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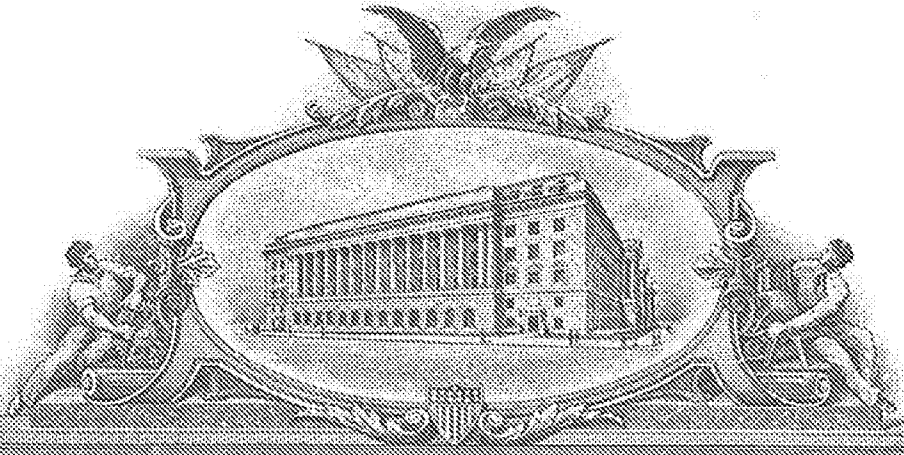
Application number: 62771508

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UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

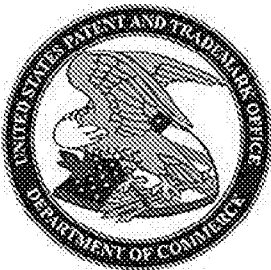
July 26, 2019

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APPLICATION NUMBER: 62/771,508

FILING DATE: *November 26, 2018*

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS *US62/771,508*



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Application Number	
Filing Date	November 26, 2018
First Named Inventor	Kevin Ross
Title	A METHOD FOR IMPROVING WIRELESS MESH NETWORK USING DIRECT OPTICAL-TO-RF AND DIRECT-RF-TO-OPTICAL CONVERSION MODULE
Art Unit	TBA
Examiner Name	TBA
Attorney Docket Number	Naim-00016

SIGNATURE of Applicant or Patent Practitioner

Signature	/Rory P. Shea/	Date (Optional)	November 26, 2018
Name	Rory P. Shea	Registration Number	60529
Title (if Applicant is a juristic entity)	Attorney of Record		
Applicant Name (if Applicant is a juristic entity)			

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.

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130085

OR

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I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

- ☒ Inventor or Joint Inventor (title not required below)
- ☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)
- ☐ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
- ☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature

Date (Optional)

Name

Kevin Ross

Title

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☐ Total of forms are submitted.

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Doc Code: PA..

Document Description: Power of Attorney

PTO/AIA/82B (07-13)

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I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

--



Inventor or Joint Inventor (title not required below)



Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)



Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)



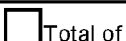
Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature	Ahsan Naim	Date (Optional)	12/05/2016
Name	Muhammad Ahsan Naim		
Title			

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.



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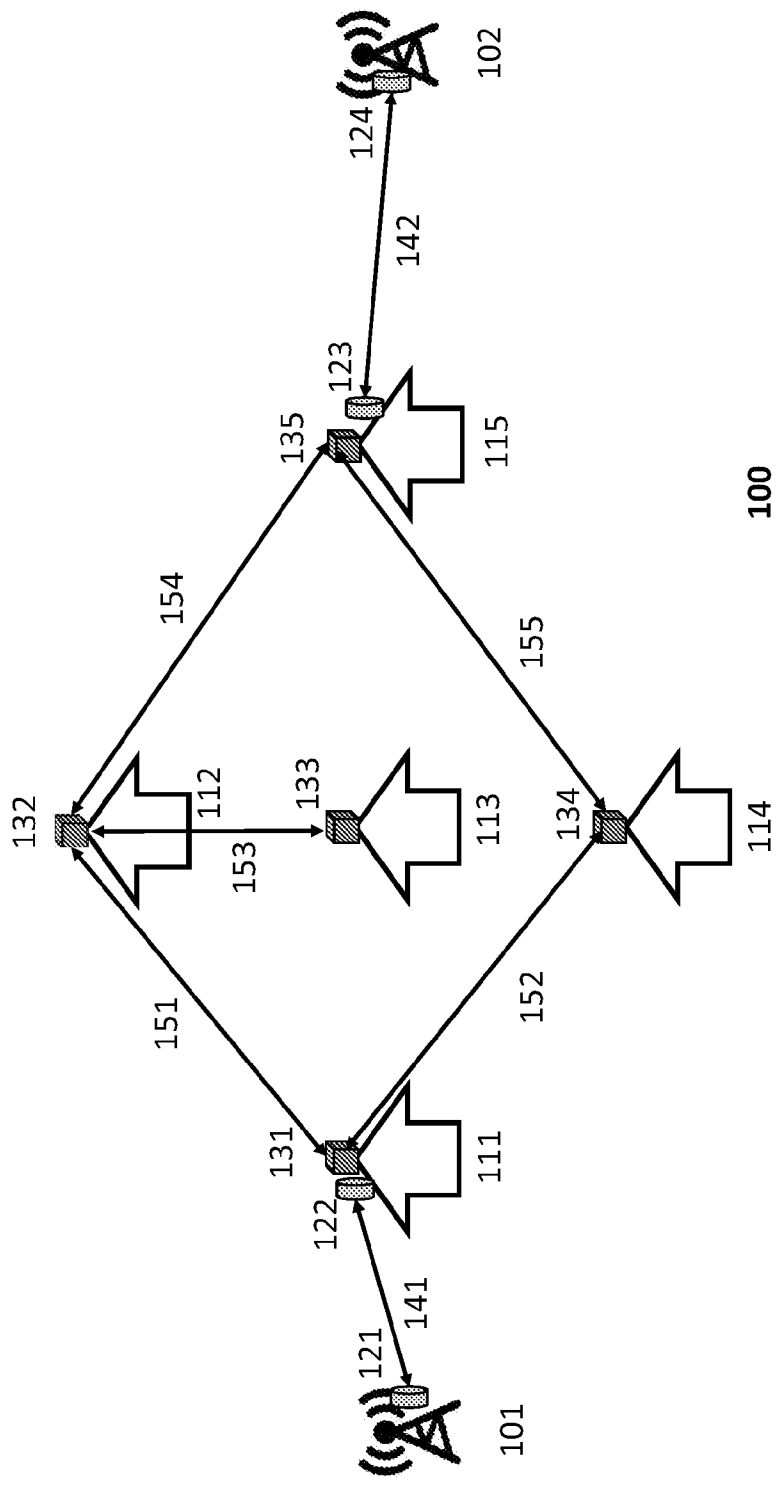


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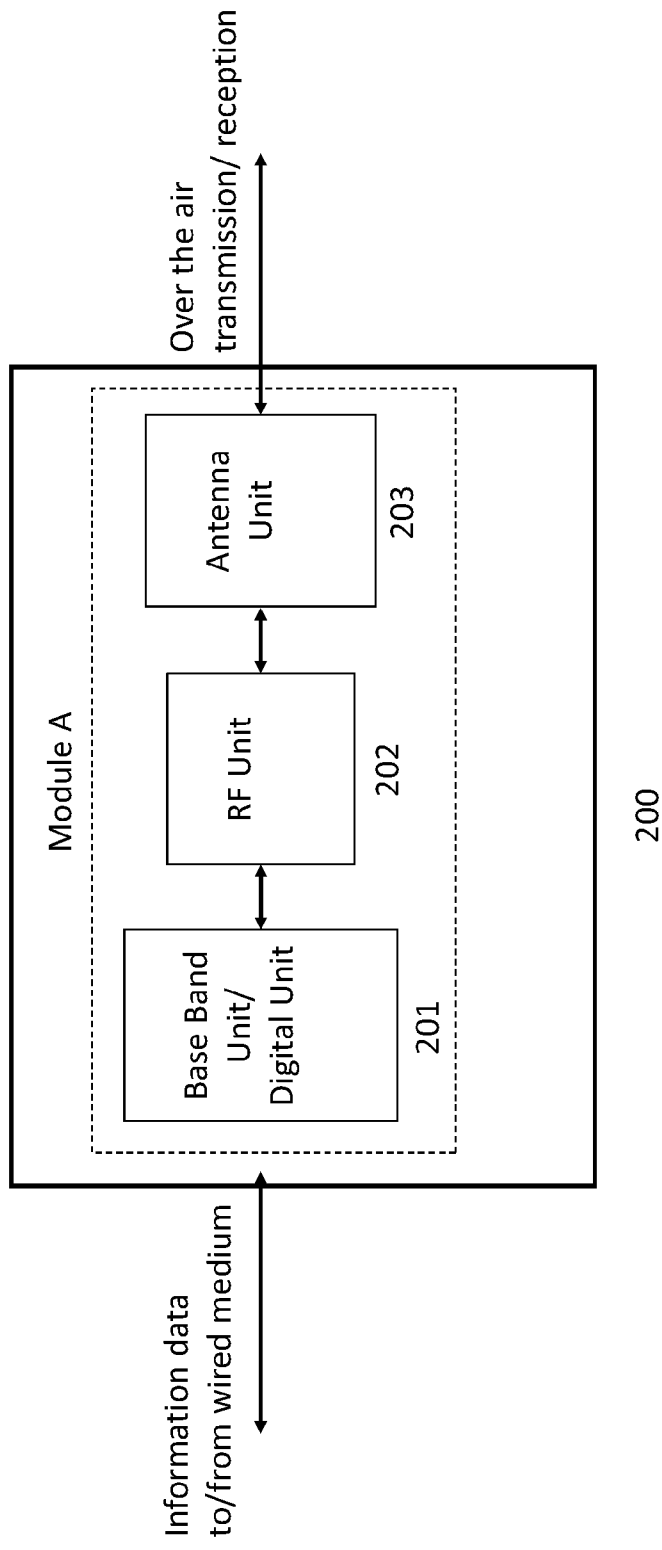


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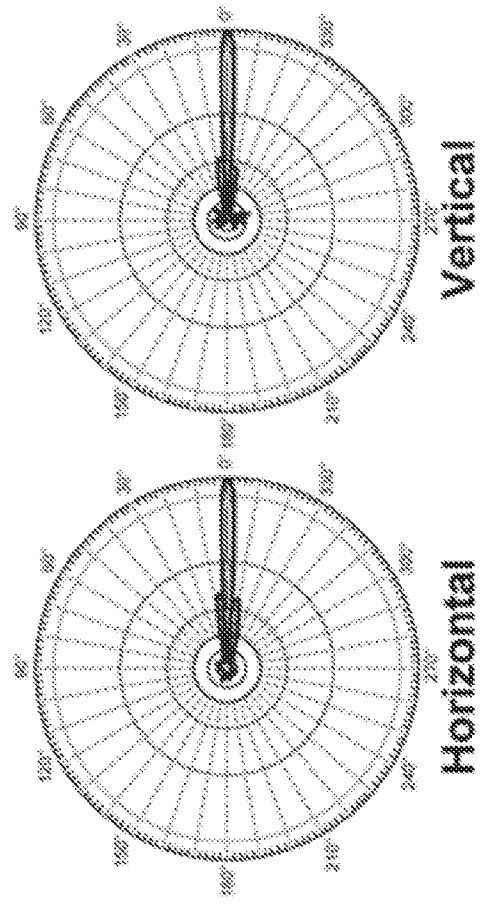


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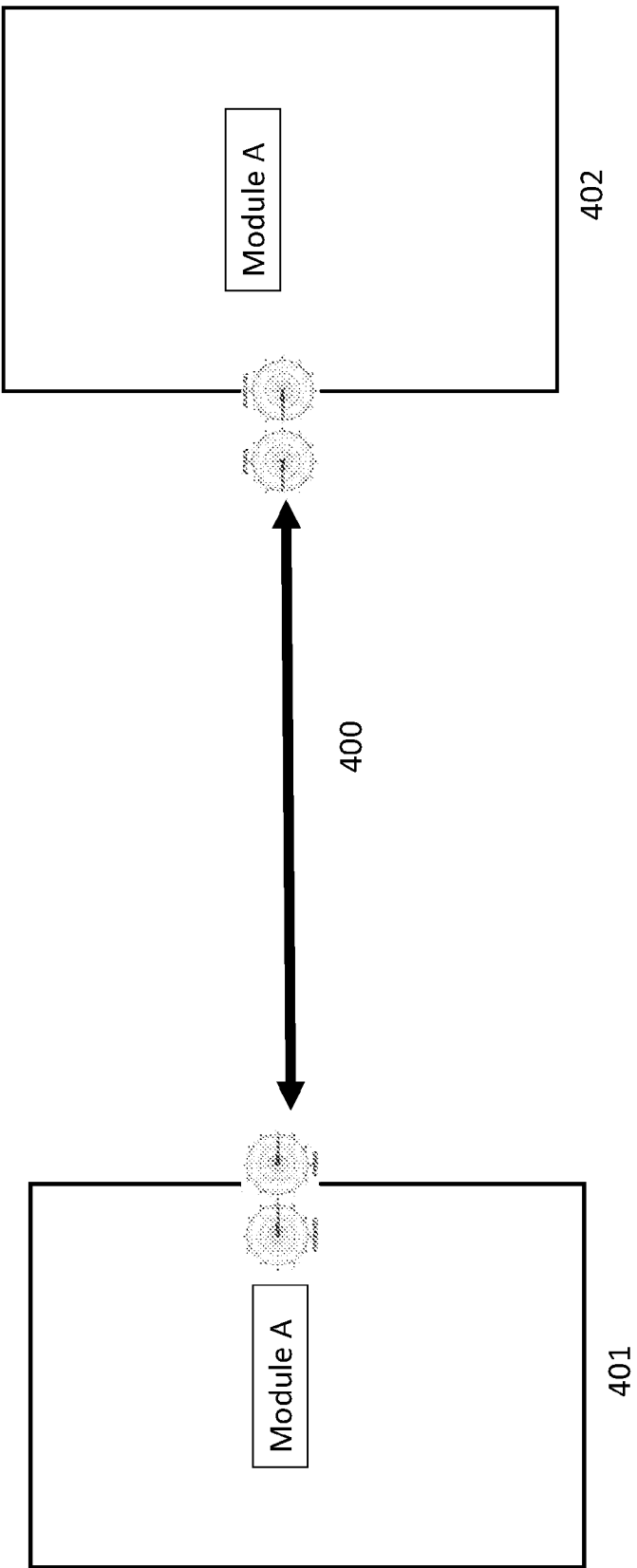


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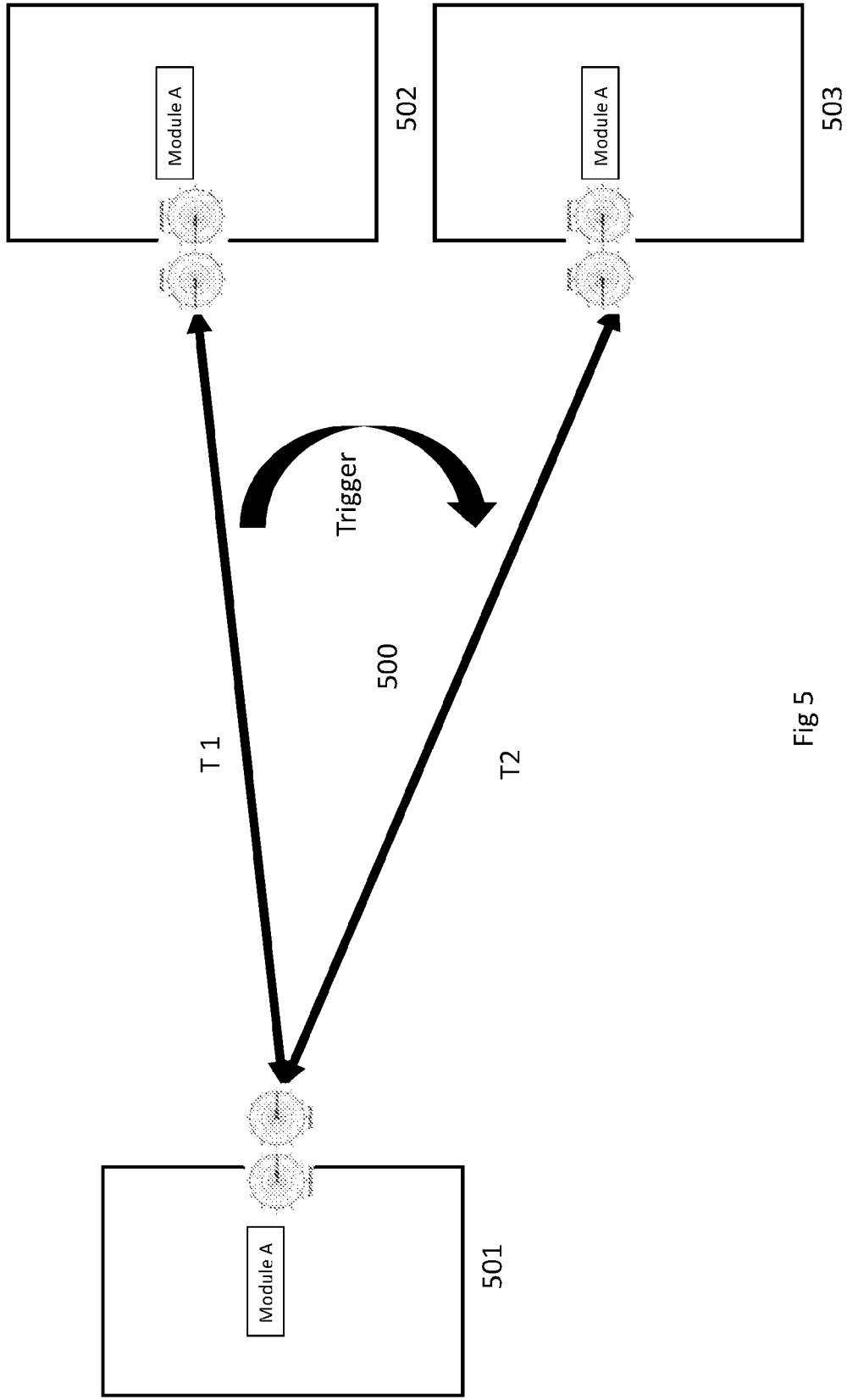


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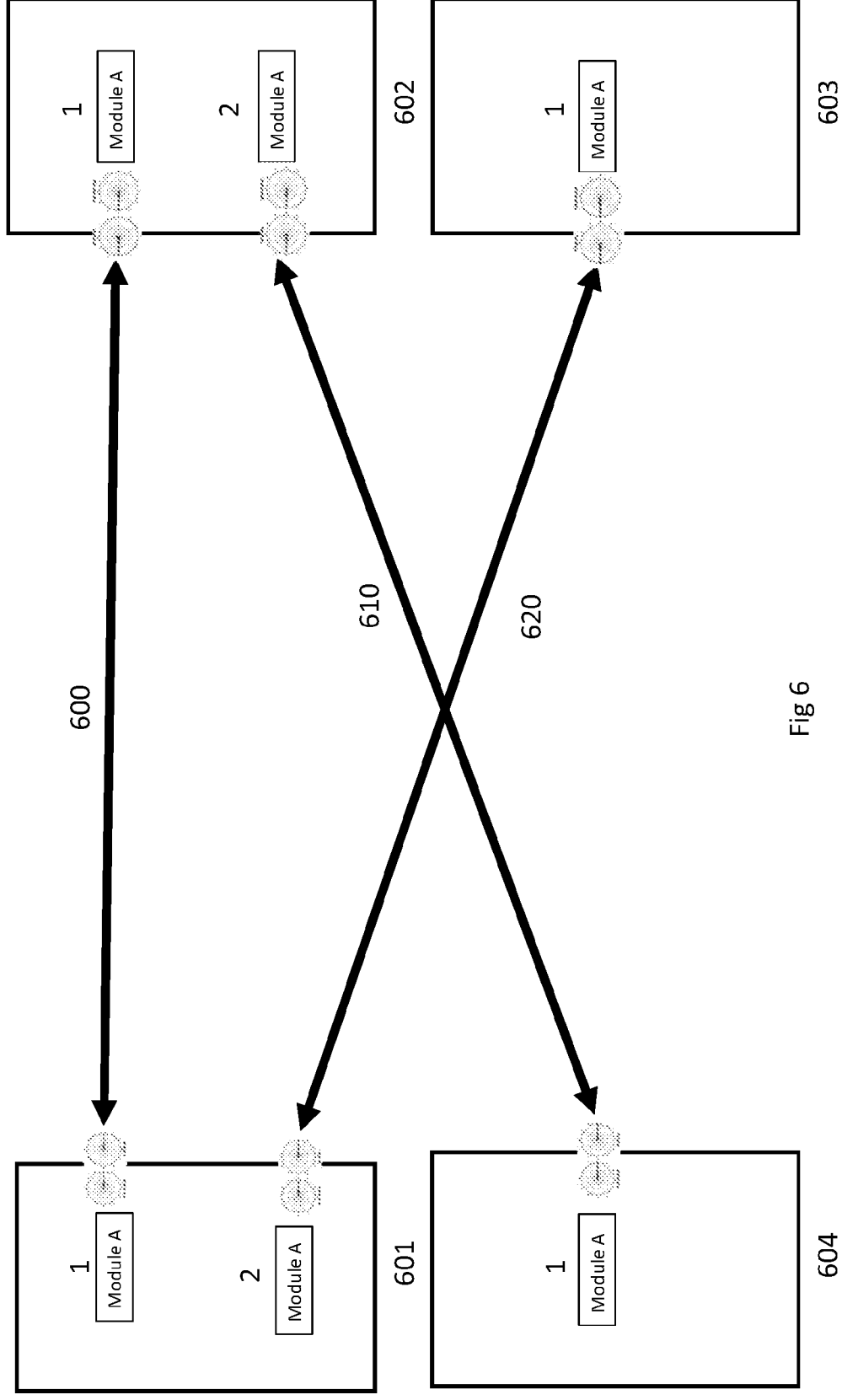


