the embodiment shown in FIG. 1 is configured to have downlink channels A, B, C and D propagate in a first direction, for example clockwise, and channels E, F, G, and H propagate in the counter direction, although it will be understood that the number of channels propagating in each direction need not be equal, nor adjacent, nor sequential. Likewise, the number of channels received at each DRU is assigned by the DAU and need not be equal, adjacent or sequential, but instead will typically be any configuration that optimizes network utilization.

Referring next to FIG. 2, an embodiment of an uplink (UL) path in accordance with the invention can be better appreciated. Channels received at the antenna associated with each DRU are converted into optical signals by each DRU 125A-125k. Optical signals received from the DRU's are de-serialized and de-framed by the DAU 105, and are also up-converted digitally using a Digital Up-Converter implemented within the DAU 105. Each data stream is then independently converted to the analog domain and up-converted to the appropriate RF frequency band, still within the DAU 105 in the illustrated implementation, although this functionality can be separate. The RF signals are then delivered to the appropriate one of a plurality of BTS' 110A-110p. As with the arrangement shown in FIG. 1, the direction of propagation of each channel is controlled by the DAU, with some channels propagating in a clockwise direction and others in a counterclockwise direction. Also as discussed in connection with FIG. 1, while adjacent channels are shown as propagating in the same direction in FIG. 2, this is not required and any channel can be selected to propagate in either direction.

Referring again to FIG. 1, it will be appreciated by those skilled in the art that, in some implementations of a DAS, more than one carrier can exist in each channel, and, as such, a DRU may receive a channel comprising a signal containing two or more carriers, or a wireless operator may have more than one RF carrier per channel allocated to a single base station. This is referred to as a "composite signal". The manner in which a composite downlink signal is managed by the present invention can be better understood with reference to FIG. 1. In such instances, the DAU will receive a composite downlink input signal 130 from, e.g., a first base station 110A belonging to one wireless operator, enters the DAU 105 at the RF input port 120A. Composite signal 130

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comprises carriers A-D. A second composite downlink input signal from e.g., a pth base station 110p belonging to the same wireless operator enters DAM at the DAU1 RF input port 120n. Composite signal 135 comprises carriers E-H. The functionality of the DAU 105, and DRU's 125A-125k, respectively, are explained in detail in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010, the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

One optical output of DAU 105 is fed to DRU 125A, via bidirectional optical cable 140A. A second optical output of DAU 105 is fed via bidirectional optical cable 145A to DRU3. Similarly, bidirectional optical cables 150, 155 and 160 connect DRU's 125A-n in a ring configuration, such that DRU 125A connects to DRU 125B via cable 150A, DRU 125B connects to DRU 125n via cable 15013, and DRU 125k connects to DRU 125C, or the kth-1 DRU, via cable 150m. This connection facilitates networking of DAU 105, which means that all of Carriers A-H are available within DAU 105 to transport data to DRU's 125A-k depending on software settings within the networked DAU system. Depending upon the embodiment, the software settings within DRU 125A are configured either manually or automatically, such that carriers A-H are present in the downlink output signal 155A at the antenna port of DRU 125A. The presence of all eight carriers means that DRU 125A is potentially able to access the full capacity of both base stations feeding DAU 105. A possible application for DRU 125A is a cafeteria in an enterprise building during the lunch hour where a large number of wireless subscribers are gathered.

DRU 125B is fed by a second optical port of DRU 125A via bidirectional optical cable 150A. The optical cable 150A performs the function of daisy chaining DRU 125A with DRU 12513. As with DRU 125A, the software settings within DRU 125B are configured either manually or automatically such that Carriers A, C, D and F are present in downlink output signal 155E at the antenna port of DRU 125B. The capacity of DRU 125B is set to a much lower value than DRU 125A by virtue of its specific channel settings as controlled by DAU 105. The individual Digital Remote Units have integrated frequency selective DUCs and DDCs with gain control for each carrier. The DAU's can remotely turn on and off the individual carriers via the gain control parameters.