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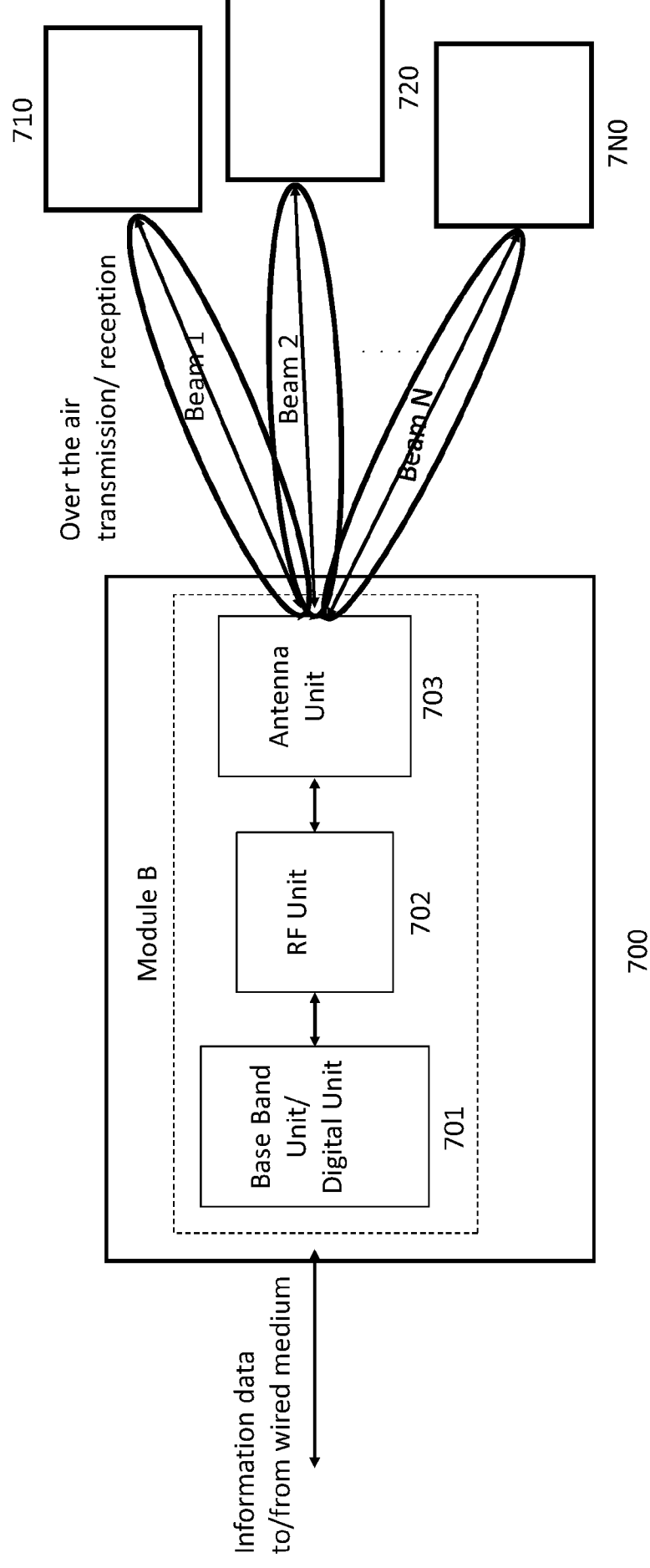


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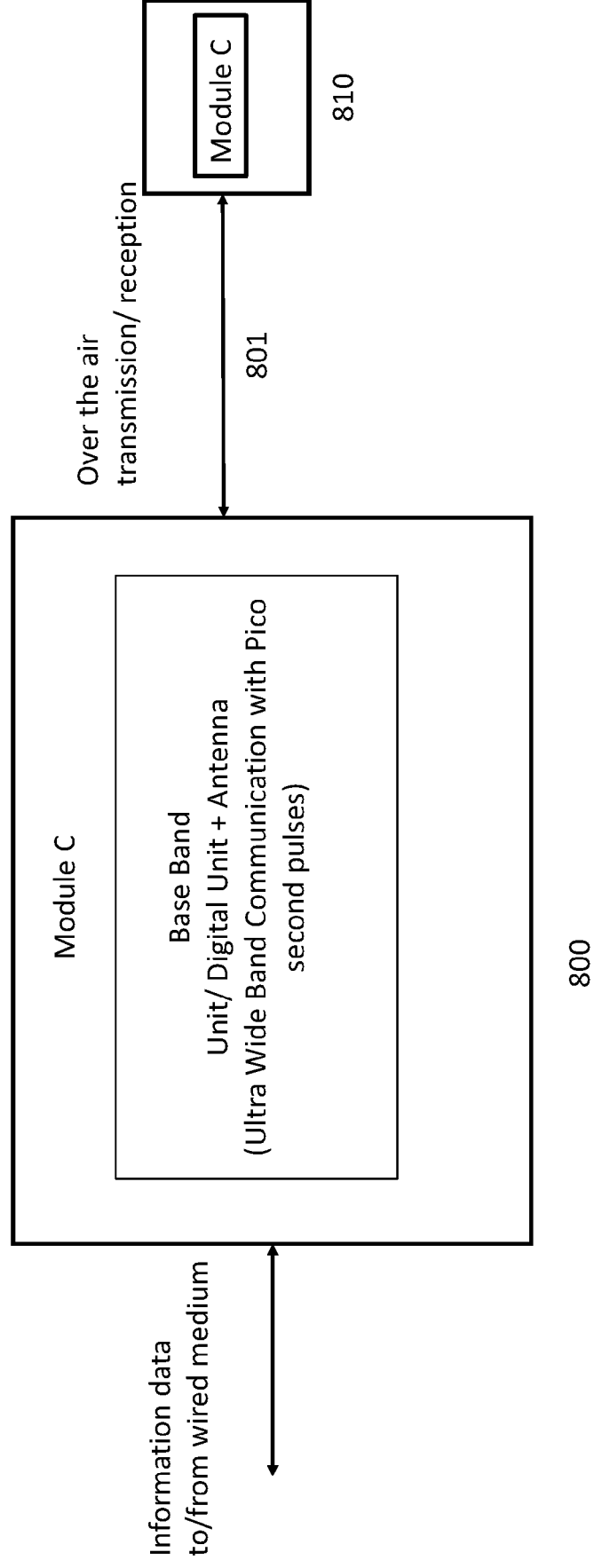


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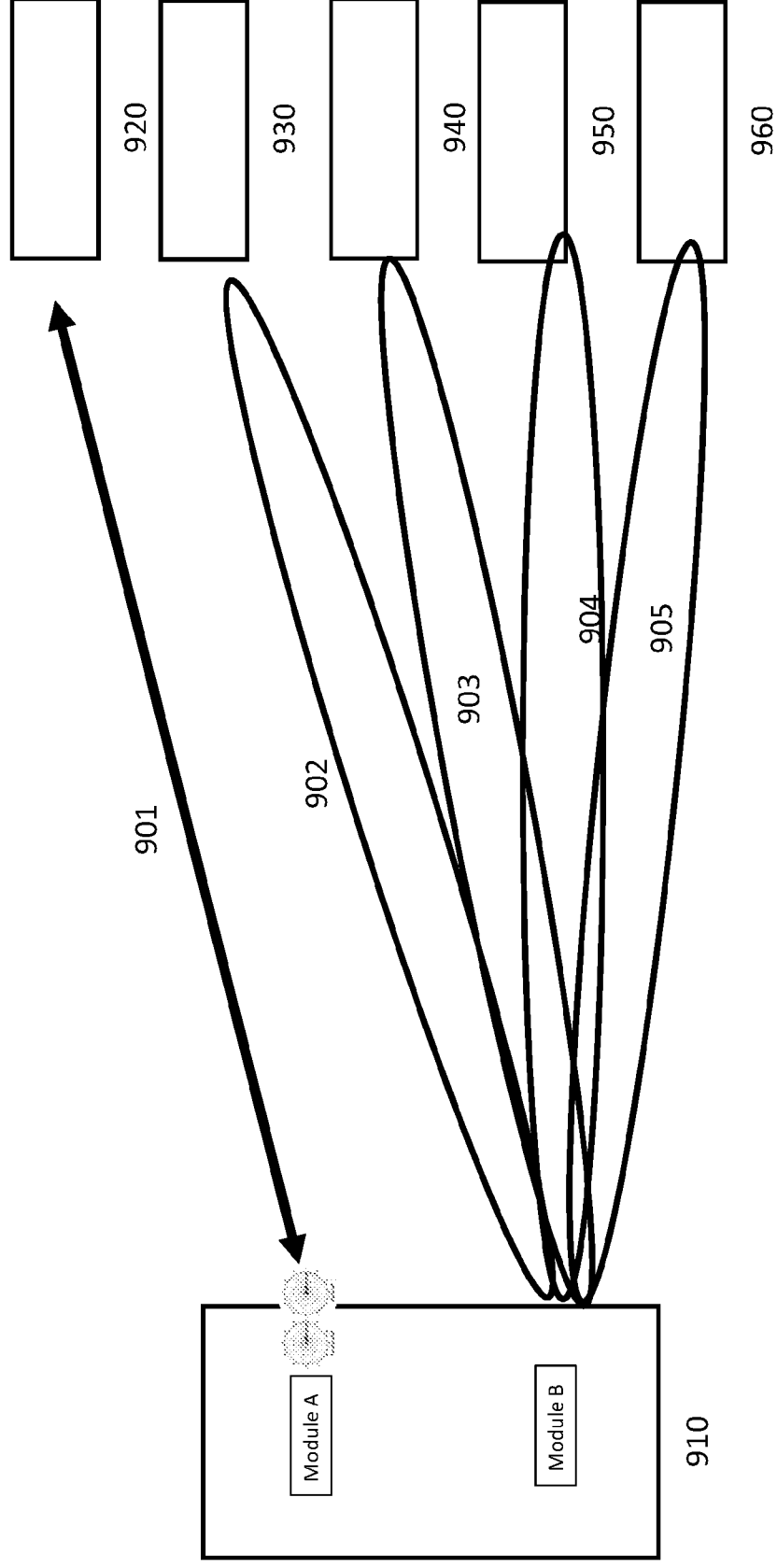


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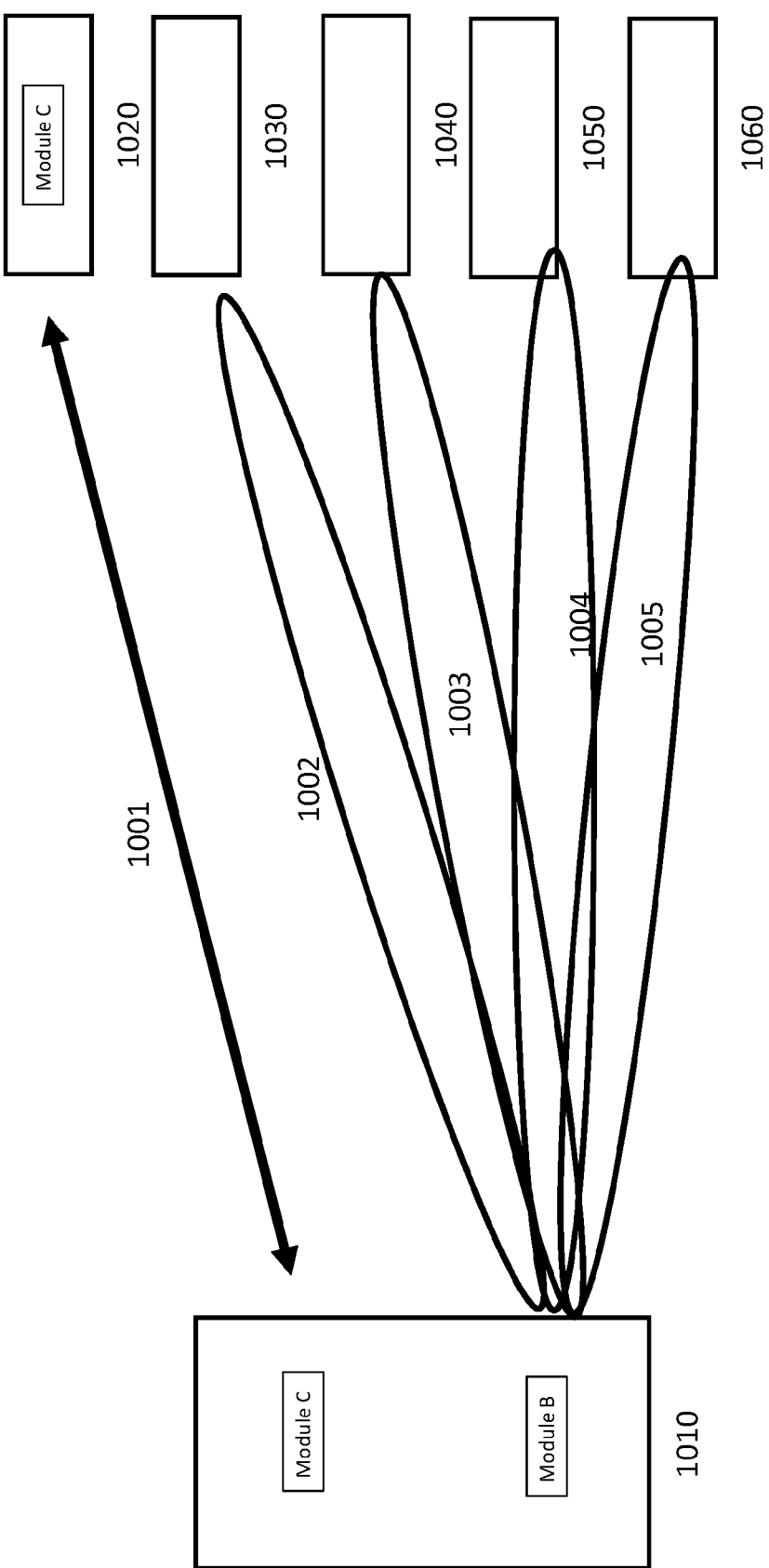


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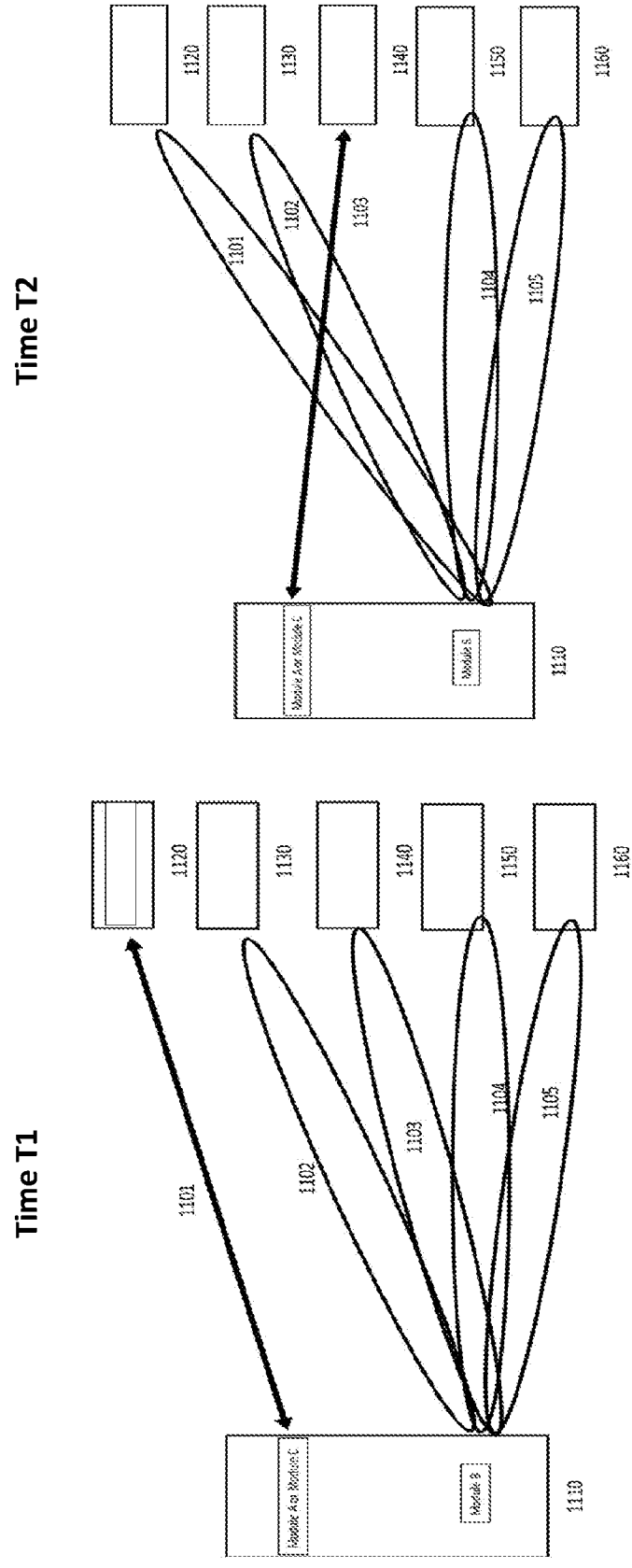


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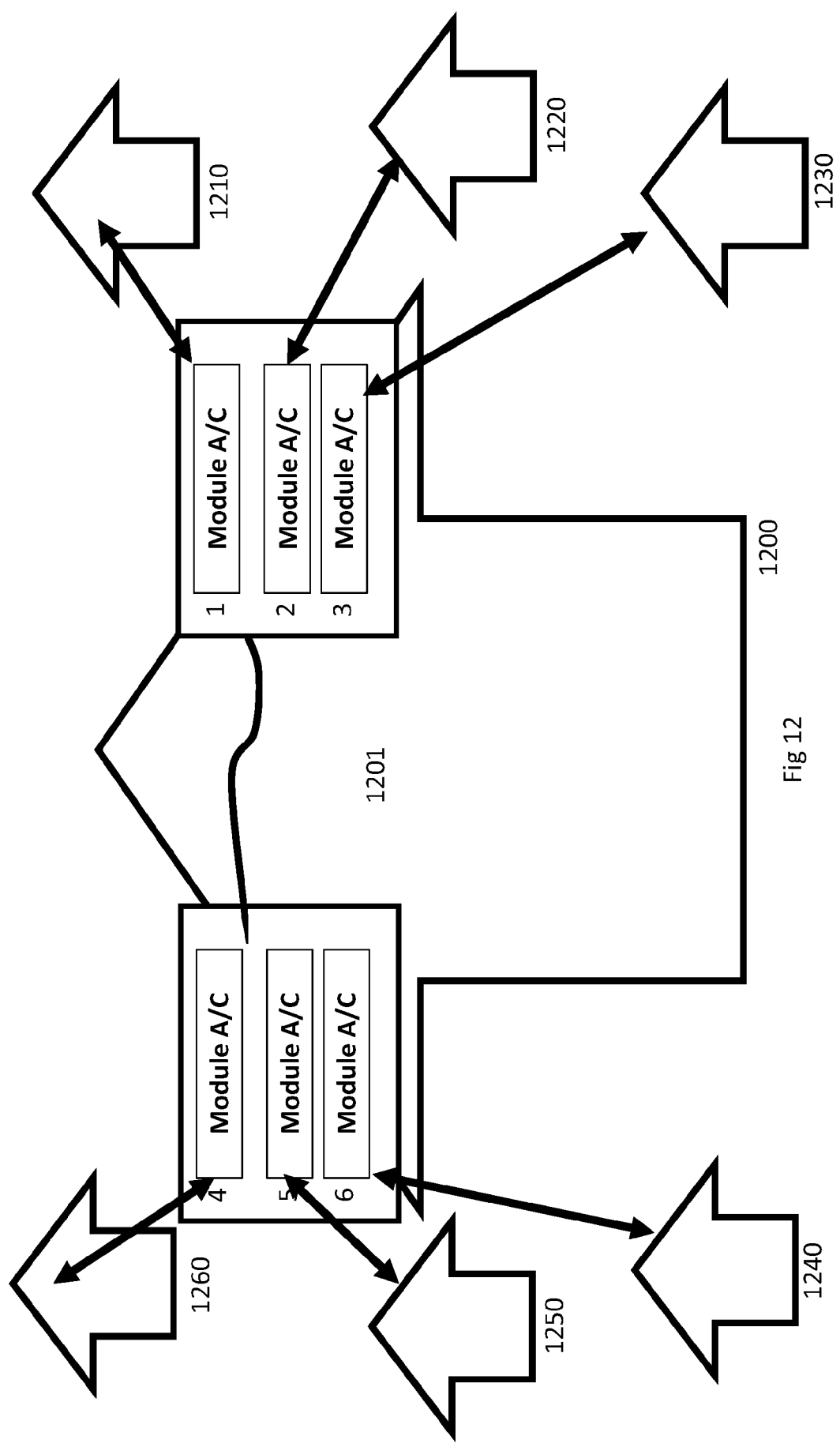


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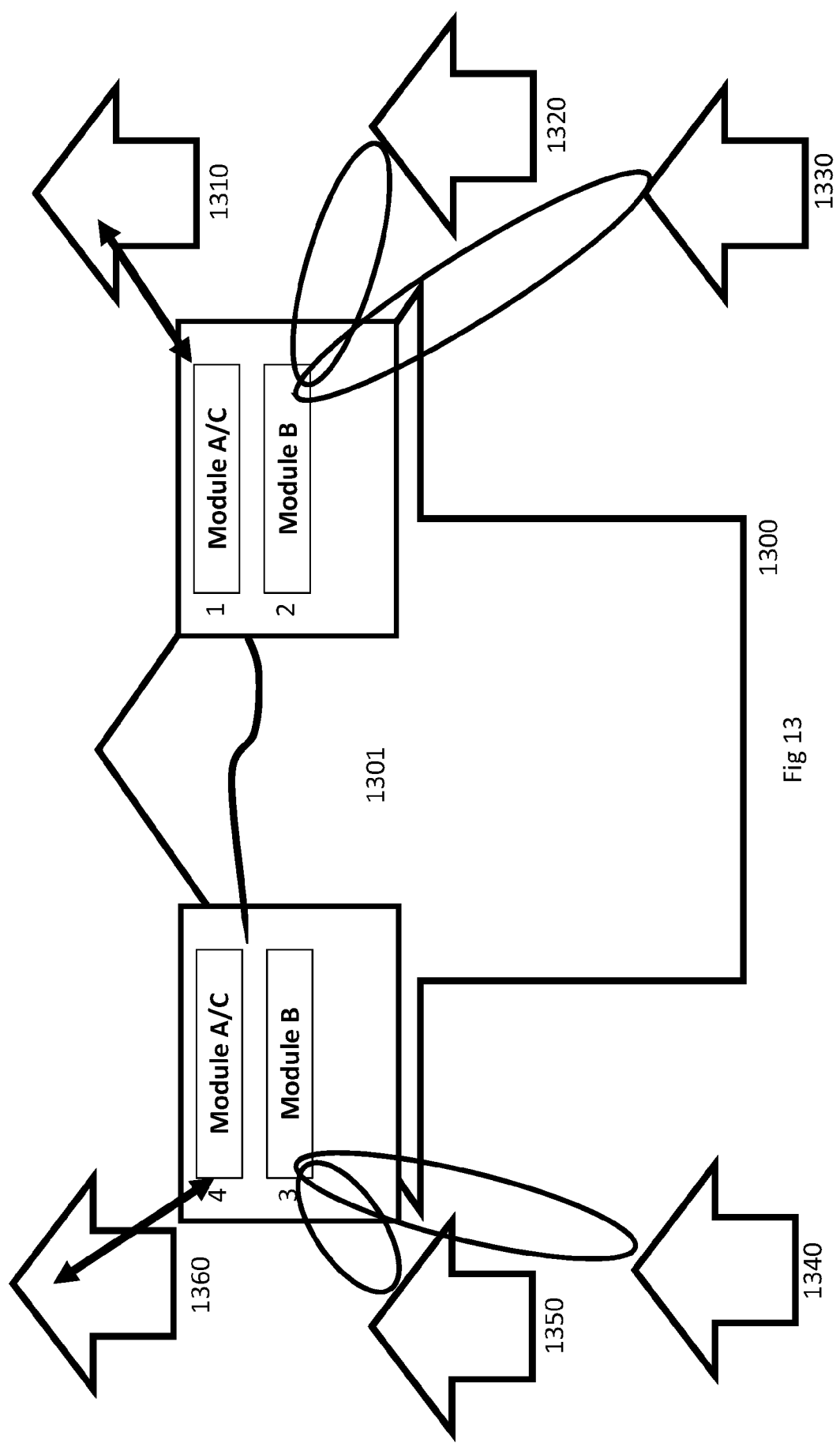