In a similar manner as described previously for DRU 125A, the software settings within DRU 125C are configured either manually or automatically such that Carriers B and F are present in downlink output signal 155C at the antenna port of DRU 125C. Compared to the downlink signal 155B at the antenna port of DRU 12513, the capacity of DRU 125C, which is also configured via its software settings, is much less than the capacity of DRU 125B. DRU 125n is fed by the optical cable 150m connected to the second optical port of the nth-1 DRU, shown for simplicity in FIG. 1 as DRU 125C. The software settings within DRU 125n are configured either manually or automatically such that carriers A, D, E and H are present in downlink output signal 155D at the antenna port of DRU 125n. Typically, the capacity of DRU 125n is set to a much lower value than DRU 125A, however, the relative capacity settings of each of DRU's 125A-n can be adjusted dynamically to meet the capacity needs within the coverage zones determined by the physical positions of antennas connected to those DRU's. As noted above, the ring connection is completed by interconnecting DRU 125B and DRU 125n through optical cable

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150B. The ring configuration insures that any optical cable breaks will not shut down the daisy chained network. The downlink and uplink signals will be rerouted around the cable break to the respective DRUs.

The present invention facilitates conversion and transport of several discrete relatively narrow RF bandwidths. This approach allows conversion of only those multiple specific relatively narrow bandwidths which carry useful or specific information. This approach also allows more efficient use of the available optical fiber transport bandwidth for neutral host applications, and allows transport of more individual operators' band segments over the optical fiber. As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 together with U.S. Provisional Application Ser. No. 61/382,836, entitled "Remotely Reconfigurable Distributed Antenna System and Methods", filed Sep. 14, 2010, both assigned to the assignee of the present invention, and also referring to FIG. 1 of the instant patent application, Digital Up Converters located within the DRU can be dynamically reconfigured as the result of commands from the NOC to transport from the DAU input to any specific DRU output any specific narrow frequency band or bands, RF carriers or RF channels which are available at the respective RF input port of either DAU. This capability is illustrated in FIG. 1 where only specific frequency bands or RF carriers appear at the output of a given DRU. More specifically, through commands received from the NOC, the FPGA's in the DAU and one or more of the associated DRU's can be reprogrammed or reconfigured to convert and transport only the desired narrow bandwidths.

A related capability of the present invention is that not only can the Digital Up Converters located within each DRU be configured to transport any specific narrow frequency band from the DAU input to any specific DRU output, but also the Digital Up Converters within each DRU can be configured to transport any specific time slot or time slots of each carrier from the DAU input to any specific DRU output. The carriers and time slots are monitored by the DAU by filtering the signals and performing power detection of the individual time slots, which information can be conveyed to the NOC as desired. Then, as with the Digital Up Converters, the Field Programmable Gate Arrays (FPGA) in the DAU or DRU can be dynamically reconfigured by commands received from the NOC in a manner analogous to software programmability. The DAU detects which carriers and corresponding time slots are active. This information is relayed to the individual DRUs via the management control and monitoring protocol software. This information is then used, as appropriate, by the DRUs for turning off and on individual carriers and their corresponding time slots.

Data transport between the Base Station and the subscribers is typically asymmetrical, whereby the downlink data rate is higher than the uplink rate. The ring network configuration of Daisy Chained DRUs can exploit this data rate asymmetry to maximize the data transport on the optical fibers 150A-150m.

The present invention balances the bidirectional data rate on the optical fibers so as to increase the maximum achievable data rate on the ring network of DRUs. The individual downlink channels are transmitted in a unidirectional sense along the ring network. Referring to FIG. 1, downlink channels A, B, C, and D are transmitted in a clockwise sense around the ring of DRU's 125A-k. On the other hand, downlink channels E, F, G and H are transmitted in a counterclockwise sense around the ring of DRUs. Referring

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to FIG. 2, the uplink channels J, K, L and M are transmitted in a counterclockwise sense whereas uplink channels N, O, P and Q are transmitted in a clockwise sense around the ring of DRUs. If the downlink and uplink data rates were the same, there would be no advantage in the transport mechanism. However, if the data transport is asymmetrical between the downlink and uplink then a significant advantage can be gained. For example, for a factor of two difference between the downlink and uplink data rates, a 4/3 factor increase in data transport can be achieved. The larger the asymmetry between the downlink and uplink data rates, the larger will be the increase in data transport using the unidirectional channel transport mechanism around the ring.

Referring again to FIG. 1, a further embodiment in accordance with another aspect of the present invention may be better understood. In the event that there is a significant change in asymmetry between the downlink and uplink data rates and/or if there is a change in channel complement at the BTS, the Management Control module [discussed in connection with FIG. 7 herein] which is typically comprised within each DAU is able to automatically and adaptively re-allocate data transport resources on the clockwise direction of the ring and on the counterclockwise direction of the ring to maximize the overall transport capacity. As stated previously, the larger the degree of asymmetry between uplink and downlink data rates for a particular DAU, the higher the increase in data transport using the unidirectional channel transport mechanism around the ring. If there is more than one DAU present, in an embodiment one DAU is designated a Master DAU by the NOC, and the Management Control module located in the Master DAU makes decisions to optimize the overall transport capacity. In the event the master DAU fails, the NOC can designate another DAU as master. Alternatively, any suitable failover algorithm can be implemented.

Referring to FIG. 3, an alternative embodiment of the present invention wherein a single DAU controls a plurality of rings, each comprising a plurality of daisy-chained DRU's, can be better understood. In FIG. 3, two daisy-chained rings, indicated at 300 and 305, are shown although the number of rings could be greater and is determined mainly as a matter of design preference up to limits imposed by network performance. The rings each link a plurality of DRU's 310A-n and 315A-m, to a single DAU 320. The directional flow of the data transport is shown as the dashed lines 325 and dotted lines 330. The downlink channels available from the plurality of DRU's are divided into two subsets which flow in opposite directions around the two daisy-chained rings. The uplink channels are transported in a similar fashion. The channels are grouped into the two subsets so as to maximize the data transport to and from the DRUs. The DAU in turn communicates with one or more BTS's via RF Ports 335A p.

Heuristic algorithms may be used to allocate RF channel data in a Dual-ring DAS. For FIG. 3, there are two fibre rings R1, R2 (clockwise and counter clockwise) and a set T of $n \geq 2$ independent RF channels K_i , $1 \leq i \leq n$ (including uplink and downlink). A channel K_i requires a bandwidth of $b(K_i)$ to transport on a fibre ring. A time-bounded algorithm exists which obtains a schedule having the optimal bandwidth allocation (i.e. the maximum aggregate bandwidth of each ring is as small as possible). A large number of advanced heuristic algorithms have been developed to solve such scheduling optimization problems. Some examples are genetic algorithm, evolutionary algorithm, greedy search, Tabu search, harmony search, simulated annealing, ant colony optimization, etc. For purposes of simplicity and

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clarity, a simple heuristic algorithm for two rings is described here, although the number of rings is not limited to two.

The algorithm begins by sorting the channels K_i decreasingly by bandwidth $b(K_i)$. Then it schedules the channel in such a way that each channel is assigned to the ring which has the smaller aggregate bandwidth. The formal description of the algorithm follows.

Input: $T = \text{set of } n \text{ independent channels } K_i \text{ with required bandwidth } b(K_i), 1 \leq i \leq n$.

Output: L_1, L_2 and D_1, D_2 . L_j is the set of channels schedule on ring R_j , and D_j is the maximum aggregate bandwidth of ring R_j , $D_j = D_j - (\sum b(K_i), 1 \leq j \leq 2)$.

Algorithm (T, L, D)

Step 1 (initialize K_i and D_1, D_2) Sort K_i such that $b(K_i) \leq b(K_{i+1}), 1 \leq i \leq n-1$. $D_1 \leftarrow 0, D_2 \leftarrow 0$.

Step 2 (Schedule a channel)

For $i=1$ to n , step 1 do

If $D_1 \leq D_2$, then [assign K_i onto $L_1, D_1 \leftarrow D_1 + b(K_i)$].

else [assign K_i onto $L_2, D_2 \leftarrow D_2 + b(K_i)$].