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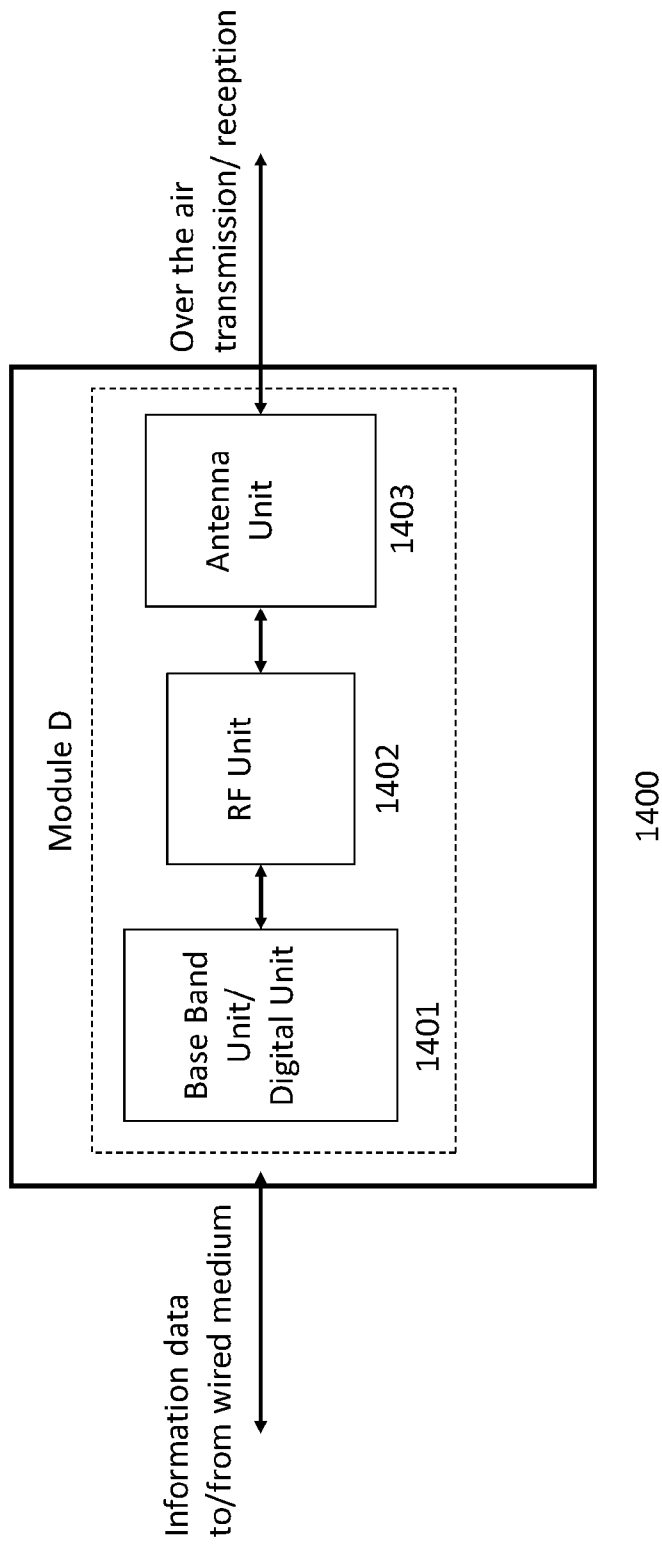


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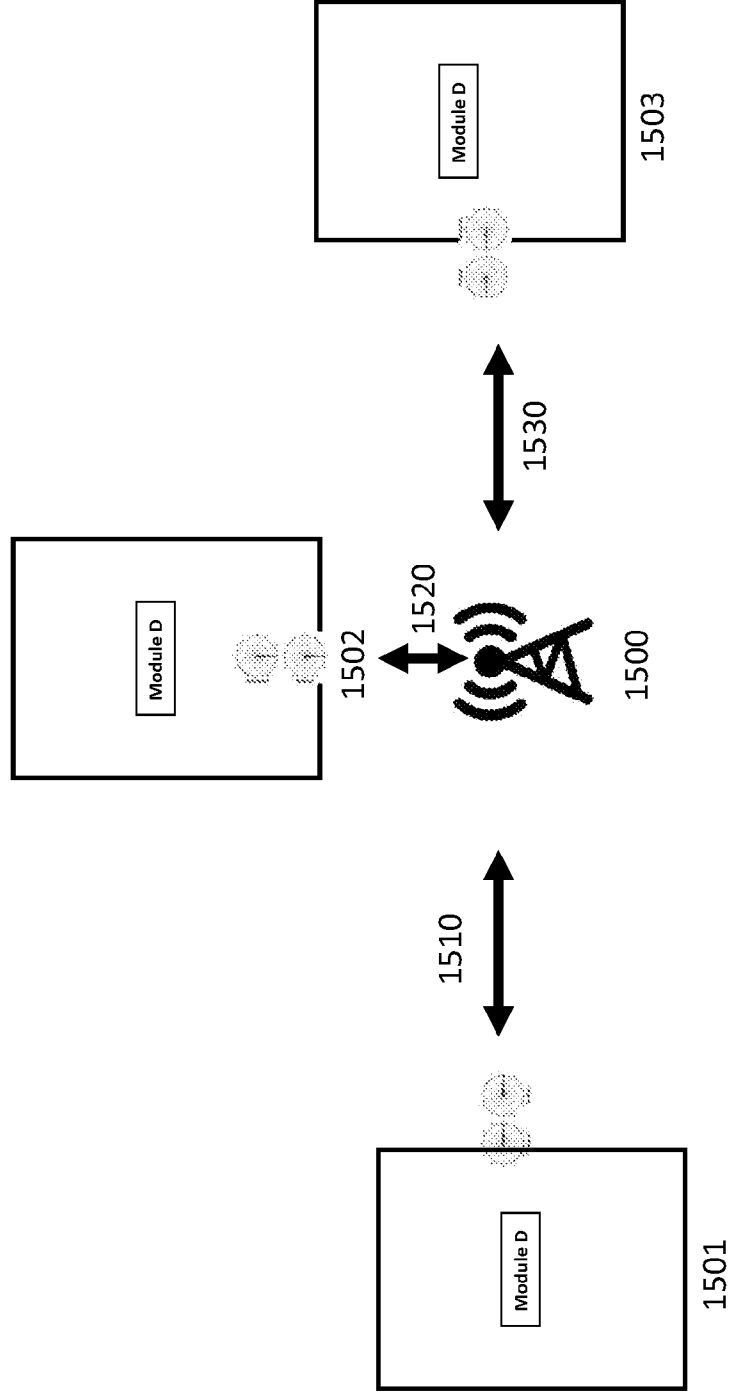


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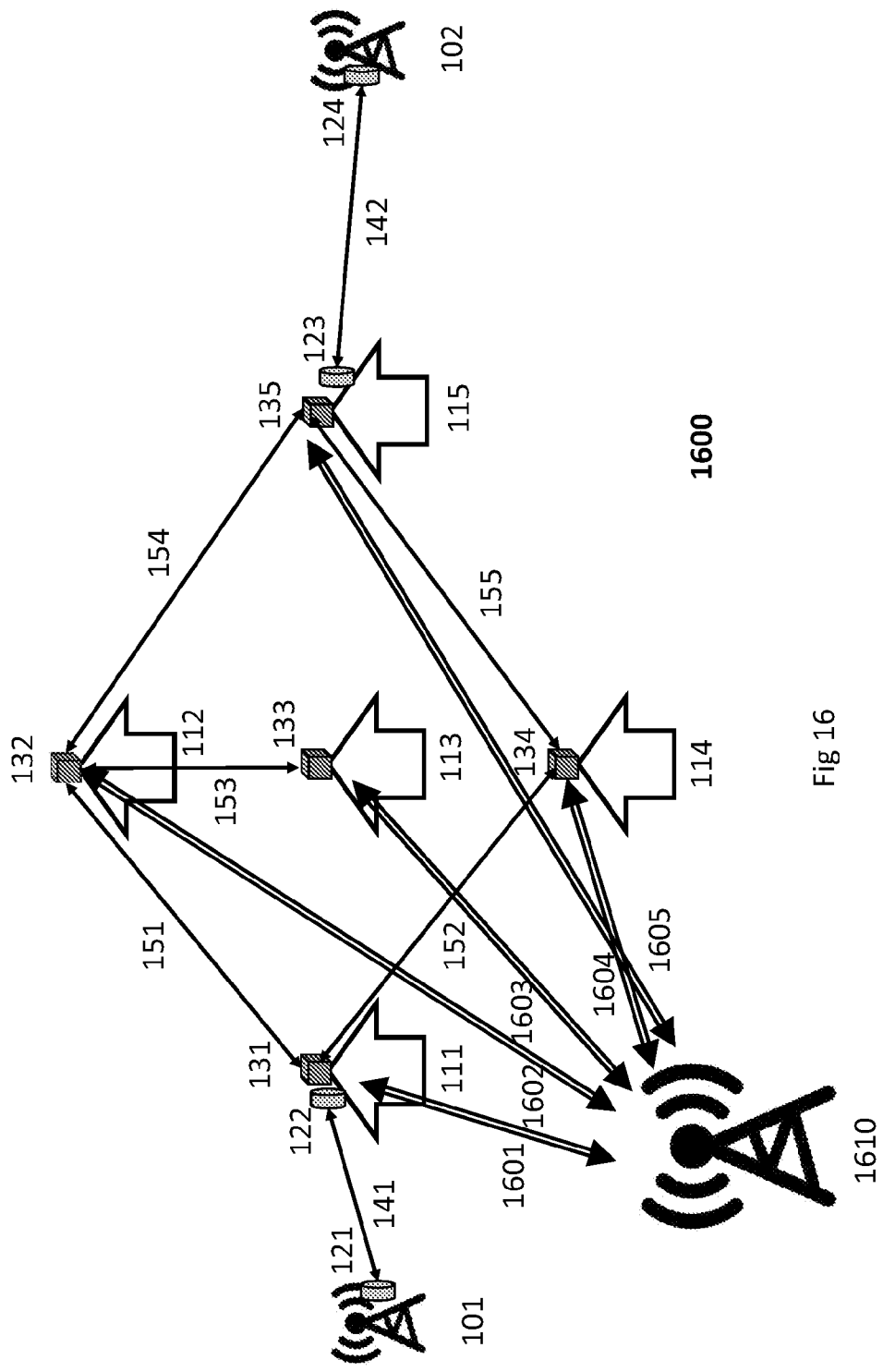


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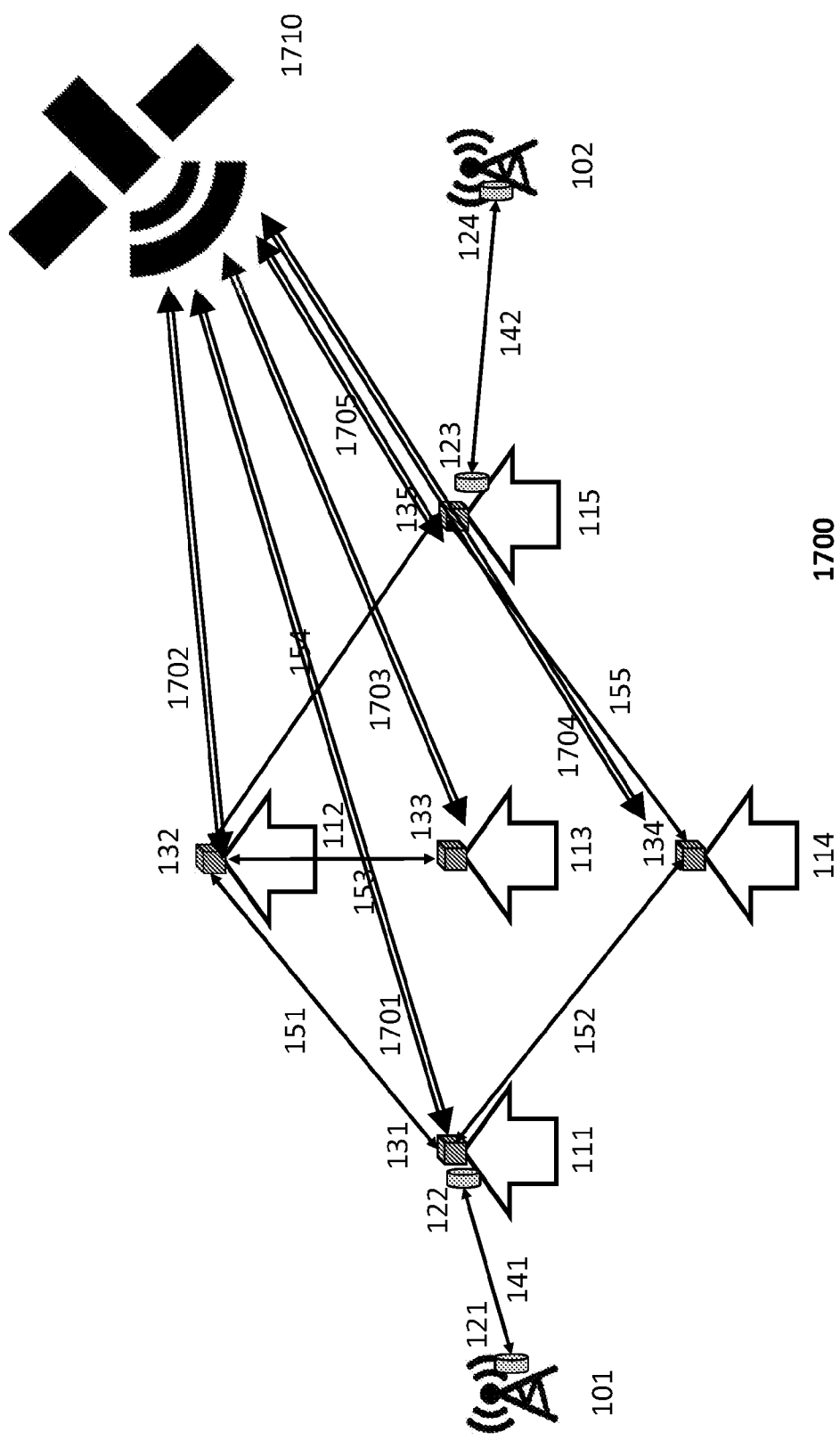


Fig 17

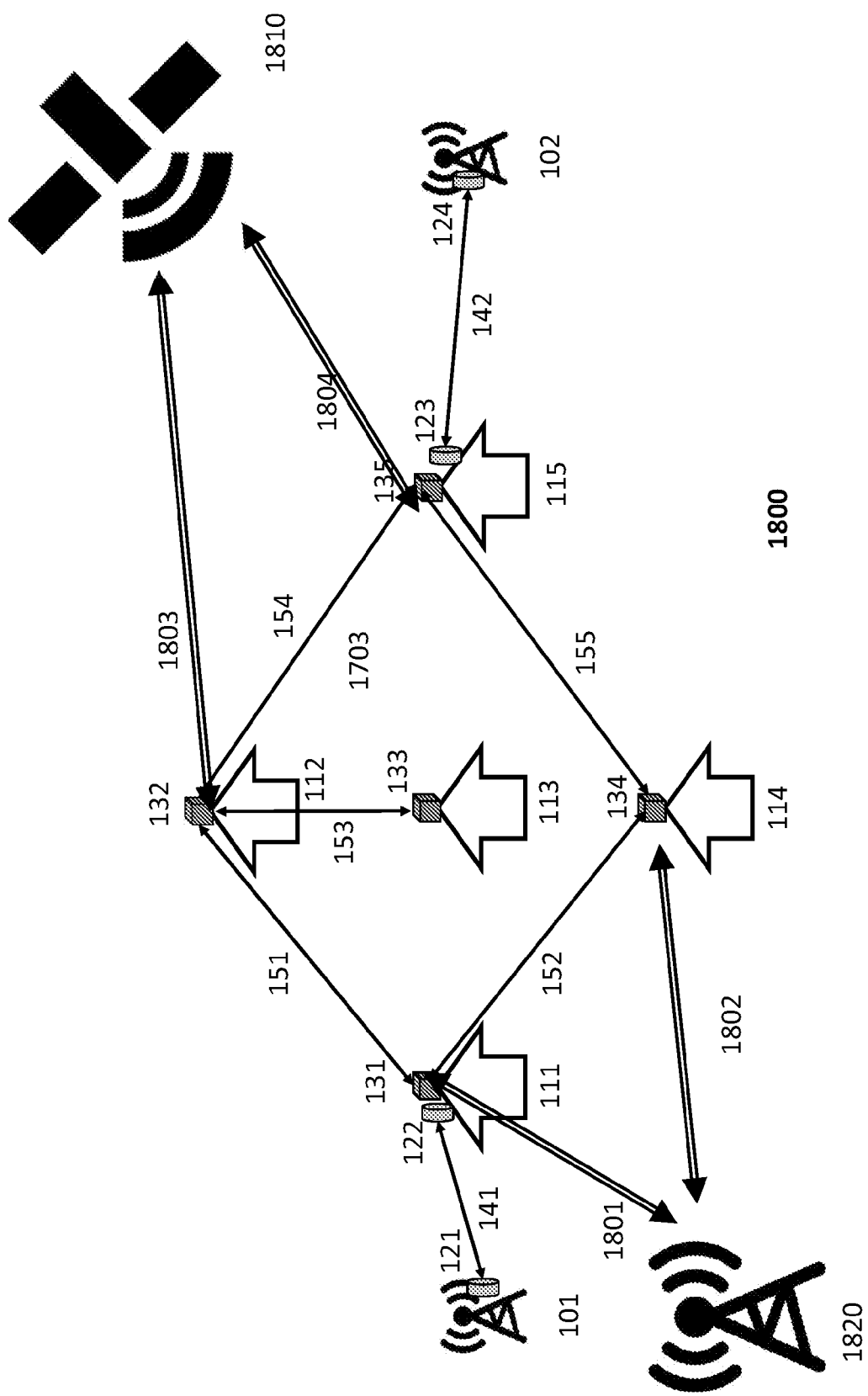


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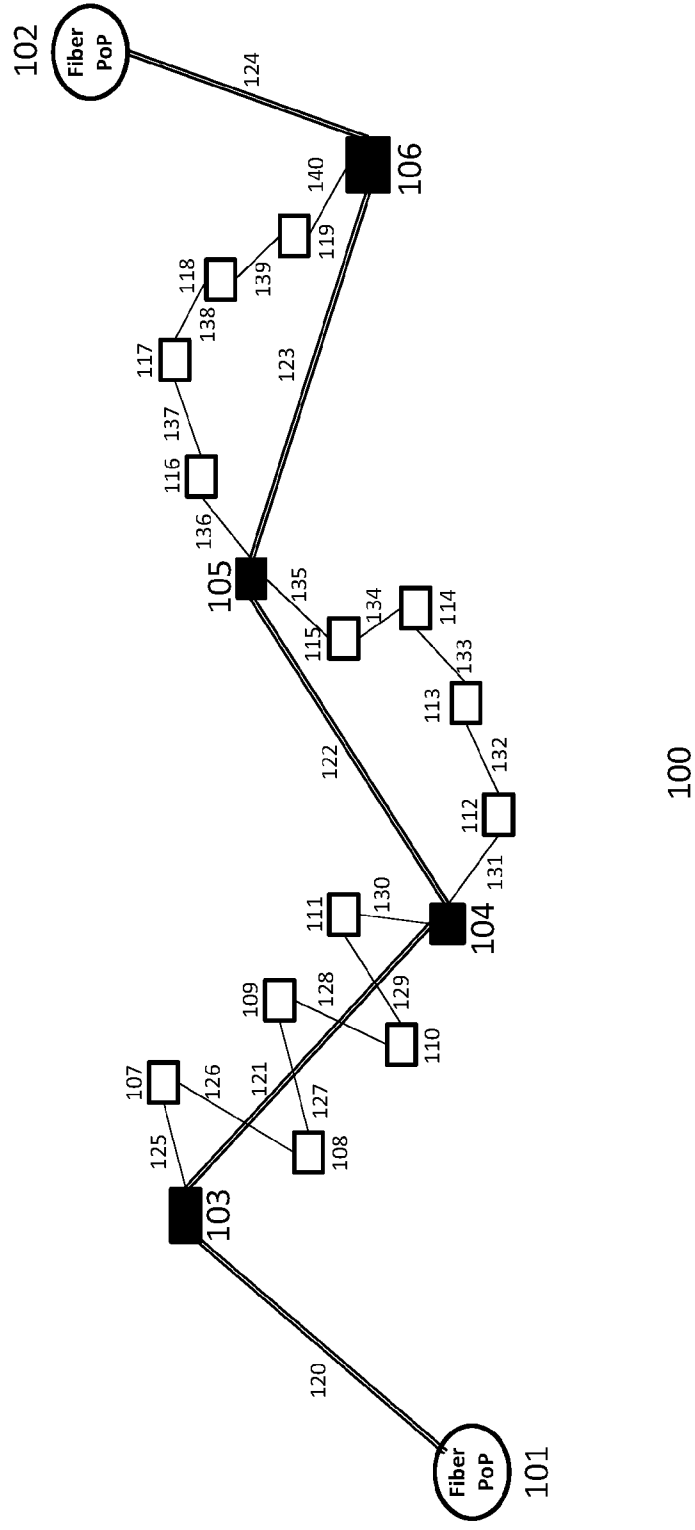
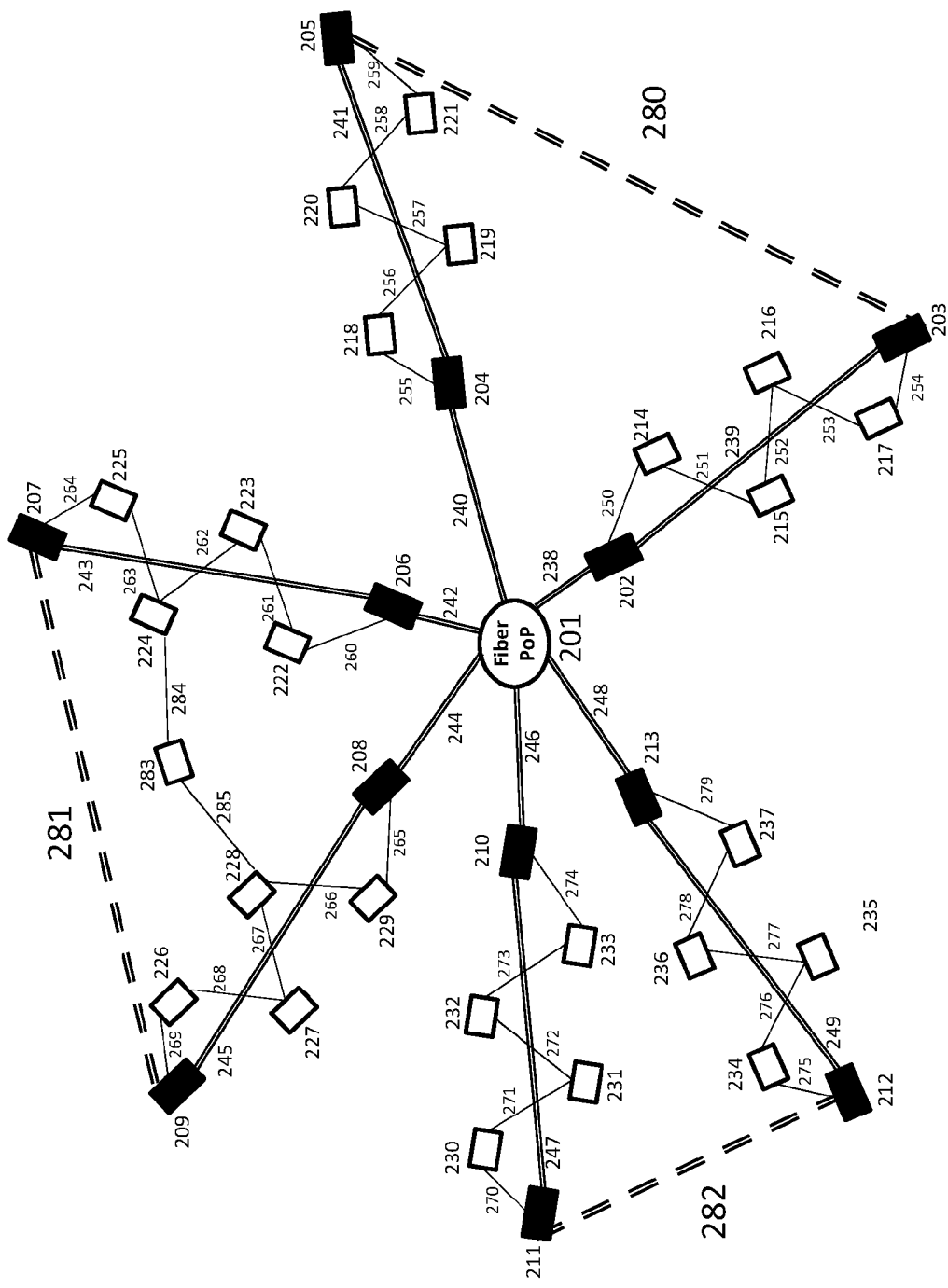