Referring next to FIG. 4, a still further an alternative embodiment of the present invention may be understood. The arrangement illustrated in FIG. 1 comprised downlink signals from two separate base stations belonging to the same wireless operator entering the DAU 105 at input ports 110A and 110P, respectively. In the embodiment of FIG. 4, a first composite signal enters a first DAU 400 at that DAU's RF input port from a base station 405, and a second composite downlink input signal from, e.g., a second base station 410 belonging to a different wireless operator enters DAU 415 at that second DAU's RF input port. DAU 400 directly supports two rings 420 and 425, DAU 415 directly supports two rings 430 and 435, and a ring 440 is shared between DAU 400 and DAU 405. Each of the rings comprises daisy-chained DRU's generally indicated at 445 and connected via, for example, fiber optic links, as discussed in connection with FIG. 1. It will be noted that channels A are transported in the opposite sense as channels B. The downlink channels in subset A are transported counterclockwise around each ring, whereas the channels in subset B are transported in a clockwise sense around each ring. In this embodiment, signals belonging to both the first operator and the second operator are converted and transported to the DRU's 445 on ring 440 because DAU 400 and DAU 405 are daisy-chained through the fiber optic cable 440. This embodiment provides an example of a neutral host wireless system, where multiple wireless operators share a common infrastructure comprised of DAU 400, DAU 415, and DRU's 445. All the previously mentioned features and advantages accrue to each of the two wireless operators. It will further be appreciated that, while FIG. 4 illustrates only two DAU's linked in daisy-chain style, it is possible to daisy chain a larger plurality of DAU's, and the daisy-chained DAU's can also be configured in a ring configuration similar to the manner in which the DRU's are connected. This arranged is illustrated in FIG. 8, below.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, entitled "Neutral Host Architecture for a Distributed Antenna System," filed Aug. 17, 2010 and again referring to FIG. 1 of the instant patent application, the Digital Up Converters present in the DRU's of the present invention can be programmed to process various signal formats and modulation types including FDMA, CDMA, TDMA, OFDMA and others. Also, the Digital Up Converters present in the respective DRUs can be programmed to operate with signals to be transmitted within various frequency bands subject to the capabilities and limitations of

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the system architecture disclosed in U.S. Provisional Application Ser. No. 61/374,593, mentioned above. In one embodiment of the present invention where a wideband CDMA signal is present within, e.g., the bandwidth corresponding to a first carrier at the input port to DAU 105, the transmitted signal at the antenna ports of DRU 125A, DRU 125B and DRUk will be a wideband CDMA signal which is virtually identical to the signal present within the bandwidth corresponding to that first carrier at the input port to DAU 105.

As disclosed in U.S. Provisional Application Ser. No. 61/374,593, again identified above, and also referring to FIG. 1 of the instant patent application, it is to be understood that the Digital Up Converters present in the respective DRUs can be programmed to transmit any desired composite signal format to each of the respective DRU antenna ports. As an example, the Digital Up Converters present in DRU 125A and DRU 125B can be dynamically software-reconfigured as described previously so that the signal present at the antenna port of DRU 125A would correspond to the spectral profile shown in FIG. 1 as 155A and also that the signal present at the antenna port of DRU 125B would correspond to the spectral profile shown in FIG. 1 as 155B. The application for such a dynamic re-arrangement of DRU capacity would be e.g., if a company meeting were suddenly convened in the area of the enterprise corresponding to the coverage area of DRU 125B.

Referring again to FIG. 2, another embodiment of the Distributed Antenna System of the present invention can be better understood. As disclosed in the aforementioned U.S. Provisional Application Ser. No. 61/374,593, and also as shown in FIG. 2, the optical ring transport mechanism can be implemented with regard to uplink signals. As discussed previously with regard to downlink signals and by referring to FIG. 1, the uplink system shown in FIG. 2 is mainly comprised of DAU 105, together with DRU's 125A-125K. In a manner similar to the downlink operation explained by referring to FIG. 1, the operation of the uplink system shown in FIG. 2 can be understood as follows.

The Digital Down Converters present in each of DRU's 125A-K are dynamically software-configured as described previously so that uplink signals of the appropriate desired signal format(s) present at the receive antenna ports of the respective DRU's 125A-125K are selected based on the desired uplink band(s) to be processed and filtered, converted and transported to the appropriate uplink output port of DAU 105. The DAU and DRUs frame the individual data packets corresponding to their respective radio signature using the Common Public Radio Interface (CPRI) standard. Other Interface standards are applicable provided they uniquely identify data packets with respective DRUs. Header information is transmitted along with the data packet which identifies the DRU and DAU that corresponds to the individual data packet.