Figure 19



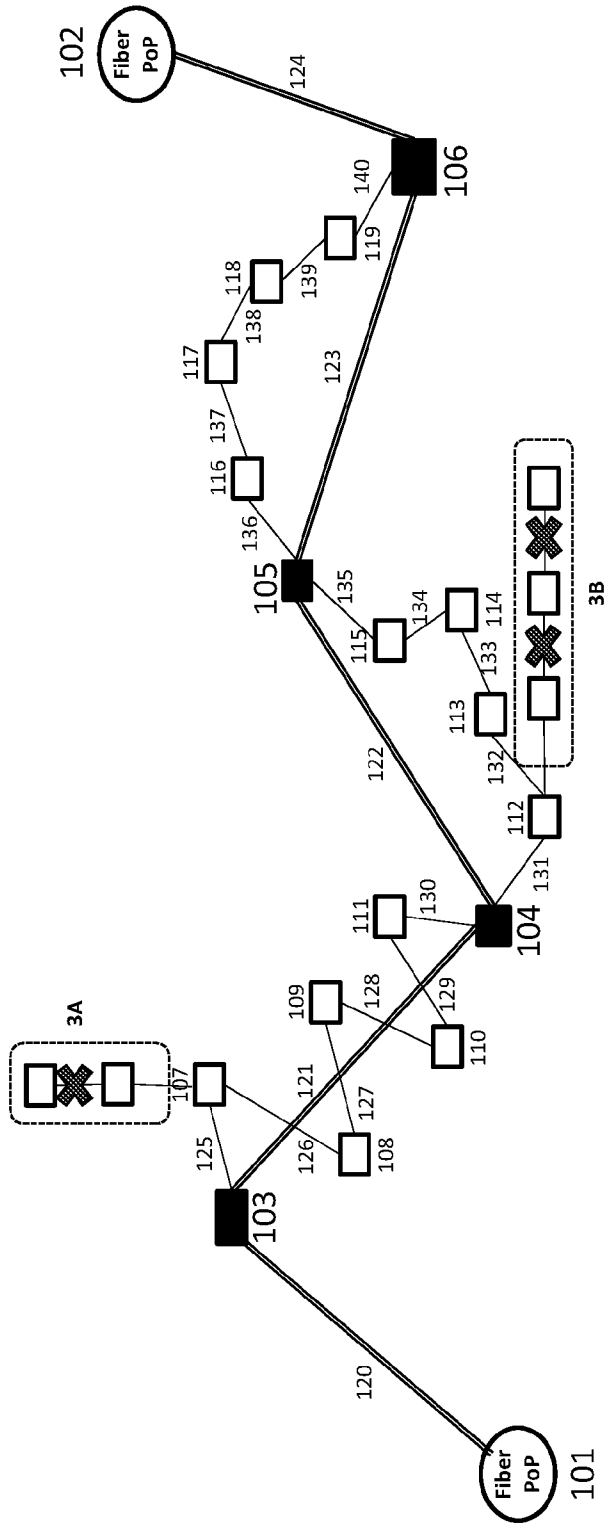


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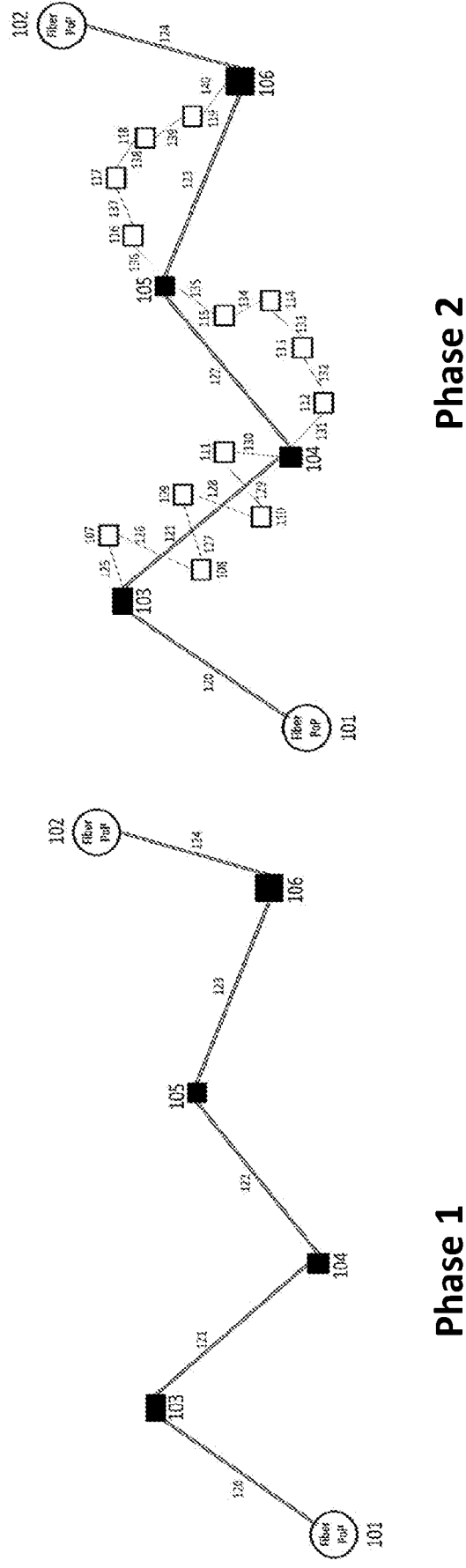
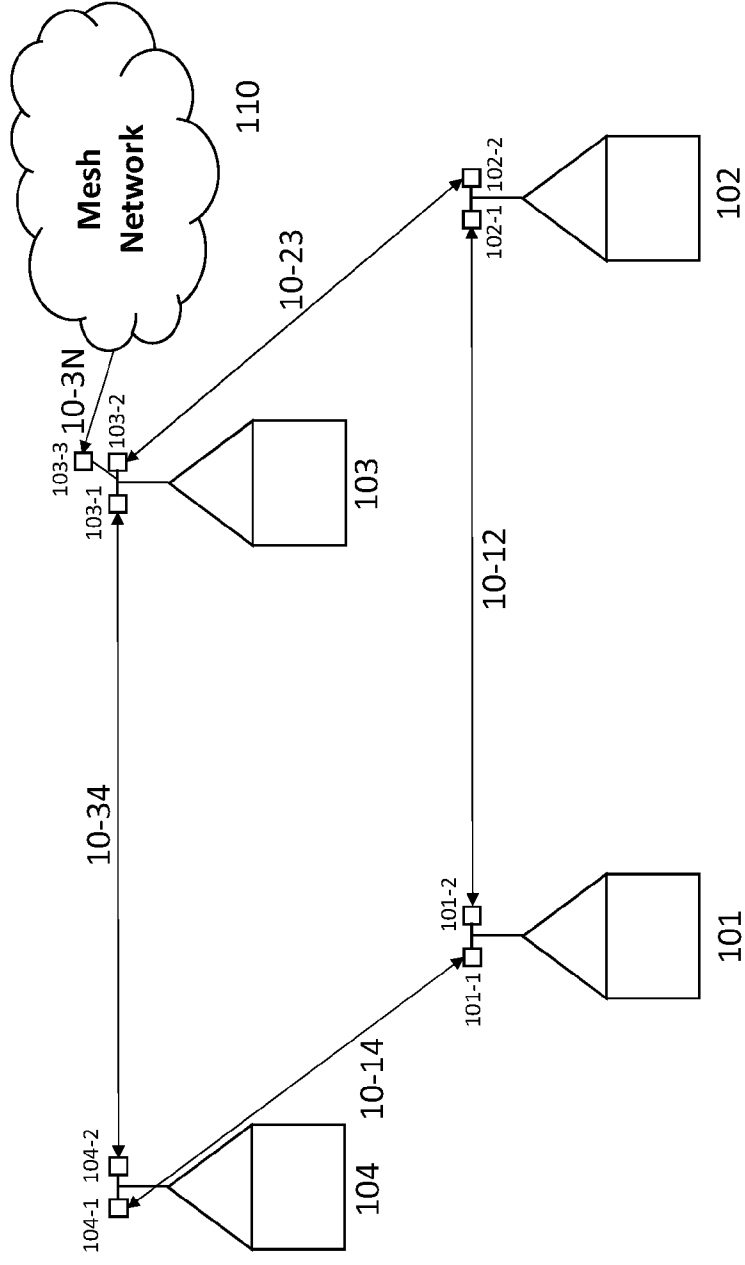


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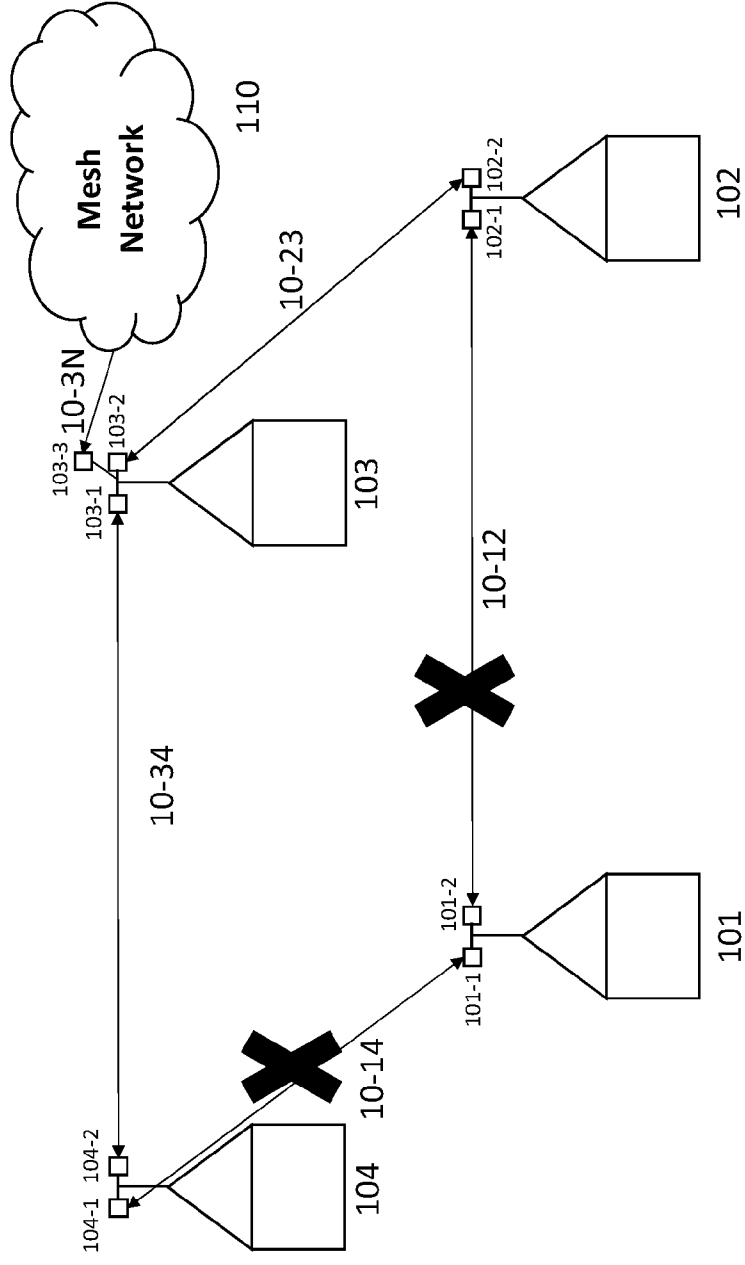


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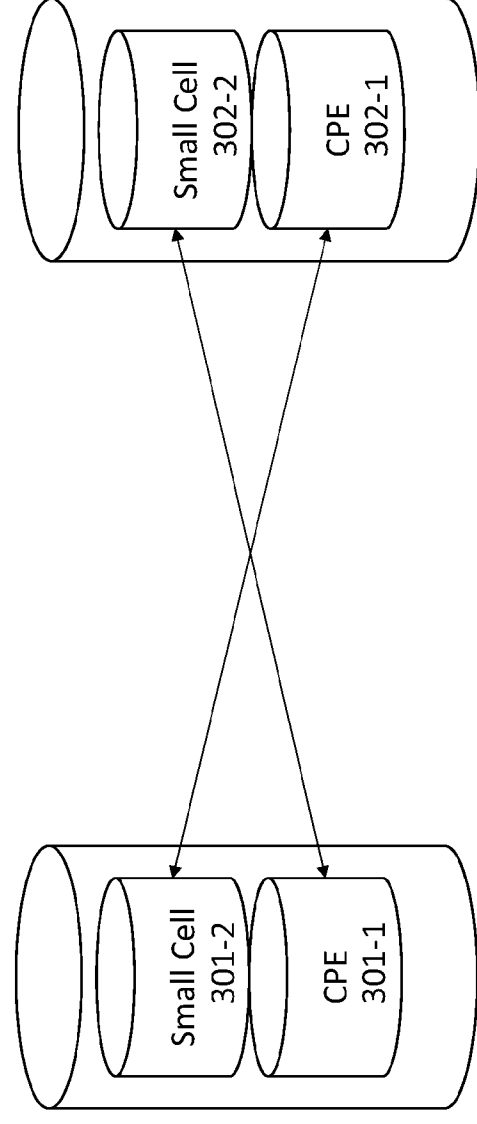
Communication Network 100

Figure 24



Communication Network 100

Figure 25



Wide beam width Communication Node 301

Wide beam width Communication Node 302

Figure 26

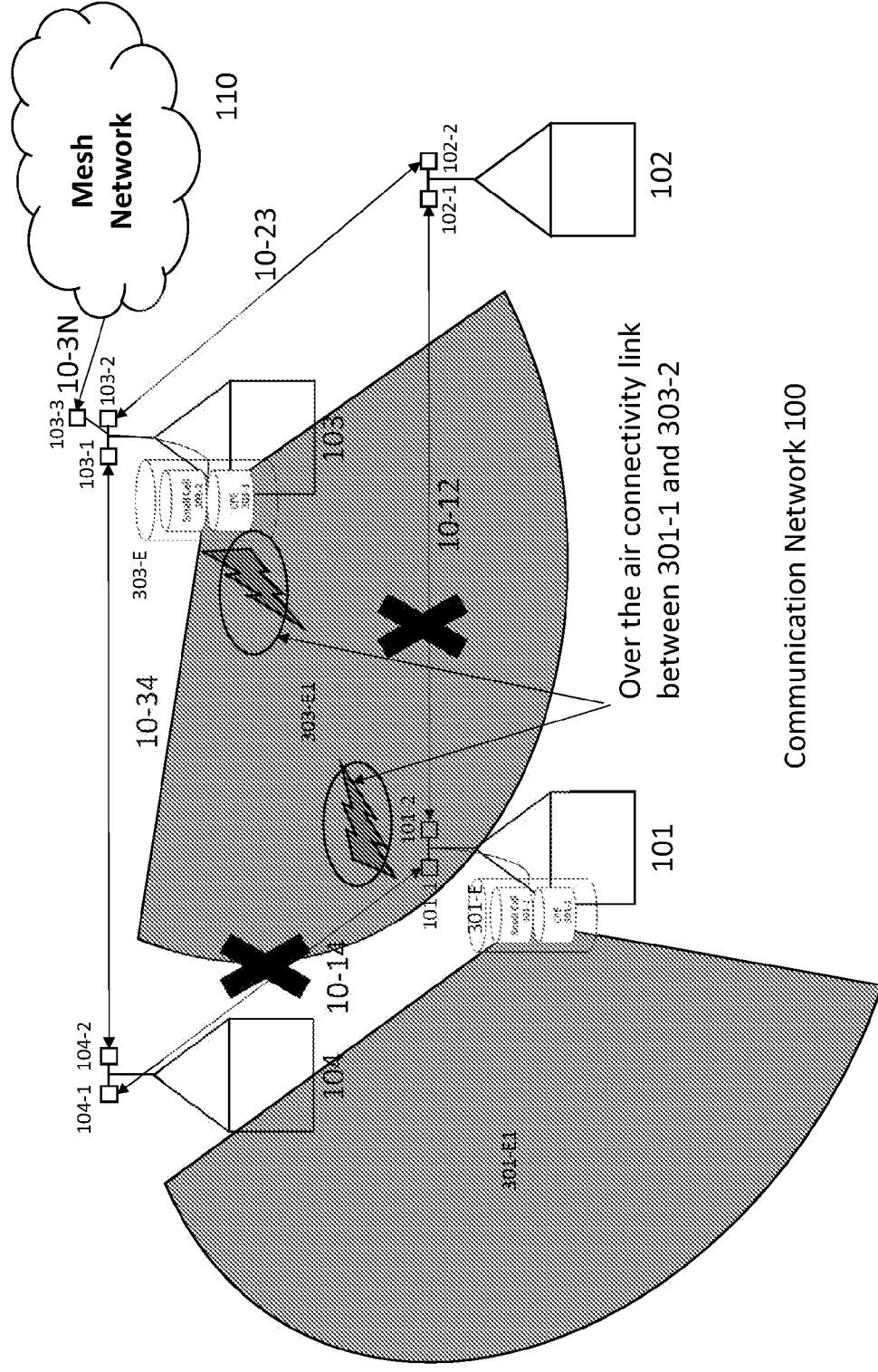


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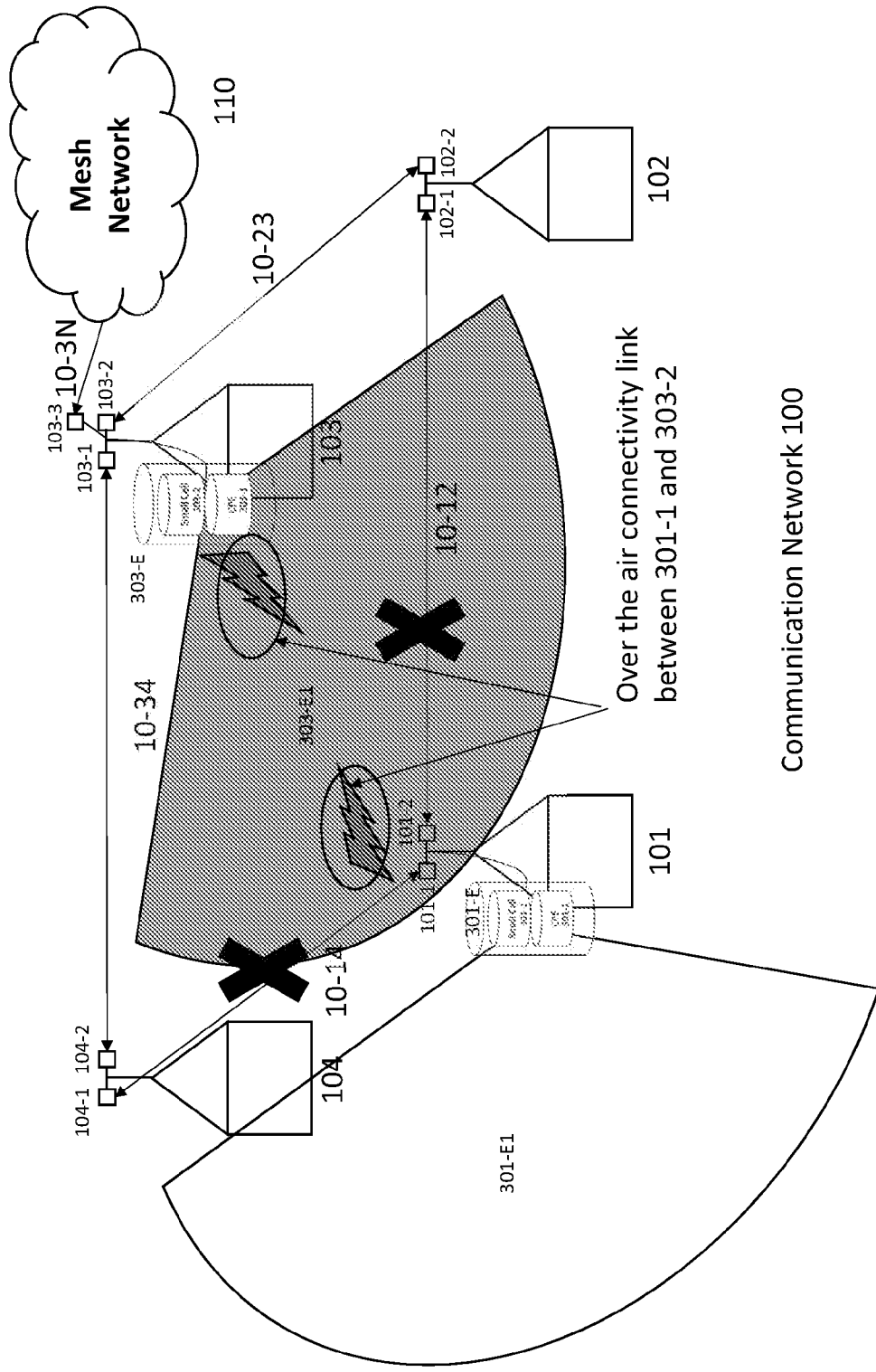