In one example for the embodiment shown in FIG. 2, DRU's 125A and 125C are configured to receive uplink signals within the Channel K bandwidth, whereas DRU 125B and DRU 125N are both configured to reject uplink signals within the Channel K bandwidth. When DRU 125C receives a strong enough signal at its receive antenna port within the Channel K bandwidth to be properly filtered and processed, the Digital Down Converters within DRU 125C facilitate processing and conversion. Similarly, when DRU 125A receives a strong enough signal at its receive antenna port within the Channel K bandwidth to be properly filtered and processed, the Digital Down Converters within DRU 125A facilitate processing and conversion. The signals from

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DRU 125A and DRU 125C are combined based on the active signal combining algorithm, and are fed to the base station connected to the uplink output port of DAU 105. The term simulcast is frequently used to describe the operation of DRU 125A and DRU 125C with regard to uplink and downlink signals within Channel K bandwidth. The term Flexible Simulcast refers to the fact that the present invention supports dynamic and/or manual rearrangement of which specific DRU are involved in the signal combining process for each Channel bandwidth.

Referring still to FIG. 2, the Digital Down Converters present in DRU 125A are configured to receive and process signals within Channel J-Q bandwidths. The Digital Down Converters present in DRU 1256 are configured to receive and process signals within Channel J, L, M and O bandwidths. The Digital Down Converters present in DRU 125C are configured to receive and process signals within Channel K and O bandwidths. The Digital Down Converters present in DRU 125n are configured to receive and process signals within Channel J, M, N and Q bandwidths. The respective high-speed digital signals resulting from processing performed within each of the four DRU are routed to the DAU. As described previously, the uplink signals from the four DRUs are combined within the respective DAU corresponding to each base station.

In summary, the Reconfigurable Distributed Antenna System of the present invention described herein efficiently conserves resources and reduces costs. The reconfigurable system is adaptive or manually field-programmable, since the algorithms can be adjusted like software in the digital processor at any time.

Referring next to FIG. 5, an alternative embodiment of the present invention may be better understood. FIG. 5 provides a daisy chain example of a distributed antenna system (DAS). Each DRU has a coverage radius that can be adjusted based on the power transmission from that particular remote unit. The DAU controls the various DRU's transmission power and can optimize the overall coverage zone. In the illustrated embodiment, DAU 502, again under the control of a NOC (not shown), is associated with a base station 501 and in turn interfaces with three DRU's 503, 504 and 505. A user 506 with a mobile device is provided relatively uniform coverage throughout the area covered by the three DRU's.

Referring next to FIG. 6, a still further alternative embodiment may be better appreciated. FIG. 6 shows an embodiment of a multi-band system illustrating one DAU supporting up to six different services operating at different frequency bands, with three optical rings of DRU's 1-60. The input frequency bands 605-630 (here denoted as six frequency bands at 700, 800, 850, 1900, 2100 and 2600 MHz) are input into the DAU 600 from the BTS's (not shown). The DAU includes, among other functionalities discussed herein, an RF IN portion for each band, and a digital distribution matrix for distributing the frequency bands to a plurality of DRU's, indicated as DRU1-DRU60, daisy-chained along three separate rings 635, 640 and 645 for achieving the desired coverage. The frequency bands are transported to either all or a subset of DRUs. The particular number of frequency bands, DAU's, DRU's and rings is exemplary only, and can, in practice, be any number appropriate to the performance capabilities and needs of the network.

Referring next to FIG. 7 that illustrates embedded software control modules, the software embedded in the DAU and DRU, which controls the operation of key functions of these devices, can be better understood. In particular, the

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DAU embedded software control module 700 comprises a DAU Management Control Module 705 and a DAU monitoring module 710. The DAU Management Control Module 705 communicates with the NOC 715, and also the DAU monitoring module 710. One such key function is determining and/or setting the appropriate amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular DRU or group of DRUs to meet desired capacity and throughput objectives. As noted previously, the NOC 715 monitors the DAS operation and sends commands to the DAU's for configuring various functions of the DRU's as well as the DAU, in at least some embodiments.