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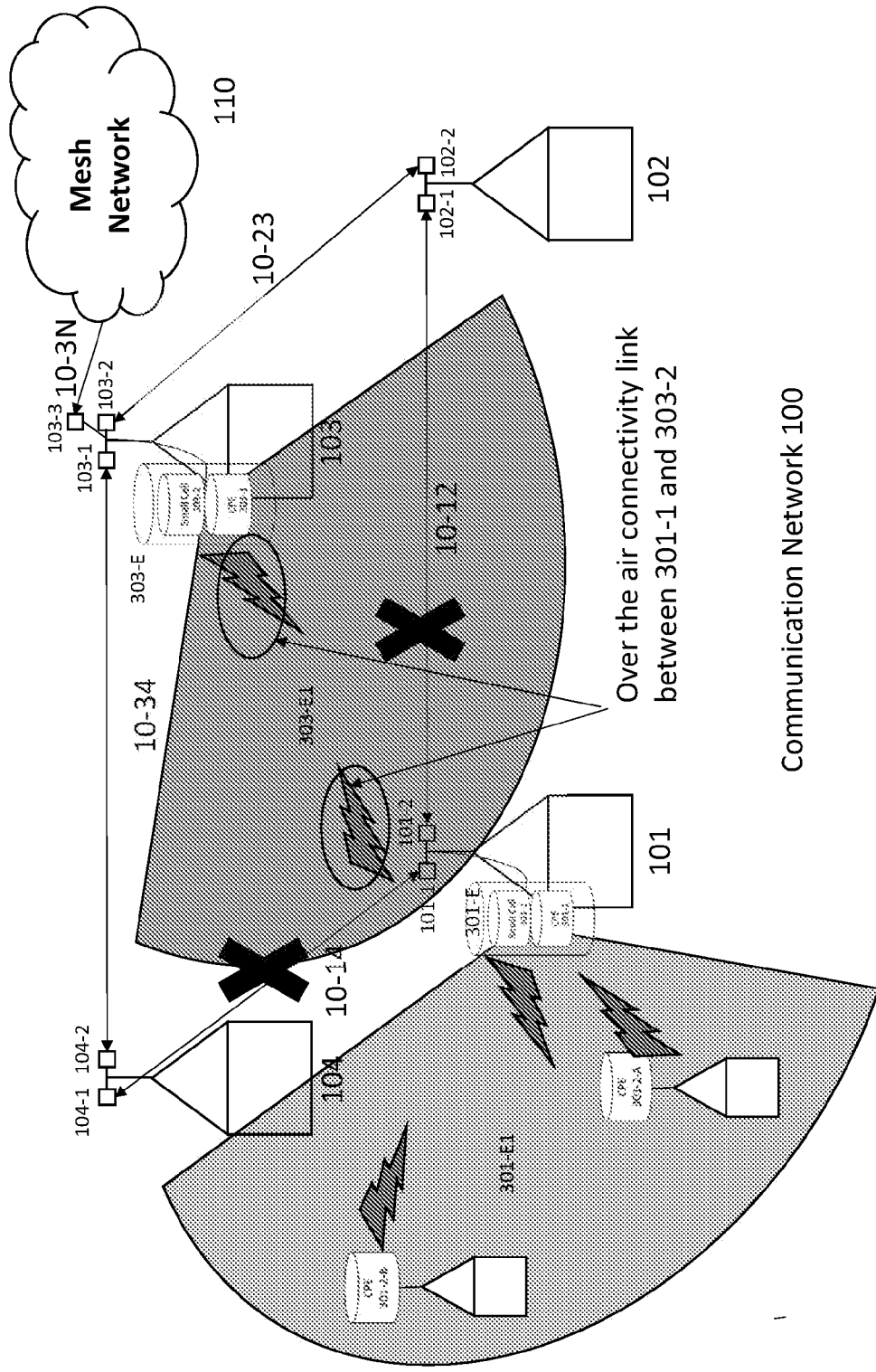


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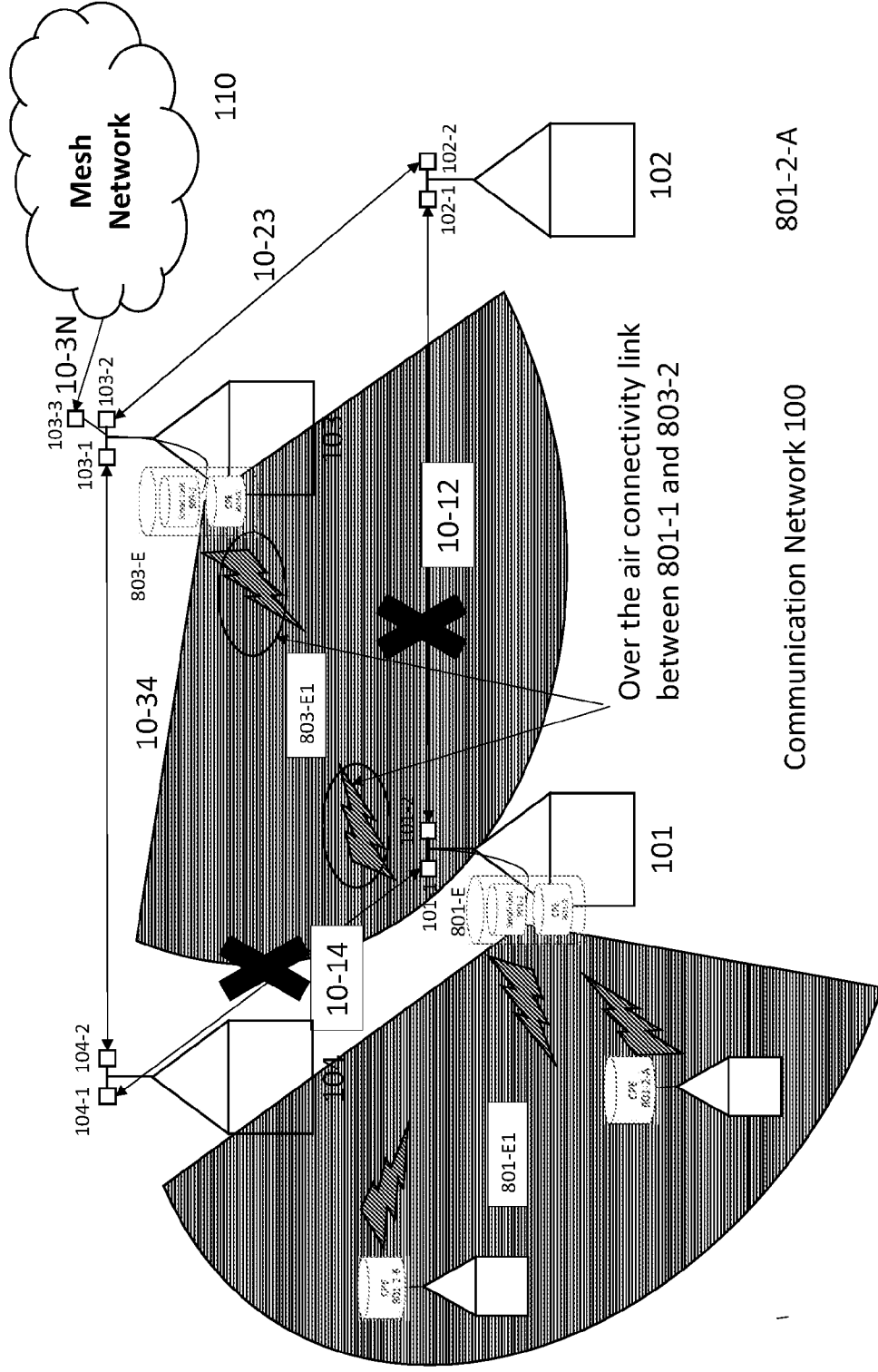


Figure 30A

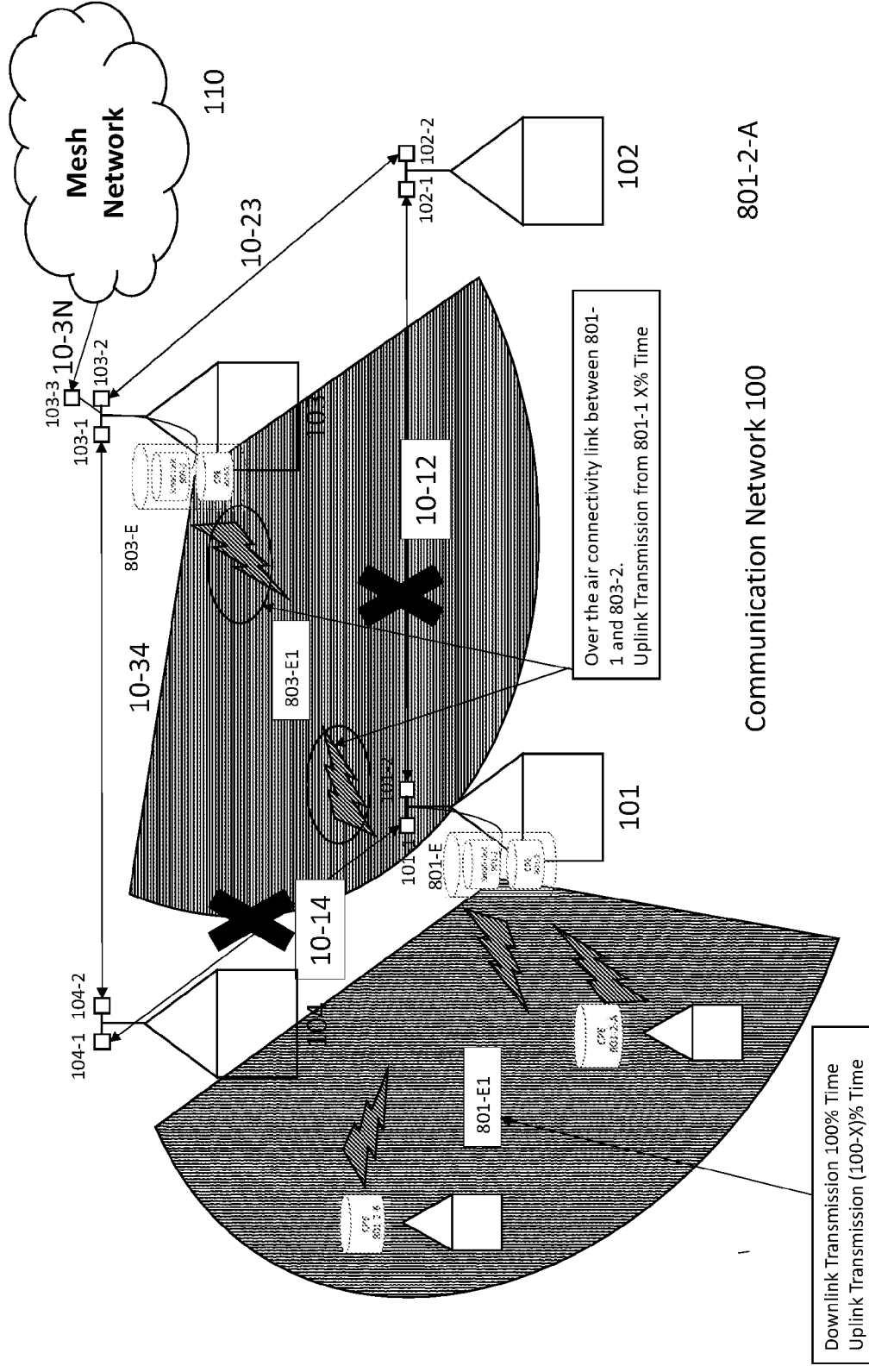


Figure 30B

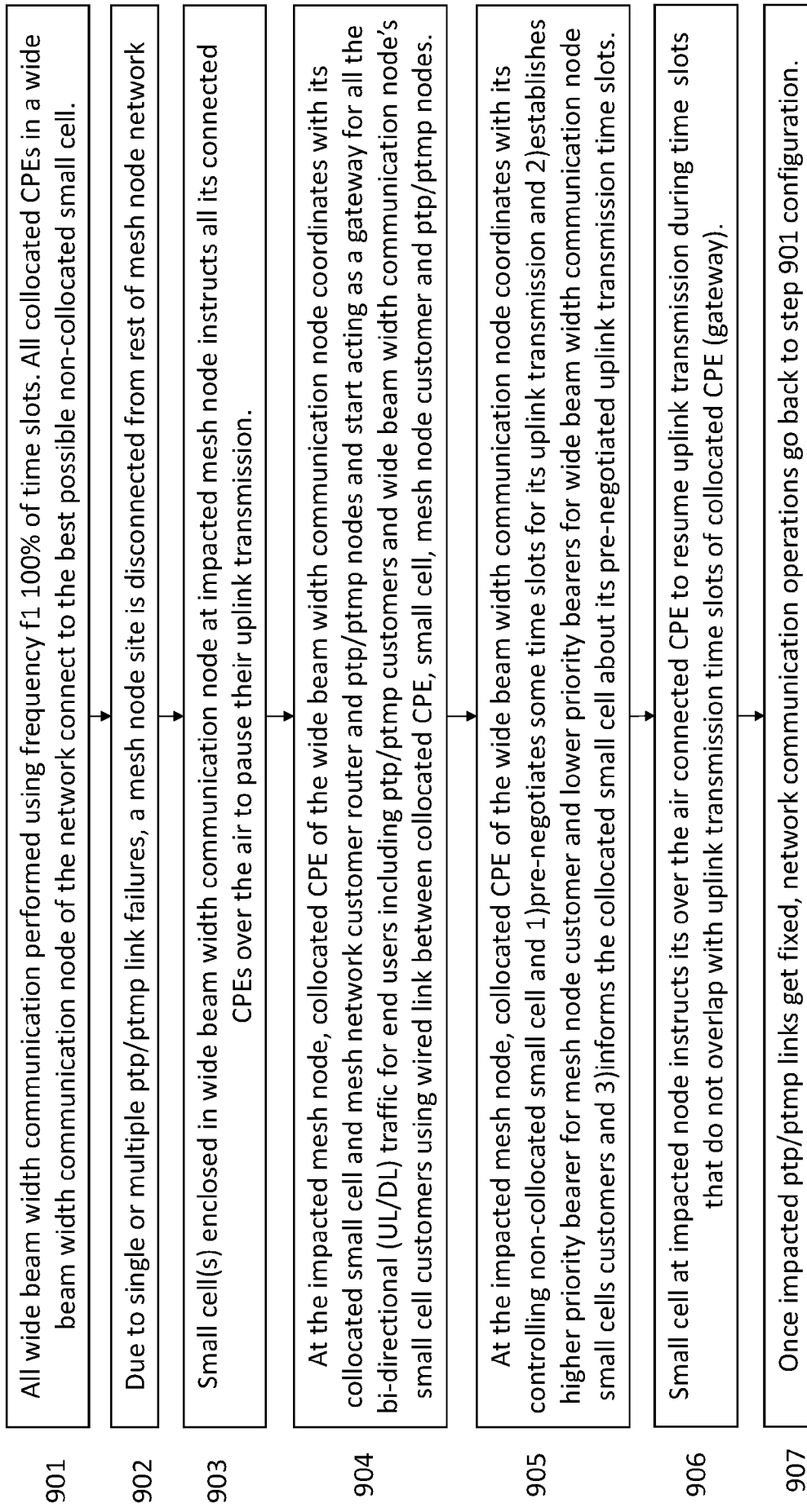


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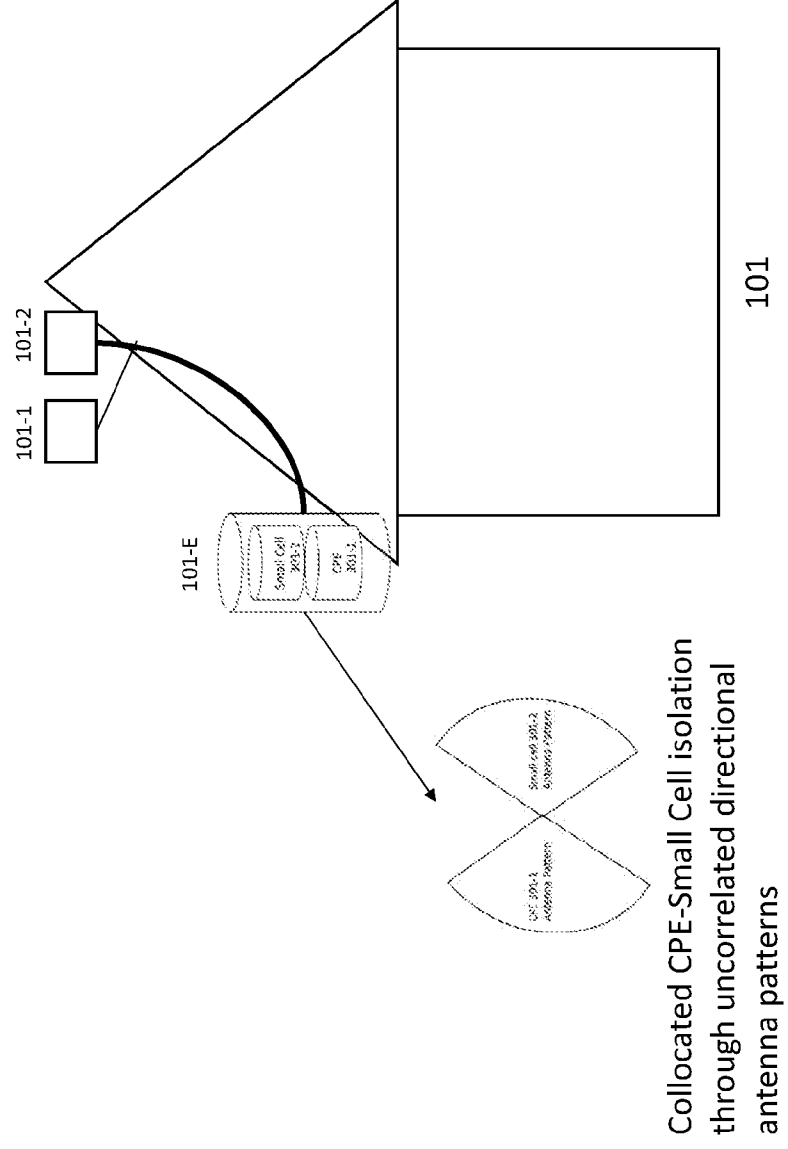


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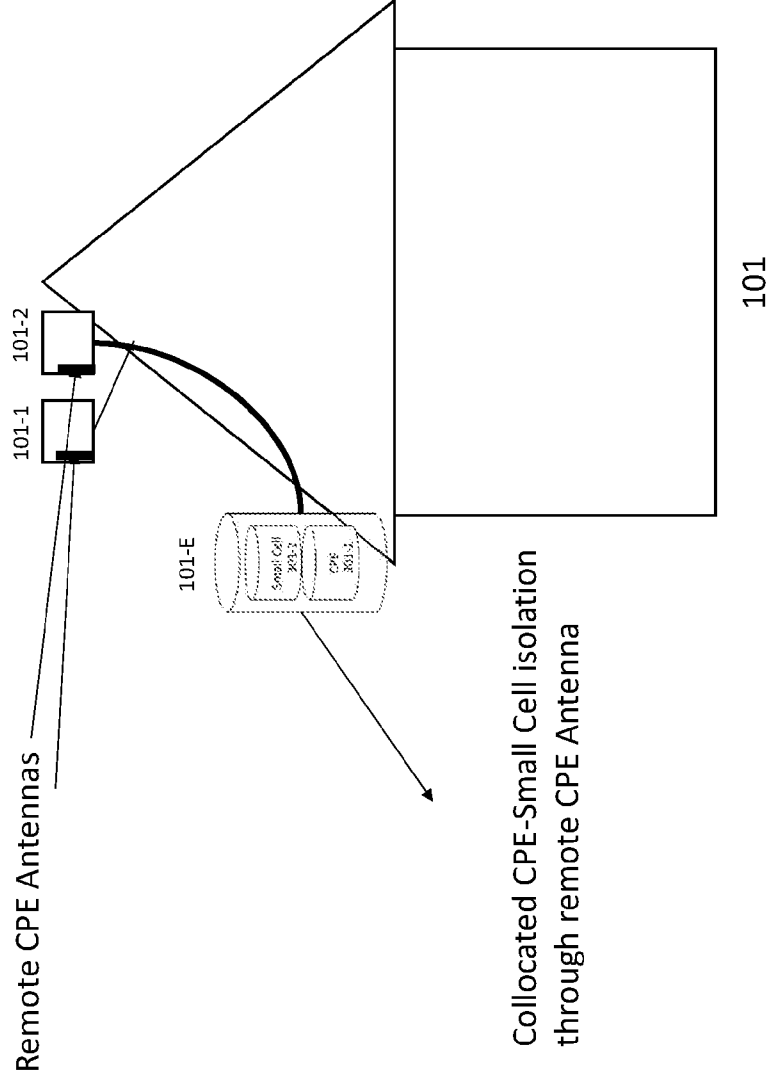
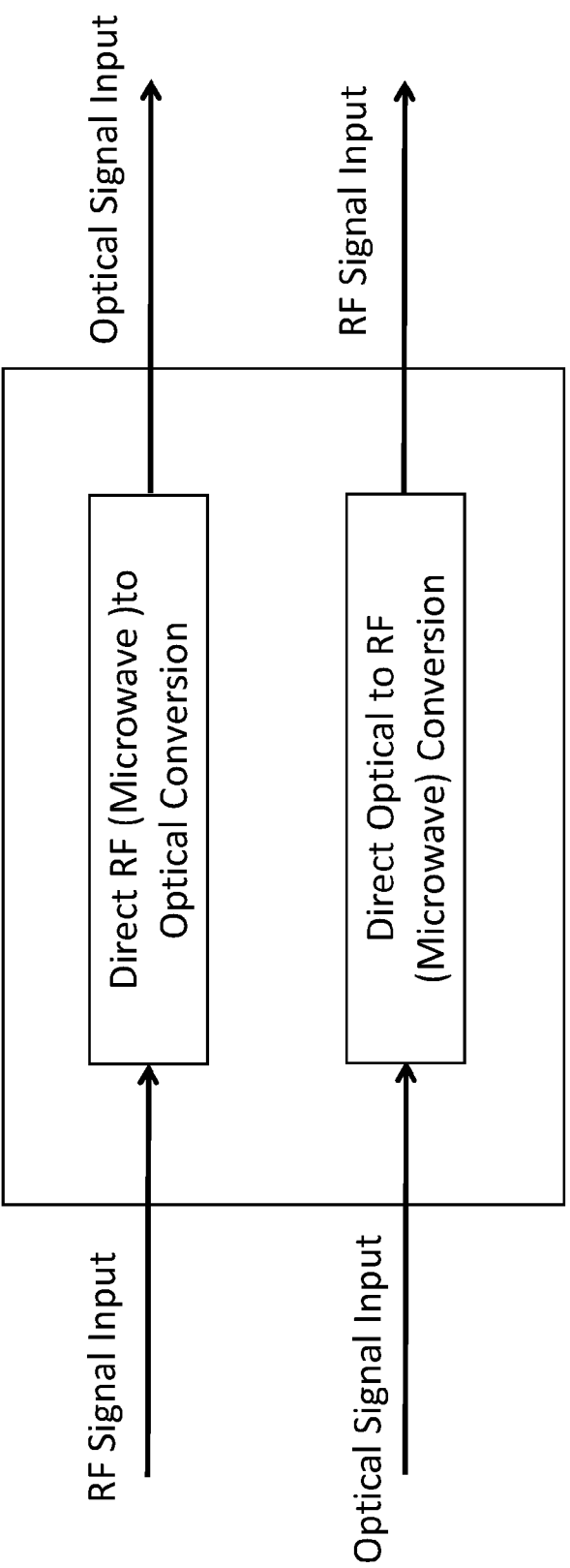