The DAU Monitoring module, in addition to other functions, detects which carriers and corresponding time slots are active for each DRU. The DAU Management Control module communicates with the DRU Embedded Software Control module 720 over a fiber optic link control channel via a control protocol. In an embodiment, the control protocol comprises headers together with packets of data, such that both control information and data are transmitted to the DRU's together as a message. DRU functions or features that the header would control in the DRU are typically implementation specific and can include, among other things, measuring uplink and downlink power, measuring gain of uplink and downlink, and monitoring alarms in the DRU.

In turn, the DRU Management Control module 725 within the DRU Embedded Software Control Module sets the individual parameters of all the DRU Digital Up-Converters 730 to enable or disable specific radio resources from being transmitted by a particular DRU or group of DRUs, and also sets the individual parameters of all the DRU Digital Down-Converters 735 to enable or disable specific radio resources from being transmitted by a particular DRU or group of DRUs. In addition, the DRU Embedded Software Control Module comprises a DRU Pilot Beacon Control Module 740, which communicates with a DRU Pilot Beacon 745.

Referring next to FIG. 8, an embodiment of a daisy-chained configuration of DAU's is illustrated, together with a daisy-chained configuration of DRU's. In an embodiment, a plurality of base stations 800A-800n are each associated with one of DAU's 805A-n. The DAU's are daisy-chained, and each DAU communicates with one or more daisy-chains 810A-810m of DRU's which may or may not be arranged in a ring configuration. It will be appreciated that the DAU's can also be configured in a ring configuration, as discussed above.

An algorithm operating within the DAU Monitoring module which detects which carriers and corresponding time slots for each carrier are active for each DRU provides information to the DAU Management Control module to help identify when, e.g., a particular downlink carrier is loaded by a percentage greater than a predetermined threshold whose value is communicated to the DAU Management Control module by the DAU's Remote Monitoring and Control function 715. If that occurs, the DAU Management Control module can adaptively modify the system configuration to begin to deploy, typically although not necessarily slowly, additional radio resources (such as RF carriers, CDMA codes or TDMA time slots) for use by a particular DRU which need those radio resources within its coverage area. At the same time, usually the DAU Management Control module adaptively modifies the system configuration to begin to remove, again typically slowly, certain radio resources (such as RF carriers, CDMA codes or TDMA time

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slots) for use by a particular DRU where that DRU no longer needs those radio resources within its coverage area.

Although the present invention has been described with reference to the preferred embodiments, it will be understood that the invention is not limited to the details described thereof. Various substitutions and modifications have been suggested in the foregoing description, and others will occur to those of ordinary skill in the art. Therefore, all such substitutions and modifications are intended to be embraced within the scope of the invention as defined in the appended claims.

APPENDIX I

Glossary of Terms

ACLR Adjacent Channel Leakage Ratio
ACPR Adjacent Channel Power Ratio
ADC Analog to Digital Converter
AQDM Analog Quadrature Demodulator
AQM Analog Quadrature Modulator
AQDMC Analog Quadrature Demodulator Corrector
AQMC Analog Quadrature Modulator Corrector
BPF Bandpass Filter
BTS Base Transceiver System or Base Station
CDMA Code Division Multiple Access
CFR Crest Factor Reduction
DAC Digital to Analog Converter
DAU Digital Access Unit
DET Detector
DHMPA Digital Hybrid Mode Power Amplifier
DDC Digital Down Converter
DNC Down Converter
DPA Doherty Power Amplifier
DQDM Digital Quadrature Demodulator
DQM Digital Quadrature Modulator
DSP Digital Signal Processing
DUC Digital Up Converter
EER Envelope Elimination and Restoration
EF Envelope Following
ET Envelope Tracking
EVM Error Vector Magnitude
FFLPA Feedforward Linear Power Amplifier
FIR Finite Impulse Response
FPGA Field-Programmable Gate Array
GSM Global System for Mobile communications
I-Q In-phase/Quadrature
IF Intermediate Frequency
LINC Linear Amplification using Nonlinear Components
LO Local Oscillator
LPF Low Pass Filter
MCPA Multi-Carrier Power Amplifier
MDS Multi-Directional Search
OFDM Orthogonal Frequency Division Multiplexing
PA Power Amplifier
PAPR Peak-to-Average Power Ratio
PD Digital Baseband Predistortion
PLL Phase Locked Loop
PN Pseudo-Noise
QAM Quadrature Amplitude Modulation
QPSK Quadrature Phase Shift Keying
RF Radio Frequency
RRH Remote Radio Head
RRU Remote Radio Head Unit
SAW Surface Acoustic Wave Filter
UMTS Universal Mobile Telecommunications System
UPC Up Converter