Figure 33



New Communication Module

Figure 34

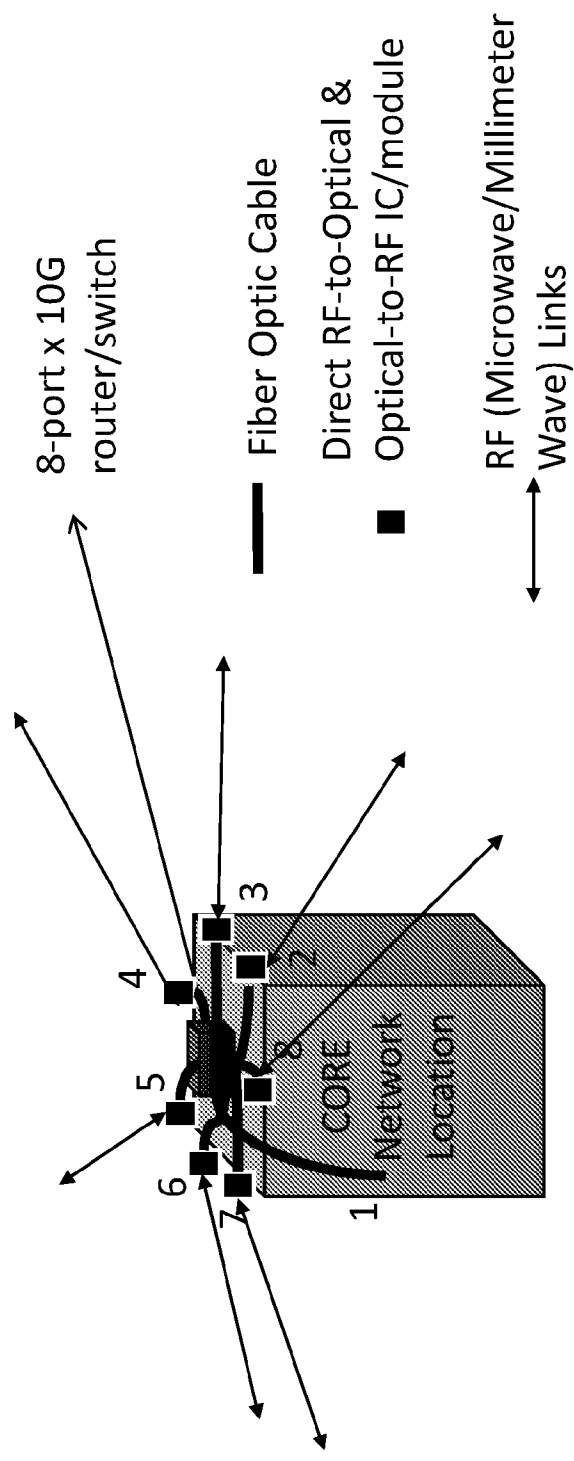


Figure 35

Electronic Acknowledgement Receipt

EFS ID:	34397640
Application Number:	62771508
International Application Number:	
Confirmation Number:	1006
Title of Invention:	A METHOD FOR IMPROVING WIRELESS MESH NETWORK USING DIRECT OPTICAL-TO-RF AND DIRECT-RF-TO-OPTICAL CONVERSION MODULE
First Named Inventor/Applicant Name:	Kevin Ross
Customer Number:	130085
Filer:	Rory Patrick Shea
Filer Authorized By:	
Attorney Docket Number:	Naim-00016
Receipt Date:	26-NOV-2018
Filing Date:	
Time Stamp:	19:27:08
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$ 140
RAM confirmation Number	112718INTEFSW19275700
Deposit Account	506632
Authorized User	Rory Shea
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: 37 CFR 1.16 (National application filing, search, and examination fees) 37 CFR 1.17 (Patent application and reexamination processing fees)	

37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Naim-00016_Spec.pdf	338385	yes	65
			22617ca2714e6e86ee594eb984a30c401d57c365		
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Specification		1	64	
	Abstract		65	65	
Warnings:					
Information:					
2	Provisional Cover Sheet (SB16)	Naim-00016_ProvCoverSheet.pdf	2032368	no	3
			b7788e4ffd43e011c6d0c92ab208a9d801ce8b51		
Warnings:					
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3	Application Data Sheet	Naim-00016_ADS.pdf	1255922	no	8
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4	Power of Attorney	Naim-00016_POA-ForFiling.pdf	839568	no	3
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Information:					
5	Drawings-only black and white line drawings	Naim-00016_Figs-FINALforFiling.pdf	15254615	no	36
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Information:					

6	Fee Worksheet (SB06)	fee-info.pdf	29611 283623ce48bd5f316d1bbe95a2707a66feb aacea	no	2
Warnings:					
Information:					
Total Files Size (in bytes):			19750469		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					

Provisional Application for United States Patent

TITLE: A METHOD FOR IMPROVING WIRELESS MESH NETWORK USING DIRECT OPTICAL-TO-RF AND DIRECT-RF-TO-OPTICAL CONVERSION MODULE

INVENTOR(S):Kevin Ross, Lehi, UT 84043
Muhammad A. Naim, South Jordan, UT 84095

[0001] BACKGROUND

[0002] The present disclosure, for example, relates to wireless networks and communications including, but not limited to, broadband internet services to end user, security and/or automation systems, and more particularly to narrow beam mesh networking and related operations and techniques.

[0003] Wired and wireless networking and communications systems are widely deployed to provide various types of communication and functional features, including but not limited to those for high speed home internet, security and automation, and/or others. These systems may be capable of supporting communication with a user through a communication connection or a system management action.

[0004] Current wireless mesh networking systems exhibit many shortcomings, including failing to account for extra protection for point-to-point narrow beam wireless path. Such paths are highly directional and work only under perfect line-of-sight or near line-of-sight conditions. Once the wireless mesh network is built, certain events such as vegetation growth or loss of an intermediary node can impact the line-of-sight paths between the links. This can result in single or multiple link failures in the network. Thus, there exists multiple needs in the art for improved systems and methods relating to wireless communication mesh network design and operation.

[0005] BRIEF SUMMARY OF THE PRESENT DISCLOSURE

[0006] The present system and methods relate to narrow beam mesh networks, associated systems, and operations relating to network communication, including, in some embodiments, adjustments and modifications. The present systems and methods may facilitate designing, operating and/or adjusting/modifying wireless networking communications. In some embodiments, the present systems and methods relate to and account for wireless communication nodes with capability of establishing point-to-point or point-to-multipoint narrow beam communication link, point-to-point/point-to-multipoint steerable narrow beam communication link, combination of point-to-point and point-to-multipoint communication links, among other things.

[0007] In some embodiments, one or multiple links in a wireless communication network can fail due to certain events including but not limited to growth in vegetation, loss of a node due to various reasons that can change the line-of-sight (LOS) conditions required for communication between two points in the wireless mesh network. In the current disclosure, some or all the nodes in the mesh network can host a 4G(LTE, LTE Advanced, LTE Pro, WiMAX, WiFi, etc.) technology based small cell (eNB) and an UE (user equipment)/CPE (customer premises equipment) in a single enclosure to provide redundant communication path between two points in a mesh network in an event direct or in-direct LOS path between two mesh nodes fails due to an event.

[0008] The foregoing has outlined rather broadly the features and technical advantages of examples according to this disclosure so that the following detailed description may be better understood. Additional features and advantages will be described below. The conception and specific examples disclosed may be readily utilized as a basis for

modifying or designing other structures for carrying out the same procedures of the present disclosure. Characteristics of the concepts disclosed herein including their organization and method of operation together with associated advantages will be better understood from the following description when considered in connection with the accompanying figures. Each of the figures is provided for the purpose of illustration and description only, and not as a definition of the limits of the claims.

[0009] BRIEF DESCRIPTION OF THE DRAWINGS

[00010] A further understanding of the nature and advantages the present disclosure may be realized by reference to the following drawings.

[00011] Figure 1. Figure 1 shows a diagram relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00012] Figure 2. Figure 2 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00013] Figure 3. Figure 3 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00014] Figure 4. Figure 4 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00015] Figure 5. Figure 5 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00016] Figure 6. Figure 6 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00017] Figure 7. Figure 7 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00018] Figure 8. Figure 8 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00019] Figure 9. Figure 9 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00020] Figure 10. Figure 10 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00021] Figure 11. Figure 11 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00022] Figure 12. Figure 12 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00023] Figure 13. Figure 13 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00024] Figure 14. Figure 14 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00025] Figure 15. Figure 15 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00026] Figure 16. Figure 16 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00027] Figure 17. Figure 17 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00028] Figure 18. Figure 18 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00029] Figure 19. Figure 19 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00030] Figure 20. Figure 20 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00031] Figure 21. Figure 21 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00032] Figure 22. Figure 22 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00033] Figure 23. Figure 23 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00034] Figure 24. Figure 24 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00035] Figure 26. Figure 26 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00036] Figure 27. Figure 27 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00037] Figure 28. Figure 28 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00038] Figure 29. Figure 29 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00039] Figure 30A. Figure 30A shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00040] Figure 30B. Figure 30B shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00041] Figure 31. Figure 31 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00042] Figure 32. Figure 32 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00043] Figure 33. Figure 33 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00044] Figure 34. Figure 35 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00045] Figure 35. Figure 35 shows designs illustrating exemplary methods relating to wireless networking and communication systems, in accordance with various aspects of this disclosure;

[00046] DETAILED DESCRIPTION

[00047] Current wireless mesh networking systems exhibit many shortcomings, including failing to account for extra protection for high reliability wireless path for

carrying backhaul data that carries control signaling data along with user data for all the users in the network segment. Current wireless mesh networking systems use same or similar beam transmission techniques for access path that carries data for a single user and backhaul path that may affect network performance as backhaul paths tend to be more sensitive to interference and other signal inhibitors and can degrade the performance of entire network segment. Thus, there exists multiple needs in the art for improved systems and methods relating to wireless communication network design and operation. Referring to figure 1, a data communication network capable of providing multigigabit internet speeds through wireless point-to-point and point-to-multipoint links is illustrated. Communication network 100 in figure 1 includes Tower/ fiber access points 101 and 102. Tower/fiber access points 101 and 102 can be co-located or can be located at different physical locations. Tower/fiber access points 101 and 102 have access to high bandwidth dark fiber capable of providing up to several hundred gigabits/second of data throughput. Tower/fiber access points provide backhaul connectivity between the core network/data center (not shown in the figure 1 for the sake of simplicity) and seed home of the communication network described below. Tower/Fiber access points 101 and 102 host wireless point-to-point communication nodes 121 and 124. Wireless communication nodes 121 and 124 are capable of reception and transmission of high bandwidth (multiple gigahertz) signals operating at very high frequency (6Ghz ~100Ghz such as 28Ghz, V band, E band, etc.). Wireless communication nodes 121 and 124 consist of baseband/digital unit equipped with components including but not limited to processor, memory etc. Wireless communication nodes 121 and 124 also consist of RF unit and antenna unit. Antenna subsystem of wireless communication nodes 121 and 124 are capable of reception and transmission of directional signals where significant portion of

the signal energy is concentrated within few degrees around the antenna boresight, both in vertical and horizontal direction, in contrast to omni directional antennas where signal energy is close to evenly spread across entire 360° degrees. Communication network 100 includes seed homes 111 and 115. Examples of seed homes include detached single-family homes, multi-dwelling units (MDUs), small/medium business (SMB), etc. where communication equipment nodes can be deployed on roof tops. Seed homes 111 and 115 host wireless point-to-point communication nodes 122 and 123. Wireless communication nodes 122 and 123 are capable of reception and transmission of high bandwidth (multiple gigahertz) signals operating at very high frequency (6Ghz ~100Ghz such as 28Ghz, V band, E band, etc.). Wireless communication nodes 122 and 123 consist of baseband/digital unit equipped with components including but not limited to processor, memory etc. Wireless communication nodes 122 and 123 also consist of RF unit and antenna unit. Antenna subsystem of wireless communication nodes 122 and 123 are capable of reception and transmission of directional signals where significant portion of the signal energy is concentrated within few degrees around the antenna boresight, both in vertical and horizontal direction, in contrast to omni directional antennas where signal energy is close to evenly spread across entire 360° degrees. Wireless communication node 121 residing in Tower/fiber access point location 101 and wireless communication node 122 residing in seed home 111 work in pair to form bi-directional high bandwidth communication point-to-point data link 141 that provides connectivity between Tower/fiber access point 101 and seed home 111 segment of the communication network 100. Similarly, wireless communication node 124 residing in Tower/fiber access point location 102 and wireless communication node 123 residing in seed home 115 work in pair to form bi-directional high bandwidth communication point-to-point data link 142

that provides connectivity between Tower/fiber access point 102 and seed home 115 segment of the communication network 100. Seed home 111, in addition to wireless communication node 122, hosts a second wireless communication node 131. Second wireless communication module 131 consists of multiple independent transmission/reception modules. Each module of the wireless communication node 131 is capable of reception and transmission of high bandwidth (multiple gigahertz) signals operating at very high frequency (6Ghz ~100Ghz such as 28Ghz, V band, E band, etc.). Each module of wireless communication node 131 contains of an independent baseband/digital unit equipped with components including but not limited to processor, memory etc. Each module in wireless communication node 131 also contains of an independent RF unit and independent antenna unit. Antenna subsystem of each wireless communication node 131's module is capable of reception and transmission of directional signals where significant portion of the signal energy is concentrated within few degrees around the antenna boresight, both in vertical and horizontal direction, in contrast to omni directional antennas where signal energy is close to evenly spread across entire 360° degrees. Communication network 100 also includes multiple anchor homes 112, 113 and 114. Each of these anchor homes hosts a wireless communication node similar to wireless communication node 131 described above. However, unlike seed homes, wireless communication node on anchor home only provide wireless connectivity to one or multiple anchor homes and/or seed homes but does not provide connectivity to the Tower/Fiber access point. For example, anchor home 112 hosts wireless communication node 132. One module of wireless communication node 132 residing in anchor home 112 and another module of wireless communication node 131 residing in seed home 111 work in pair to form bi-directional high bandwidth communication point-

to-point data link 151 that provides connectivity between seed home 111 and anchor home 112 segment of the communication network 100. Similarly, another module of wireless communication node 132 residing in anchor home 112 and a module of wireless communication node 133 residing in anchor home 113 work in pair to form bi-directional high bandwidth communication point-to-point data link 153 that provides connectivity between anchor home 112 and anchor home 113, another module of wireless communication node 132 residing in anchor home 112 and a module of wireless communication node 135 residing in seed home 115 work in pair to form bi-directional high bandwidth communication point-to-point data link 154 that provides connectivity between anchor home 112 and seed home 115, another module of wireless communication node 131 residing in seed home 111 and a module of wireless communication node 134 residing in anchor home 114 work in pair to form bi-directional high bandwidth communication point-to-point data link 152 that provides connectivity between anchor home 114 and seed home 111, another module of wireless communication node 134 residing in anchor home 114 and a module of wireless communication node 135 residing in seed home 115 work in pair to form bi-directional high bandwidth communication point-to-point data link 156 that provides connectivity between anchor home 114 and seed home 115. Bi-directional communication links 141, 142, 151, 152, 153, 154 & 155 shown in figure 1 can use various different multiple access schemes for transmission and reception including but not limited to frequency division multiple access (FDMA), time division multiple access (TDMA), single carrier FDMA (SC-FDMA), single carrier TDMA (SC-TDMA), code division multiple access (CDMA), orthogonal frequency division multiple access (OFDMA), non-orthogonal multiple access (NOMA) as described in various generations of communication

technologies including 1G, 2G, 3G, 4G, 5G and 6G etc. Bi-directional communication links 141, 142, 151, 152, 153, 154 & 155 formed by the pairs of communication nodes from the set including 121, 122, 123, 124, 131, 132, 133, 134 & 135 are capable of data information transfer via a variety of digital transmission schemes including but not limited to amplitude modulation (AM), phase modulation (PM), pulse amplitude modulation/quadrature amplitude modulation (PAM/QAM), ultra-wide band (UWB) pulse modulation (pico-second pulses), etc. In figure 1, two Tower/fiber access points 101 & 102, two seed homes 111 & 115 and three anchor homes 112, 113 & 114 and seven bi-directional point to point data links 141, 142, 151, 152, 153, 154 & 155 are shown to illustrate an example of a communication network. However, in general, communication network 100 can include different numbers of Tower/fiber nodes, seed homes, anchor homes and communication links depending on the specific layout of a particular instantiation of the communication network deployed in the field. Similarly, although, figure 1 shows four communication nodes 121, 122, 123 & 124 that provide connectivity between Tower/fiber access point and seed home, five communication nodes 131, 132, 133, 134 & 135 that provide connectivity between two anchor homes or between anchor and seed home, number of these communication nodes can vary from one communication network to another communication network based on the specific size and layout of a particular instantiation of the communication network. Communication network may also contain other nodes such as network switches/routers etc., that are omitted here for the sake of simplicity.

[00048] Referring to figure 2, one possible embodiment of wireless communication node 131 of figure 1 is shown labelled as 200. Wireless communication node 200 in figure 2 consists of a single module labelled as Module A. Module A

consists of base band unit or digital unit 201 which runs the physical layer level protocol including digital modulation/demodulation (modem) and other higher layer protocols such as MAC layer etc. Base band unit 201 interacts with other nodes of communication network that are external to the wireless communication node 200 via wired medium. Module A also includes RF unit 202 which among other things perform processing of intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received with the Module A, etc. RF unit 202 is capable of operating over a wide range of frequencies for example V band frequencies ranging from 57Ghz to 71 Ghz. Finally, module A also consist of antenna unit 203 which performs the transmission and reception of over the air radio signals. Antenna unit 203 is capable of transmitting and receiving extremely narrow beam of signals. Antenna unit 203 is constructed with metamaterials that have excellent properties of controlling the directionality of radio signals that cannot be exhibited by ordinary antennas. Module A with the help of antenna module 203 is capable of establishing point-to-point links with a different module residing in a different wireless communication node. Referring to figure 3, an example of an antenna pattern of Module A created by antenna unit 203 is shown. It can be seen from antenna pattern in figure 3 that beam width of antenna unit 203 of Module A is extremely narrow (less than a degree) and side lobes power levels start to drop at a rapid rate. Just 5~6 degrees from main lobe, power levels drop by more than 30dB. Antenna pattern of antenna unit 203 shown in figure 3 is just one example showing the extremely narrow beam antenna pattern generation capability of Module A. In other instances, due to change in antenna elements, size, frequency, etc.), different patterns are generated. In some embodiments, module A can be constructed using metamaterials described above. In some other embodiments, module A can be constructed using a

parabolic antenna or other types of antennas. However, the main characteristic of generation of extremely narrow antenna beam pattern generation is common to all the instances of module A.

[00049] Referring to figure 4, a point-to-point wireless communication link 400 established between two wireless communication nodes 401 and wireless communication node 402 is shown. Both wireless communication nodes 401 and 402 each host a single communication Module A as depicted in figure 2 and described above. Due to the antenna unit characteristics of Module A in wireless communication node 401 and 402, the bi-directional point-to-point link 400 has extremely narrow beam. This transmission and reception capability of radio signals over extremely narrow beam via this point-to-point link 400 provides interference immunity in scenarios where there are large number of wireless communication links established by multiple wireless communication nodes concentrated in a small area and operating in same frequency.

[00050] In another embodiment, Module A can additionally provide beam steerability characteristic in addition to the capability of transmission and reception of data over extremely narrow beams as explained above and illustrated in the context of figure 2, figure 3 and figure 4. Referring to figure 5, a wireless communication node 501 consisting of a single Module A, a second wireless communication node 502 consisting of a single Module A and third wireless communication node 503 consisting of a single Module A is shown. During time T1, Module A of wireless communication node 501 and Module A of wireless communication node 502 work in pair to establish extremely narrow beam based bi-directional link 500 for the exchange of information data between wireless communication nodes 501 and 502. Due to some trigger, Module A of wireless communication node 501 invokes the beam steering capability of the module and changes

the direction of the antenna transmission and reception beam towards wireless communication node 503 and works in pair with Module A of wireless communication node 503 to dynamically establish the bi-directional extremely narrow beam-based link 500 between wireless communication node 501 and wireless communication node 503 during time T2. Trigger for this beam steering can be due to changes in the link condition between wireless communication node 501 and wireless communication node 502 due to various factors including but not limited to change from LOS path to non-LOS path due to change in environment, increased interference, change in position of wireless communication node 502 with respect to wireless communication node 501, instructions from higher layers, etc. In one embodiment, wireless communication node 503 can be different than wireless communication node 502. In other embodiment, wireless communication node 503 can be same as wireless communication node 502 but with a different physical location.

[00051] In another embodiment, wireless communication nodes defined above and discussed in the context of figure 2, figure 3, figure 4 and figure 5 can host more than one Module A. This allows a wireless communication node to communicate simultaneously with multiple wireless communication nodes by establishing multiple extremely narrow beam bi-directional links with the help of multiple Module A belonging to different wireless communication nodes working in pair. Referring to figure 6, wireless communication nodes 601 and 602 each host two Module A, 1 and 2 while wireless communication nodes 603 and 604 each host single Module A. 1st Module A of wireless communication node 601 and 1st Module A of wireless communication node 602 work in pair to establish extremely narrow bi-directional beam-based link 600 to provide wireless connection between wireless communication node 601 and 602. Similarly, 2nd Module A

of wireless communication node 601 and 602 and 1st (and only) Module A of wireless communication node 603 and 604 respectively work in pair to establish extremely narrow bi-directional beam-based links 610 and 620 to provide wireless connection between wireless communication node pairs 601-603 and 602-604 respectively. In one embodiment, 1st and 2nd Module As of wireless communication nodes 601 and 602 can be inside same physical enclosure and in other embodiment 1st Module A of wireless communication nodes 601 and 603 be inside one physical enclosure and 2nd Module A of wireless communication nodes 601 and 603 be inside a different physical enclosure. In case of different Module As belonging to same wireless communication node contained in separate physical enclosures, these can be connected via wired link as they are co-located in same seed home or anchor home. In figure 6, a maximum of two Module As are shown to be contained in a wireless communication node that enables the wireless communication node to establish two independent bi-directional links with different wireless communication nodes simultaneously. However, wireless communication node can host more than two module As and the maximum number of Module As (greater than two) that a wireless communication node can host depends on the maximum total power available to the wireless communication node. In one embodiment, all Module As belonging to same wireless communication node operate on same carrier frequencies of a frequency band. In another embodiment, different Module As belonging to same wireless communication node operate on different carrier frequencies of a frequency band.

[00052] Referring to figure 7, another embodiment of wireless communication node 131 of figure 1 is shown labelled as 700. Wireless communication node 700 in figure 7 consists of a single module labelled as Module B. Module B consists of base band unit or digital unit 701 which runs the physical layer level protocol including digital

modulation/demodulation (modem) and other higher layer protocols such as MAC layer etc. Base band unit 701 interacts with other nodes of communication network that are external to the wireless communication node 700 via wired medium. Module B also includes RF unit 702 which among other things perform processing of intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received with the Module B, etc. RF unit 702 is capable of operating over a wide range of frequencies for example V band frequencies ranging from 57Ghz to 71 Ghz. Finally, module B also consists of antenna unit 703 which performs the transmission and reception of over the air radio signals. Antenna unit 703 is an active antenna system (AAS) that consists of phased array of transmitters and receivers that are capable of doing beamforming and creating multiple beams simultaneously in different directions. By virtue of simultaneous creation of multiple beams in different direction, AAS system of antenna unit 703 enables the wireless communication node 700 to establish point-to-multipoint wireless communication links with multiple wireless communication nodes. Hence Module B with the help of antenna unit 703 is capable of establishing point-to-multipoint links with a different module residing in a different wireless communication node. Referring to figure 7, Module B residing in wireless communication node 700 is shown to create 1 to N multiple beams with the help of AAS of antenna unit 703. Value N depends on number of transmit and received antennas in AAS of antenna unit 703. Specifically, it can be seen that wireless communication unit 700 is connected to wireless communication unit 710, wireless communication unit 720 and wireless communication unit 7N0 via bi-directional beam 1, beam 2 and beam N respectively. It can also be seen from antenna pattern in figure 7 that beam width of point-to-multipoint beams of antenna unit 703 of Module B are not extremely narrow

(e.g. 3dB beam width of 7~10 degree) and side lobes power levels **don't** start to drop at a rapid rate which is in contrast to antenna pattern of antenna unit belonging to Module A described above and discussed in the context of figure 2 to figure 6.

[00053] Referring again to figure 7, Module B of wireless communication node 700 also differs from Module A (discussed above in the context of figures 2-6) with respect to the limitation of all the multiple bi-directional links to be operated in a single frequency range at one time. For example, signal beams 1 to N that connect wireless communication node 700 to wireless communication nodes 710 to 7N0 respectively can only operate within a same frequency range at one instant of time. It is to be noted that at a different time instant, all beams 1 to N can switch to operate at a frequency range different from the frequency range used in the previous time instant, however, frequency range of an individual beam remains same as the frequency range of all the other N-1 beams at a given instant. Hence, Module B although due to phased antenna arrays can create multiple beams to create point-to-multi point links to connect one wireless communication node with multiple wireless communication nodes as shown in figure 7, interference profile at the receiver side with such point-to-multipoint network is inferior to interference profile of point-to-multiple point network where a wireless communication node hosts multiple Module A and create multiple point-to-point links as shown in figure 6 where wireless communication node 601 uses two Module A to connect to wireless communication node 602 and wireless communication node 603 simultaneously. The main reasons of high interference with Module B is due to 1) individual phased antenna array-based beams not narrow as extremely narrow beams generated by metamaterial-based antenna of Module A and 2) all beams of Module B belonging to one wireless communication unit cannot operate at different frequency

ranges unlike multiple point-to-point narrow beams of wireless communication node that host multiple Module A.

[00054] Referring to figure 8, another possible embodiment of wireless communication node 131 of figure 1 is shown labelled as 800 and 810. Wireless communication node 800 in figure 8 consists of a single module labelled as Module C. Module C consists of base band unit or digital unit which runs the physical layer level protocol including digital modulation/demodulation (modem) and other higher layer protocols such as MAC layer etc. Module C's baseband unit of wireless communication node 800 interacts with other nodes of communication network that are external to the wireless communication node 800 via wired medium. Module C also includes ultra-wide band antenna embedded with the baseband unit. Module C is capable of generation, transmission and reception of extremely short duration pulse (few pico seconds long) and uses pulse modulation (and its variations such as pulse amplitude modulation, etc.) to transmit data at extremely high rate such as greater than 100Gbps by transmitting signals over a very wide range of frequencies. In one embodiment, pulses used for communication by Module C can use frequencies ranging from few hundred megahertz to few hundred gigahertz. In a different embodiment, range of frequencies used by pulses generated by Module C of wireless communication unit 800 can take a different range. The fundamental characteristic of signals generated by Module C that is different from signals generated by Module A and Module B is that these signals are ultra wide band signals and their power spectral density over the entire range of frequencies is very low. Hence these UWB signals do not create interference with other signals operating on a narrow band of frequencies as these UWB signals are treated as noise by receivers of normal wireless communication nodes. Figure 8 shows that Module C of wireless

communication node 800 and Module C of wireless communication unit 810 establish a link 801 by working in pair. As explained above, such a communication link 801 operates over an ultra-wide range of frequencies. However, even in the presence of other wireless communication nodes (not shown in figure 8) such as wireless communication nodes with Module A or Module B that operate on a narrow band of frequencies compare to Module C of wireless communication node 800, performance of network is not impacted as power spectral density over the frequency range of communication link 801 that overlaps with frequency ranges on which a nearby wireless communication node using narrow band signals using for example Module A and/or Module B operates is very low and is treated as noise by the receivers of Module A and/or Module B.

[00055] In another preferred embodiment, wireless communication nodes 131 in figure 1 can host two types of modules. This allows a wireless communication node to communicate simultaneously with multiple wireless communication nodes and with two different interference profiles. Referring to figure 9, wireless communication node 910 hosts one Module A and one Module B. Module A of wireless communication node 910 and a communication module of wireless communication node 920 work in pair to establish extremely narrow bi-directional beam-based link 901 to provide wireless connection between wireless communication nodes 910 and 920. Simultaneously, Module B of wireless communication node 910 which is based on AAS and generates multiple beams simultaneously creates a point-to-multipoint link that connects wireless communication node 910 with wireless communication nodes 930, 940, 950 and 960. Specifically, Module B of wireless communication node 910 coordinates with, module of wireless communication node 930 to establish bi-directional beam 902, module of wireless communication node 940 to establish bi-directional beam 903, module of

wireless communication node 950 to establish bi-directional beam 904 and module of wireless communication node 960 to establish bi-directional beam 905. In one embodiment, extremely narrow beam 901 and group of beams including 902, 903, 904 and 905 all operate on same range of carrier frequencies at same time. In another embodiment, extremely narrow beam 901 operates on a different range of frequencies compared to range of frequencies used by group of beams including 902, 903, 904 and 905 at the same time.

[00056] In one embodiment, Module A and Module B of wireless communication node 910 can be inside same physical enclosure and in other embodiment Module A and Module B of wireless communication node 910 can be inside two separate physical enclosures. In case of Module A and Module B belonging to same wireless communication node contained in separate physical enclosures, these can be connected via wired link as they are co-located in same seed home or anchor home. In figure 9, a maximum of two modules i.e. a single Module A and a single Module B are shown to be contained in a wireless communication node 910 that enables the wireless communication node to establish two independent and different types of bi-directional links with different wireless communication nodes simultaneously. However, wireless communication node 910 can host more than two module such as multiple Module A and single Module B or multiple Module B and single Module A or a different combination of number of Module A and Module B and the maximum number of total modules that a wireless communication node can host depends on the maximum total power available to the wireless communication node. In one embodiment, all modules belonging to same wireless communication node operate on same carrier frequencies of a frequency band. In

another embodiment, different modules belonging to same wireless communication node operate on different carrier frequencies of a frequency band.

[00057] In another preferred embodiment, wireless communication nodes 131 in figure 1 can host more than one type of modules. This allows a wireless communication node to communicate simultaneously with multiple wireless communication nodes and with different interference profiles. Referring to figure 10, wireless communication node 1010 hosts one Module C and one Module B. Module C of wireless communication node 1010 and Module C of wireless communication node 1020 work in pair to establish extremely high data rate ultra-wide frequency low power spectral density beam-based link 1001 to provide wireless connection between wireless communication nodes 1010 and 1020. Simultaneously, Module B of wireless communication node 1010 which is based on AAS and generates multiple beams simultaneously creates a point-to-multipoint link that connects wireless communication node 1010 with wireless communication nodes 1030, 1040, 1050 and 1060. Specifically, Module B of wireless communication node 1010 coordinates with, module of wireless communication node 1030 to establish bi-directional beam 1002, module of wireless communication node 1040 to establish bi-directional beam 1003, module of wireless communication node 1050 to establish bi-directional beam 1004 and module of wireless communication node 1060 to establish bi-directional beam 1005.

[00058] In one embodiment, Module C and Module B of wireless communication node 1010 can be inside same physical enclosure and in other embodiment Module C and Module B of wireless communication node 1010 can be inside two separate physical enclosures. In case of Module C and Module B belonging to same wireless communication node contained in separate physical enclosures, these can be connected

via wired link as they are co-located in same seed home or anchor home. In figure 10, a maximum of two modules i.e. a single Module C and a single Module B are shown to be contained in a wireless communication node 1010 that enables the wireless communication node to establish two independent and different types of bi-directional links with different wireless communication nodes simultaneously. However, wireless communication node 1010 can host more than two types of module such as a single Module C, single Module A and a single Module B or a different combination of number of Module A, Module B and Module C and the maximum number of total modules that a wireless communication node can host depends on the maximum total power available to the wireless communication node. In one embodiment, all modules belonging to same wireless communication node operate on same carrier frequencies of a frequency band. In another embodiment, different modules belonging to same wireless communication node operate on different carrier frequencies of a frequency band.

[00059] In another preferred embodiment, wireless communication nodes 131 in figure 1 can host more than one type of modules and dynamically change type of links between wireless communication nodes they are connected with. This allows a wireless communication node to communicate simultaneously with multiple wireless communication nodes and with different interference profiles and to adapt with changes in network environment. Referring to figure 11, wireless communication node 1110 hosts single Module C or Module A and a single Module B. During time T1, Module A/Module C of wireless communication node 1110 and communication module of wireless communication node 1010 work in pair to establish either an extremely high data rate ultra-wide frequency low power spectral density beam or extremely narrow beam-based link 1101 to provide wireless connection between wireless communication

nodes 1110 and 1120. Simultaneously, at the same time duration T1, Module B of wireless communication node 1110 which is based on AAS and generates multiple beams simultaneously creates a point-to-multipoint link that connects wireless communication node 1110 with wireless communication nodes 1130, 1140, 1150 and 1160. Specifically, Module B of wireless communication node 1110 coordinates with, module of wireless communication node 1130 to establish bi-directional beam 1102, module of wireless communication node 1140 to establish bi-directional beam 1103, module of wireless communication node 1150 to establish bi-directional beam 1104 and module of wireless communication node 1160 to establish bi-directional beam 1105. At a different time T2, due to some trigger, Module A/Module C of wireless communication node 1110 dynamically switches its wireless link from wireless communication node 1120 to wireless communication node 1140 by steering the beam towards wireless communication node 1140. At the same time or after receiving instructions from higher layer, Module B of wireless communication node 1110 disconnects its link with wireless communication node 1140 via beam 1103 and generates a new beam 1101 in the direction of wireless communication node 1120 and establishes connection with wireless communication node 1120. Trigger for this beam steering can be due to changes in the link condition between wireless communication node 1110 and wireless communication node 1120 or 1140 due to various factors including but not limited to change from LOS path to non-LOS path due to change in environment, increased interference, change in position of wireless communication node 1120 or 1140 with respect to wireless communication node 1110, instructions from higher layers, etc. In figure 11, dynamic link switching occurs between wireless communication nodes 1110, 1120 and 1140. However, dynamic switching can also occur between a different communication of nodes.

It may also happen that one or multiple wireless communication nodes leave the communication network. In such case, such links between nodes are dropped and communication network dynamically re-aligns its self by adjusting/switching links types between the remaining number of wireless communication nodes in the communication network to best suit the needs to the wireless communication nodes and communication network. In some embodiments, wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can host multiple modules of same or different types. For example, one, some or each one of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can host one Module A and one Module B. Hence, when wireless communication node 1110 makes a point-to-point link using its Module A or Module C with first communication modules (Module A or C) of wireless communication nodes 1120, 1130, 1140, 1150 and 1160, then the other Module B of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-multipoint wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here. Similarly, when wireless communication node 1110 makes a point-to-multipoint links using its Module B with first communication modules (Module A or C) of wireless communication nodes 1120, 1130, 1140, 1150 and 1160, then the other Module B of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-multipoint wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here. In another embodiment, one, some or each one of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can host two Module A or Module C. Hence, when wireless communication node 1110 makes a point-to-point link using its Module A or Module C with first Module A or C of wireless communication nodes 1120, 1130, 1140, 1150 and

1160, then the other Module A or Module C of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-point wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here. Similarly, when wireless communication node 1110 makes a point-to-multipoint links using its Module B with first communication modules (Module A or C) of wireless communication nodes 1120, 1130, 1140, 1150 and 1160, then the other Module A or C of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-point wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here. In another embodiment, wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can host multiple Module A or Module C and Module B. For example, one, some or each of wireless communication node 1120, 1130, 1140, 1150 and 1160 can host two Module A or Module C and one Module B. Hence, when wireless communication node 1110 makes a point-to-point link using its Module A or Module C with first Module A or C of wireless communication nodes 1120, 1130, 1140, 1150 and 1160, then the other Module A or Module C of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-point wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here and third Module B of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-multipoint wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here. Similarly, when wireless communication node 1110 makes a point-to-multipoint links using its Module B with first communication modules (Module A or C) of wireless communication nodes 1120, 1130, 1140, 1150 and 1160, then the other Module A or C of

wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-point wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here and third Module B of wireless communication nodes 1120, 1130, 1140, 1150 and 1160 can simultaneously create point-to-multipoint wireless communication links with other modules of wireless communication nodes in the mesh network that are not shown here.

[00060] It is to be noted that wireless communication links established by Module A or Module C have high reliability due to interference immunity either due to extremely narrow beams or due to transmission of data over ultra-high bandwidth. These features make these links more suitable to carry control information and data for multiple or all users of the wireless communication network mesh. Hence links established by Module A or Module C can act as wireless backhaul for the network mesh while links established with Module B can provide access to individual users of the communication network.

[00061] In one embodiment, entire wireless mesh can be composed of point-to-point links where both links providing backhaul and access have interference immunity. Such links although are more expensive due to the requirement of separate modules to establish individual links but suitable when certain high service quality or reliability is required to be ensured for all customers of the network. For example, figure 12 shows a location 1200 of a communication network that can be a seed or an anchor home. Location 1200 hosts a wireless communication node 1201 that contains a total of 6 communication modules that belong to either Module A or Module C class. Hence this wireless communication node is capable of establishing six point-to-point links. Wireless communication node 1201 uses 1st and 4th Module A/ Module C to establish connections with location 1210 and location 1260 respectively that serve as backhaul links while

wireless communication node 1201 uses 2nd, 3rd, 5th and 6th Module A/Module C to establish point-to-point links with location 1220, 1230, 1250 and 1240 respectively to provide access links. In other words, links between locations 1200-1220, locations 1200-1230, locations 1200-1240 and locations 1200-1250 only carry data for individual users, whereas links between locations 1200-1260 and locations 1200-1210 carry signaling and data for all the locations including 1200, 1210, 1220, 1230, 1240, 1250 and 1260.

[00062] In another embodiment, entire wireless mesh can be composed of combination of point-to-point links and point-to-multipoint links where point-to-point links act as backhaul links and point-to-multipoint links act as access links to individual users. Such wireless mesh network due to presence of point-to-multipoint links although does provide interference immunity to all the users of the communication network but are less expensive due to the non-requirement of separate modules to establish individual links. For example, figure 13 shows a location 1300 of a communication network that can be a seed or an anchor home. Location 1300 hosts a wireless communication node 1301 that contains a total of 4 communication modules that belong to either Module A/ Module C or Module B class. Hence this wireless communication node is capable of establishing two point-to-point links and two point-to-multipoint links. Wireless communication node 1301 uses 1st and 4th Module A/ Module C to establish connections with location 1310 and location 1360 respectively that serve as backhaul links while wireless communication node 1301 uses 2nd Modules B to establish point-to-multipoint links with locations 1320, 1330, and used 3rd Module B to establish point-to-multipoint links with locations 1350 and 1340 respectively to provide access links. In other words, links between locations 1300-1320, locations 1300-1330, locations 1300-1340 and locations 1300-1350 only carry data for individual users, whereas links between locations 1300-1360 and locations

1300-1310 carry signaling and data for all the locations including 1300, 1310, 1320, 1330, 1340, 1350 and 1360.

[00063] Referring to figure 14, another possible embodiment of wireless communication node 131 of figure 1 is shown labelled as 1400. Wireless communication node 1400 in figure 14 consists of a single module labelled as Module D. Module D consists of base band unit or digital unit 1401 which runs the physical layer level protocol including digital modulation/demodulation (modem) and other higher layer protocols such as MAC layer etc. Base band unit 1401 interacts with other nodes of communication network that are external to the wireless communication node 1400 via wired medium. Module D also includes RF unit 1402 which among other things perform processing of intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received with the Module D, etc. RF unit 1402 is capable of operating over a wide range of frequencies for example 5Ghz band frequencies ranging from 5 Ghz to 6 Ghz. Finally, module D also consist of antenna unit 1403 which performs the transmission and reception of over the air radio signals. Antenna unit 1403 is capable of transmitting and receiving extremely narrow beam of signals. Antenna unit 1403 is constructed with either 1 dimensional or 2-dimentional antenna element arrays that have excellent properties of controlling the directionality of radio signals using beam forming and can propagate even in a non-line of sight environment. Module D with the help of antenna module 1403 is capable of establishing point-to-multipoint links with tower capable of performing massive MIMO (multiple input multiple output) beams. In one embodiment, Module D can be designed and manufactured at least in part using ASIC (Application specific integrated circuit) and integrated RF unit called RFIC. Referring to figure 15, an example of multiple Module Ds connected to a tower 1500 is

shown. Specifically, wireless communication node 1501 hosting a Module D described above is connected to tower 1500 via massive MIMO beam link 1510 that can be both line-of-sight and non-line-of-sight, wireless communication node 1502 hosting a Module D described above is connected to tower 1500 via massive MIMO beam link 1520 that can be both line-of-sight and non-line-of-sight and a third wireless communication node 1503 hosting a Module D described above is connected to tower 1500 via massive MIMO beam link 1530 that can be both line-of-sight and non-line-of-sight. The tower 1500 is equipped with a Massive MIMO module can create multiple bi-directional narrow beam links simultaneously in all direction covering entire 360 degrees of coverage area. In one embodiment, tower 1500 can operate in 5Ghz band including frequencies ranging from 5000Mhz to 6000Mhz. In other embodiments, tower 1500 and associated wireless communication nodes 1501, 1502 and 1503 can operate on a different frequency band. Figure 15 shows only one tower and just three wireless communication nodes hosting Module D in the network. However, a network can have multiple towers similar to 1500 and these towers can each be connected to a large number of wireless communication nodes providing these nodes host beside other modules a Module D. The route that a particular packet takes from source to destination is dynamically selected based on factors including but not limited to link quality, loading, latency etc. For example, referring to figure 16 that shows and communication system 1600 that is similar to communication system 100 and has all the components described originally in the context of figure 1. Additionally, system 1600 of figure 16 includes a tower 1610 which is similar to tower 1500 described in the context of figure 15. In contrast to communication system 100 in figure 1, wireless communication nodes 131, 132, 133, 134 and 135 host an additional Module D besides Module A/Module B or Module C that enables these

wireless communication nodes to optionally establish bi-directional links with features described in the context of figure 14 and 15 with tower 1610 using massive MIMO beamforming capabilities. Such links labelled as 1601, 1602, 1603, 1604 and 1605 can work in both line-of-sight and non-line of sight environment and can provide alternate communication path to wireless communication nodes 131, 132, 133, 134 and 135 in an event where point-to-point or point-to-multipoint links that connect one wireless communication node to a peer wireless communication node to form a mesh network fails or experience performance degradation due to various reasons including but not limited to change on the line-of-sight profile of millimeter wave link between two wireless communication nodes. In figure 16, only 1 tower 1610 capable of massive MIMO point-to-multipoint communication is shown to be connected to five wireless communication nodes 131-135. However, in general, a communication system can also have a different number of towers each connected to multiple different wireless communication nodes provided those wireless communication nodes host beside other modules at least one Module D. In areas within tower 1500 (and other towers of same type) coverage area, communication network can initially start in a point-to-multipoint manner where tower 1500 (and other towers of same type) providing access to individual customers using sub 6Ghz massive MIMO point-multipoint beams. Later, nodes in the network can opportunistically connect with other nodes using regular modules (e.g. Module A/Module B/Module C) in the presence of line-of-sight. This way, network evolves into mesh network with point-to-point and point-to-multipoint connection between nodes in addition to each communication node having a path directly (non-line-of-sight) to tower 1500 (and other towers of same type) that fall within the coverage area. A route that a packet takes from source to destination in this network is

optimized by considering various factors including latency, congestion, reliability etc. Communication network can later also add seed homes such as 111 and 115 in figure 1 along with tower/fiber access points 101 and 102 to provide alternate backhaul as per need basis.

[00064] In another embodiment, instead of providing massive MIMO point-to-multipoint networking capability using a terrestrial tower, point to multipoint massive MIMO capability to networks wireless communication nodes can also be provided by a satellite for example a low earth orbit (LEO) satellite. For example, referring to figure 17 that shows and communication system 1700 that is similar to communication system 100 and has all the components described originally in the context of figure 1. Additionally, system 1700 of figure 17 includes a satellite 1710 which is capable of doing massive MIMO transmission and reception on frequencies including but not limited to 5-6Ghz similar to tower 1500 described in the context of figure 15. In contrast to communication system 100 in figure 1, wireless communication nodes 131, 132, 133, 134 and 135 host an additional Module D besides Module A/Module B or Module C that enables these wireless communication nodes to optionally establish bi-directional links with features described in the context of figure 14 and 15 with satellite 1710 using massive MIMO beamforming capabilities. Such links labelled as 1701, 1702, 1703, 1704 and 1705 can provide alternate communication path to wireless communication nodes 131, 132, 133, 134 and 135 in an event where point-to-point or point-to-multipoint links that connect one wireless communication node to a peer wireless communication node to form a mesh network fails or experience performance degradation due to various reasons including but not limited to change on the line-of-sight profile of millimeter wave link between two wireless communication nodes. In figure 17, only one satellite 1710 capable of massive

MIMO point-to-multipoint communication is shown to be connected to five wireless communication nodes 131-135. However, in general, a communication system can also have a different number of satellites each connected to multiple different wireless communication nodes provided those wireless communication nodes host beside other modules at least one Module D.

[00065] In another embodiment, some of the wireless communication nodes that provide backhaul functionality can be equipped with multiple communication modules that enables these wireless communication nodes to provide transport backhaul data between end user and the network using multiple different types of communication links. For example, referring to figure 18 that shows and communication system 1800 that is similar to communication system 100 and has all the components described originally in the context of figure 1. Additionally, system 1800 of figure 18 includes a satellite 1810 which is capable of doing massive MIMO transmission and reception on frequencies including but not limited to 5-6Ghz similar to tower 1500 described in the context of figure 15 along with a massive MIMO cable tower 1820 which is also similar to tower 1500 described in the context of figure 15. In contrast to communication system 100 in figure 1, wireless communication nodes 131, 132, 133, 134 and 135 host an additional Module D besides Module A/Module B or Module C that enables these wireless communication nodes to optionally establish bi-directional links with features described in the context of figure 14 and 15 with satellite 1810 and tower 1820 using massive MIMO beamforming capabilities. Such links labelled as 1801, 1802, 1803 and 1804 can provide alternate communication path to wireless communication nodes 131, 132, 133, 134 and 135 in an event where point-to-point or point-to-multipoint links that connect one wireless communication node to a peer wireless communication node to form a mesh

network fails or experience performance degradation due to various reasons including but not limited to change on the line-of-sight profile of millimeter wave link between two wireless communication nodes. Specifically, satellite 1810 in figure 18 is connected to seed home 115 using wireless communication node 135 via link 1804 and to anchor home 112 using wireless communication node 132 via link 1803. Seed home 115 thus has multiple options to route backhaul traffic to the network. In one embodiment, seed home 115 using wireless communication node 135 at one time can pick a satellite link 1804 to transport backhaul data and based on some trigger at a different time instruct wireless communication module 135 to switch links for backhaul data transmission from 1804 to a point-to-point or point-to-multipoint millimeter wave (e.g. E-band) based links to tower/fiber access point 102. Such trigger includes but not limited to latency, bandwidth, packet loss requirements, etc. of a particular application. Figure 18 also shows a end user home 113 where wireless communication node 133 transports the data using anchor home 112's wireless communication node 132. Wireless communication node 132 is shown to have multiple options to transport end user data of home 113 including direct satellite link connection using 1803, in-direct satellite link connection using 1804 via anchor node 135 or through point to point/ point-multi-point connections using millimeter wave through towers 101 or 102 via seed homes 111 and 115 respectively besides other options. In one embodiment, wireless communication node 132 can dynamically switch connection link it uses to route packets/data to and from end user home 113. For example, due to some trigger similar to triggers described above, wireless communication node 132 can dynamically switch from satellite link 1803 to satellite link 1804 via wireless communication node 135 to transport data to and from end user home 113. Links 1803 and 1804 can be part of same massive MIMO beam or links 1803 and

1804 can be part of different massive MIMO beams. Satellite links 1802 and 1804 can use same frequency range of communications or these can be operating on different frequency ranges. In figure 18, only one satellite 1810 capable of massive MIMO point-to-multipoint communication is shown to be connected to two wireless communication nodes 132 and 135. However, in general, a communication system can also have a different number of satellites each connected to multiple different wireless communication nodes provided those wireless communication nodes host beside other modules at least one Module D.