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WCDMA Wideband Code Division Multiple Access

WLAN Wireless Local Area Network

What is claimed is:

1. A system to transport wireless communications, comprising:
 - a digital access unit;
 - a plurality of signal sources, including at least a first signal source and a second signal source;
 - a plurality of remote units, including at least a first remote unit and a second remote unit; wherein the digital access unit comprises a plurality of interfaces to communicatively couple the digital access unit to the plurality of signal sources;
 - wherein the digital access unit is configured to receive a plurality of radio resources from the first signal source and the second signal source;
 - wherein the digital access unit is configured to send a digital representation of a first set of radio resources to the first remote unit at a first point in time, the first set of radio resources for transmission at an antenna of the first remote unit;
 - wherein the digital access unit is configured to send a digital representation of a second set of radio resources to the first remote unit at a second point in time, the second set of radio resources for transmission at the antenna of the first remote unit;
 - wherein a number of radio resources in the first set of radio resources is different from a number of radio resources in the second set of radio resources at least based on dynamic load balancing and resource management; and
 - wherein the digital access unit is configured to receive digital signals from each of the plurality of remote units.
2. The system of claim 1, wherein the system determines load and selects traffic paths based at least in part on the determined load.
3. The system of claim 1, wherein the dynamic load balancing and resource management controls routes from a digital access unit port to a remote unit port.
4. The system of claim 1, wherein the dynamic load balancing and resource management dynamically adjusts a capacity of at least the first remote unit.
5. The system of claim 1, wherein the dynamic load balancing and resource management uses uplink summing to combine signals from at least the first and second remote units.
6. The system of claim 1, wherein the dynamic load balancing and resource management uses steering to route signal traffic in the system.
7. The system of claim 1, wherein the dynamic load balancing and resource management uses capacity steering to route signal traffic in the system.
8. The system of claim 1, wherein the dynamic load balancing and resource management uses network capacity to route signal traffic in the system.
9. The system of claim 1, wherein the first remote unit is a low power radio capable of using multiple frequency bands.
10. The system of claim 1, wherein the digital signals communicated between the digital access unit and the remote units are sent via optical cables.
11. The system of claim 1, wherein the remote units are automatically configured by the system.
12. A method for wireless communications comprising: receiving, at a digital access unit, a plurality of radio resources from a first signal source and a second signal

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source, wherein the digital access unit comprises a plurality of interfaces to communicatively couple the digital access unit to a plurality of signal sources;

5 sending, by the digital access unit, a digital representation of a first set of radio resources to a first remote unit at a first point in time, the first set of radio resources for transmission at an antenna of the first remote unit; and

10 sending, by the digital access unit, a digital representation of a second set of radio resources to the first remote unit at a second point in time, the second set of radio resources for transmission at the antenna of the first remote unit,

15 wherein a number of radio resources in the first set of radio resources is different from a number of radio resources in the second set of radio resources at least based on dynamic load balancing and resource management.

20 13. The method of claim 12, further comprising determining a load and selecting traffic paths based at least in part on the determined load.

14. The method of claim 12, wherein the dynamic load balancing and resource management controls routes from a digital access unit port to a remote unit port.

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15. The method of claim 12, wherein the dynamic load balancing and resource management dynamically adjusts a capacity of at least the first remote unit.

16. The method of claim 12, wherein the dynamic load balancing and resource management uses uplink summing to combine signals from at least the first and a second remote unit.

17. The method of claim 12, wherein the dynamic load balancing and resource management uses steering to route signal traffic.

18. The method of claim 12, wherein the dynamic load balancing and resource management uses capacity steering to route signal traffic.

19. The method of claim 12, wherein the dynamic load balancing and resource management uses network capacity to route signal traffic.

20. The method of claim 12, wherein the first remote unit is a low power radio capable of using multiple frequency bands.

21. The method of claim 12, wherein the signals communicated between the digital access unit and remote units are sent via optical cables.

22. The method of claim 12, further comprising automatically configuring remote units.

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