[00066] Additionally, tower 1820 in figure 18 is connected to seed home 111 using wireless communication node 135 via link 1804 and to anchor home 112 using wireless communication node 131 via link 1801 and to anchor home 114 using wireless communication node 134 via link 1802. This provides anchor home 114 to route packets to the network in multiple ways including a) through point-to-point or point-to-multipoint millimeter wave-based links 152 or 155 and b) via direct massive MIMO based link to tower 1820 via link 1802. Similarly, seed home 111 has multiple options to route backhaul traffic to the network. In one embodiment, seed home 111 using wireless communication node 131 at one time can pick a satellite link 1801 to transport backhaul data and based on some trigger at a different time instruct wireless communication module 131 to switch links for backhaul data transmission from 1801 to a point-to-point or point-to-multipoint millimeter wave (e.g. E-band) based links to tower/fiber access point 101. Such trigger includes but not limited to latency, bandwidth, packet loss requirements, etc. of a particular application. In figure 18, only one tower 1820 capable of massive MIMO point-to-multipoint communication is shown to be connected to two wireless communication nodes 131 and 134. However, in general, a communication

system can also have a different number of massive MIMO towers each connected to multiple different wireless communication nodes provided those wireless communication nodes host beside other modules at least one Module D.

[00067] In another embodiment, some or every single wireless communication node described above and discussed with the aid of the figures 1-18 in this disclosure can additionally be an edge computing node by hosting a processor (separate or shared), memory, digital contents, software, etc. and other components for computing, storage and other required operations for edge computing in addition to the high speed low latency networking capability that has already been described above. This enables communication system to provide cloud services in a distributed manner closer to the end user as wireless communication nodes are distributed across the network and provide interface between the network and the end-user. This memory unit can store a copy of local digital contents and can additionally store a copy of portion of digital content that that are not local. The non-local digital contents amongst other things can include digital contents belonging to other nodes. This provides content redundancy in the communication system. Hence, when an end user of a communication system requests for a digital content or data, then this edge computing mechanism allows request to be fulfilled in a variety of different ways including request processed by a local node and/or remote node based various criteria including but not limited to latency, network congestion, etc. of the application making the request.

[00068] Current wireless mesh system design using line-of-sight based point-to-point or point-to-multipoint links exhibit many shortcomings, including failing to account for a way to limit the maximum number of hops required to connect end user to fiber PoP (or core network) other than constraining the wireless mesh network to an area within a

certain maximum distance from fiber PoP. Limiting the maximum number of hops between end-user and fiber PoP ensures that packet latency doesn't exceed beyond a certain threshold which may be required for certain real-time applications. Thus, there exists need in the art for improved systems and methods relating to wireless communication network design and operation where wireless mesh network can be extended to regions that are far distance from fiber PoP yet end-user's packet latency remains within certain threshold value. Referring to figure 19, a data communication network capable of providing multigigabit internet speeds through wireless point-to-point and point-to-multipoint links is illustrated. Communication network 100 in figure 19 includes Tower/ fiber access points 101 and 102. Tower/fiber access points 101 and 102 can be co-located or can be located at different physical locations. Tower/fiber access points 101 and 102 have access to high bandwidth dark fiber capable of providing up to several hundred gigabits/second of data throughput. Tower/fiber access points provide backhaul connectivity between the core network/data center (not shown in the figure 19 for the sake of simplicity) and seed home of the communication network described below. Tower/Fiber access points 101 and 102 host hardware equipment that establish wireless point-to-point connectivity with communication nodes 103 and 106 respectively. Specifically, fiber PoP 101 is connected to wireless communication node 103 via the long hop link 120 that is capable of operating on of high bandwidth (multiple gigahertz) signals operating at very high frequency (6Ghz ~100Ghz such as 28Ghz, V band, E band, etc.). Similarly, fiber PoP 102 is connected to wireless communication node 106 via the long hop link 124 that is capable of operating on of high bandwidth (multiple gigahertz) signals operating at very high frequency (6Ghz ~100Ghz such as 28Ghz, V band, E band, etc.). In addition, wireless communication node 103 is connected to wireless

communication node 104 via long hop link 121, wireless communication node 104 is connected to wireless communication node 105 via long hop link 122, and finally wireless communication node 105 is connected to wireless communication node 106 via long hop link 123 as shown in figure 19. The long hops link 120, 121, 122, 123 and 124 have longer length compare to short hop links. For example, in one embodiment, longer hop links can have 500~600meter length. In a different embodiment, long hops links can be shorter of longer than 500~600 meters. Communication network 100 also consists of a number of short hops as shown in figure 19. Specifically, wireless communication node 103 is connected with wireless communication node 107 via the short hop link 125, wireless communication node 107 is connected with wireless communication node 108 via short hop link 126, wireless communication node 108 is connected with wireless communication node 109 via short hop link 127, wireless communication node 109 is connected with wireless communication node 110 via short hop link 128, wireless communication node 110 is connected with wireless communication node 111 via short hop link 129 and finally wireless communication node 111 is connected with wireless communication node 104 via short hop link 130 to close the zic-zac path of short hop links that originated from wireless communication node 103 and ended at wireless communication node 104. Similarly, figure 19 shows that wireless communication node 104 is connected with wireless communication node 112 via short hop link 131, wireless communication node 112 is connected with wireless communication node 113 via short hop link 132, wireless communication node 113 is connected with wireless communication node 114 via short hop link 133, wireless communication node 114 is connected with wireless communication node 115 via short hop link 134, and finally wireless communication node 115 is connected with wireless communication node 105

via short hop link 135 to close the path of short hop links that originated from wireless communication node 104 and ended at wireless communication node 105. Similarly, figure 19 shows that wireless communication node 105 is connected with wireless communication node 116 via short hop link 136, wireless communication node 116 is connected with wireless communication node 117 via short hop link 137, wireless communication node 117 is connected with wireless communication node 118 via short hop link 138, wireless communication node 118 is connected with wireless communication node 119 via short hop link 139, and finally wireless communication node 119 is connected with wireless communication node 106 via short hop link 140 to close the path of short hop links that originated from wireless communication node 104 and ended at wireless communication node 105. The path of short hop links that connects wireless communication node 103 to wireless communication node 104 is shown to consist of 5 intermediary wireless communication nodes 107-111 and 6 short hop links 125-130. Similarly, path of short hop links that connect wireless communication node 104 to 105 and 105 to 106 each consists of 4 intermediary wireless communications nodes and 5 short hop links. However, in general, wireless communication system 100 can have any number of intermediary nodes in the path of short hop links that connect two wireless communication nodes that are already connected directly to each other via long hop link.

[00069] It is to be noted here that use of long hop links in combination with short hop links greatly reduce the maximum number of hops the data packets need to pass in order to transport packet between end user and fiber PoP. For example, consider end user associated with wireless communication node 113. In the absence of long hop links 121, 122 and 123, data packet originated from end-user connected with wireless

communication node 113 would pass through a large number of intermediary wireless communication nodes or hops. In the event, where a packet needs to be transmitted between fiber PoP 101 and wireless communication node 113, packet would go through 8 intermediary nodes including 112, 104, 111, 110, 109, 108, 107, and 103 for scenario with no long hop links in the mesh network. However, as shown in the figure 19, in the presence of long hop links, packet would only go through 3 nodes including 112, 104 and 103 as wireless communication nodes 103 and 104 are directly connected via long hop link 121. This greatly reduces the latency or packet delay as packet delay as latency increases linearly with the increasing number of intermediary nodes. Above example shows how end-user associated with wireless communication node 113 can benefit from presence of long hop links for improving the latency or packet delay. However, in general a large number of wireless communication nodes especially the ones that are indirectly connected to wireless communication nodes with long hop links can get benefit of improved network latency or packet delay with such wireless mesh network design. In addition, presence of long hop links improves the reliability of the network by increasing the number of available wireless mesh network paths between the source and the destination. For example, end user associated with wireless communication node 113 can take A) path consisting of intermediary nodes $112 \leftrightarrow 104 \leftrightarrow 103 \leftrightarrow 101$, B) path consisting of intermediary nodes $112 \leftrightarrow 104 \leftrightarrow 111 \leftrightarrow 110 \leftrightarrow 109 \leftrightarrow 108 \leftrightarrow 107 \leftrightarrow 103 \leftrightarrow 101$, C) path consisting of intermediary nodes $114 \leftrightarrow 115 \leftrightarrow 105 \leftrightarrow 106 \leftrightarrow 102$, D) path consisting of intermediary nodes $114 \leftrightarrow 115 \leftrightarrow 105 \leftrightarrow 116 \leftrightarrow 117 \leftrightarrow 118 \leftrightarrow 119 \leftrightarrow 106 \leftrightarrow 102$ to connect to the core network. These alternative paths increase reliability of the overall network. For

example, in the event of short hop link 125 failure, option B described above for end user of wireless communication node 113 will fail however, other options including A, C and D will still work and can be used to transfer packets or traffic between wireless communication node 113 and core network.

[00070] Bi-directional communication links 120 to 140 shown in figure 19 can use various different multiple access schemes for transmission and reception including but not limited to frequency division multiple access (FDMA), time division multiple access (TDMA), single carrier FDMA (SC-FDMA), single carrier TDMA (SC-TDMA), code division multiple access (CDMA), orthogonal frequency division multiple access (OFDMA), non-orthogonal multiple access (NOMA) as described in various generations of communication technologies including 1G, 2G, 3G, 4G, 5G and 6G etc. Bi-directional communication links 120 to 140 formed by the pairs of communication nodes from the set including 101 to 119 are capable of data information transfer via a variety of digital transmission schemes including but not limited to amplitude modulation (AM), phase modulation (PM), pulse amplitude modulation/quadrature amplitude modulation (PAM/QAM), ultra-wide band (UWB) pulse modulation (pico-second pulses), etc. In figure 1, two Tower/fiber access points (PoP) 101 & 102, 5 long hop bi-directional links 120-124 and 16 bi-directional point to point short hop links 125-140 are shown to illustrate an example of a communication network. However, in general, communication network 100 can include different numbers of Tower/fiber nodes (PoP), long hop links, short hop communication links depending on the specific layout of a particular instantiation of the communication network deployed in the field. Communication network may also contain other nodes such as network switches/routers etc., that are omitted here for the sake of simplicity.

[00071] Referring to figure 20, a different layout of wireless communication network consisting of long hop links and short hops links described above is shown. Specifically, figure 20 shows a fiber PoP node 201 and a number of segments of long hop links originating from the fiber PoP 201 in the shape of wheel spokes along with wireless communication nodes interconnected via short hop links. For example, a long hop links 242 and 243 that connect the nodes 201 to 206 and 206 to 207 respectively form a segment of long hop links (1st spoke). Similarly, long hop links 244 and 245 that connect the node 201 to 208 and 208 to 209 respectively form another segment of long hop links (2nd spoke). Likewise, long hop links 246 and 247 that connect the node 201 to 210 and 210 to 211 respectively form another segment of long hop links (3rd spoke). In the same manner, long hop links 248 and 249 that connect the node 201 to 213 and 213 to 212 respectively form another segment of long hop links (4th spoke). Similarly, long hop links 238 and 239 that connect the node 201 to 202 and 202 to 203 respectively form another segment of long hop links (5th spoke). Similarly, long hop links 240 and 241 that connect the node 201 to 204 and 204 to 205 respectively form another segment of long hop links (6th spoke). The different spokes that are formed from segments of long hop links are also interconnected via long hop links. For example, 1st spoke and 2nd spoke are connected via long hop link 281. Similarly, 3rd and 4th spokes are connected via long hop link 282 and spokes 5 and 6 are interconnected via long hop link 280 as shown in figure 2. Figure 20 shows 6 segments of long hop links or spokes originating from fiber PoP 201. However, proposed wireless mesh network layout can have any number of spokes and number is depended on the specific terrain of the network, density of homes (potential node locations) and line-of-sight profile. In addition, network layout in figure 20 shows a number of wireless communication nodes connected to each other and to those wireless

communication nodes that are already connected via long hop links through short hops links. Specifically, wireless communication node 201 is connected to wireless communication node 214 via short hop link 250, wireless communication node 214 is connected to wireless communication node 215 via short hop link 251, wireless communication node 215 is connected to wireless communication node 216 via short hop link 252, wireless communication node 216 is connected to wireless communication node 217 via short hop link 253, and finally wireless communication node 217 is connected to wireless communication node 203 via short hop link 254 to form a segment of short hop links that connects the wireless communication node 202 and 203 thereby providing an alternative path between nodes 202 and 203. Similarly, wireless communication node 204 is connected to wireless communication node 218 via short hop link 255, wireless communication node 218 is connected to wireless communication node 219 via short hop link 256, wireless communication node 219 is connected to wireless communication node 220 via short hop link 257, wireless communication node 220 is connected to wireless communication node 221 via short hop link 258, and finally wireless communication node 221 is connected to wireless communication node 205 via short hop link 259 to form a segment of short hop links that connects the wireless communication node 204 and 205 thereby providing an alternative path between nodes 204 and 205. Similarly, wireless communication node 206 is connected to wireless communication node 222 via short hop link 260, wireless communication node 222 is connected to wireless communication node 223 via short hop link 261, wireless communication node 223 is connected to wireless communication node 224 via short hop link 262, wireless communication node 224 is connected to wireless communication node 225 via short hop link 263, and finally wireless communication node 225 is connected to wireless

communication node 207 via short hop link 264 to form a segment of short hop links that connects the wireless communication node 206 and 207 thereby providing an alternative path between nodes 206 and 207. Similarly, other short hop links ranging from 265 to 279 connects a number of wireless communication nodes to each other. Nodes belonging to different spokes or segments of long hop links can also be interconnected via short hop links. For example, node 224 and node 228 are associated with two different spoke or segments of long hop links. However, both 224 and 228 are connected to another wireless communication node 283 via short hop links 284 and 285 respectively thereby creating a path along wireless mesh network that can connect nodes associated with different spokes via short hop links in addition to long hop links 280, 281 and 282 described above. In addition, it is also possible to connect any to adjacent spokes via direct long hop links. For example, although not shown in figure 20, it is also possible to connect wireless communication node 211 and wireless communication node 209 via a long hop link in the presence of line-of-sight path between 211 and 209. Similar to figure 19, it can be easily demonstrated that layout of wireless mesh network design consisting of long hop links and short hop links greatly reduces the maximum number of hops a data packet needs to pass through before reaching the destination. In addition, long hop links increases the reliability of network by providing alternative paths in the event where original path of traffic flow breaks due to failure of a link or multiple links similar to the description in the context of figure 19.

[00072] Referring to figure 21, another embodiment of proposed mesh network design is depicted where adjacent short hop links are constraint to not form a straight line in order to avoid mutual interference from adjacent wireless communication nodes. For example, consider a segment 3A consisting of two nodes that are in the direct north of

wireless communication node 107. In segment 3A short hop link that connects the two nodes north of 107 cannot be allowed as it would cause interference to node 107 as their signal propagation path overlaps. Similarly, a segment 3B consists of 3 nodes that are on the east of node 112. Two nodes on the far east of node 112 cannot be allowed as their two short hop links would create interference for node 112 as their signal propagation path overlaps. In general, nodes that are connected via short hop links in such a manner that the segment of short hop links form a straight line cannot be allowed in order to avoid interference among adjacent nodes connected via short hop links.

[00073] In one embodiment, proposed wireless mesh network can be built in phases. For example, in shown in figure 22, phase 1 consists of building the network with only long hop links. This allows quick access and coverage to large area with small number of nodes. In the second phase, short hop links are added that provide connectivity to large number of end users that are spread over a large region with the help of long hop links that are created in the phase 1. Availability of long hops in phase 2 allows easy design of short hops links as segments of short hop links can be terminated at any close by node that is connected to via a long hop link to another node or fiber PoP.

[00074] Figure 23 shows a real-world depiction of techniques and design principles proposed in this invention. Red links in figure 23 represents long hop links described in the context of figure 19 to 22 and yellow links represent short hop links that provide connectivity to end users. Long hop links help connect the wireless mesh network to the two fiber PoP shown with blue circles in the figure 23. It can be easily seen that use of long hops greatly reduces the maximum number of hops a data packet is required to pass through in order to reach from source to destination there by improving the latency and packet delay of the network. Long hop links also improve the overall

network reliability by providing alternate paths for traffic flow incase original path of wireless mesh network fails for some reason.

[00075] Current wireless mesh networking systems exhibit many shortcomings, including failing to provide alternative communication path in the event of change in LOS conditions of the link/path between two or more nodes due to various reasons including but not limited to vegetation growth, loss of an intermediary network node, etc. Thus, there exists multiple needs in the art for improved systems and methods relating to wireless communication network design and operation. Referring to figure24, a data communication network capable of providing multigigabit internet speeds through wireless point-to-point and point-to-multipoint links is illustrated. Figure 24 shows communication network 100. Figure 24 shows a portion of wireless mesh network consisting of 4 network nodes that are connected with the rest of mesh network 110. Mesh network 110 consists of multiple other nodes of various kind (such as ptp/ptmp nodes, routers, switches, gateways, etc.) and also includes links that connect the mesh network 110 to CORE network including data center, ISP, IMS, EMS, billings, AAA, etc. that are not shown for the sake of simplicity. Specifically, 4 nodes 101, 102, 103 and 104 are shown that are connected to rest of the mesh network 110. Mesh network node 101 hosts two point-to-point/point-to-multipoint nodes 101-1 and 101-2. Likewise, mesh network node 102 hosts two point-to-point/point-to-multipoint nodes 102-1 and 102-2, mesh network node 103 hosts three point-to-point/point-to-multipoint nodes 103-1, 103-2 and 103-3. Lastly, mesh network node 104 hosts two point-to-point/point-to-multipoint nodes 104-1 and 104-2. In figure 24, mesh network nodes are shown to host 2 or 3 nodes, but in general, mesh network nodes can host any positive integer number of point-to-point/point-to-multipoint nodes greater than or equal to 1. Ptp/ptmp node 101-2 of mesh

node 101 and ptp/ptmp node 102-1 of mesh node 102 establish a bi-directional narrow beam link 10-12 to connect mesh nodes 101 and 102. Similarly, ptp/ptmp node 102-2 of mesh node 102 and ptp/ptmp node 103-2 of mesh node 103 establish a bi-directional narrow beam link 10-23 to connect mesh nodes 102 and 103, ptp/ptmp node 103-1 of mesh node 103 and ptp/ptmp node 104-2 of mesh node 104 establish a bi-directional narrow beam link 10-34 to connect mesh nodes 103 and 104, ptp/ptmp node 104-1 of mesh node 104 and ptp/ptmp node 101-1 of mesh node 101 establish a bi-directional narrow beam link 10-14 to connect mesh nodes 101 and 104, and lastly, ptp/ptmp node 103-3 of mesh node 103 and ptp/ptmp node of mesh network (not shown in the figure) establish a bi-directional narrow beam link 10-3N to connect mesh nodes 103 (and group of 3 other nodes 101, 102, 104 indirectly) and the rest of the mesh network 110 of the communication network 100. Figure 24 highlights just 4 nodes however, in general any number of nodes can be connected to the mesh network 110.

[00076] Figure 25 shows in a preferred embodiment due to an event, link 10-12 connecting mesh node 101 to mesh node 102 and link 10-14 connecting mesh node 101 and 104 fails. As a result, connectivity of the mesh node 101 with mesh node 104 and mesh node 102 is dropped. The event causing the connectivity drop can occur due to various reasons. In one embodiment, link failures described above can occur due to loss of a mesh network node. For example, a customer residing in the node 101 leaves to a different location and cancels the subscription to the mesh network and the node 101 no longer participates in the mesh network. Another example can be the new residents of the dwelling may remove the ptp/ptmp nodes 101-1 and 101-2 from the roof (or other location where 101-1 and 101-2 were mounted) or disconnect the power supply to 101-1 and 101-2 or take an action that stops the mesh node 101 and its associated ptp/ptmp

nodes 101-1 and 101-2 to communicate with other ptp/ptmp nodes of the wireless network. In another embodiment, growth of vegetation can impact the LOS connectivity between 101-2 and 102-1 for the link 10-12 and LOS connectivity between 101-1 and 104-1. In yet, another embodiment, connectivity drop of the links 10-14 and 10-12 can occur due to single or multiple ptp/ptmp node malfunctioning at nodes 101, 102 and 104. In another embodiment, an example of cause of the above link failures can include combination of the above described reasons. It is also to be noted here that two link failures are shown here as an example that impacts mesh node 101. However, in general, any number of link failures can occur at single mesh node or multiple mesh nodes and can impact multiple mesh nodes or other customers. For example, in addition to ptp/ptmp links 10-14 and 10-12 that connects mesh node 101 to mesh nodes 104 and 102, mesh node 101 can also be directly (not shown in the figure 25) connected to other mesh nodes through other ptp/ptmp nodes or to nodes that are not directly connected to mesh network via ptp/ptmp as explain later in this disclosure.

[00077] Referring to figure 26, a wireless communication node 301 and 302 are shown. The distinctive feature of these nodes is that contrary to narrow beam communication beams/links formed by the nodes 101-1, 101-2, 102-1, 102-2, 103-1, 103-2, 103-3, 104-1 and 104-2 described in the figures 24 and 25, the wireless communication node 301 and 302 operate on wide beam width communication links. For example, in one embodiment 3dB beam width of these nodes can be 20 degrees. In other embodiments, 3dB beam width of communication nodes 301 and 302 can be greater than 20 degrees or less than 20 degrees. For example, beam width of nodes 301 and 302 can be 15, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 degrees. In other embodiment, beam width of nodes 301 and node 302 can take a different value. Second way nodes 301 and 302 differ

from nodes 101-1, 101-2, 102-1, 102-2, 103-1, 103-2, 103-3, 104-1 and 104-2 of figure 24 and 25 is that nodes 301 and 302 operate at much lower frequencies compared. For example, in some embodiments, nodes 101-1, 101-2, 102-1, 102-2, 103-1, 103-2, 103-3, 104-1 and 104-2 operate on millimeter wave frequency (e.g. 60Ghz) and nodes 301 and 302 operate at sub 6Ghz frequency which allows the links between different wide beam width communication nodes such as 301 and 302 to operate and work in non-LOS environment where as links formed by 101-1, 101-2, 102-1, 102-2, 103-1, 103-2, 103-3, 104-1 and 104-2 require LOS or near LOS conditions. Another way node 301 and 302 differ from nodes 101-1, 101-2, 102-1, 102-2, 103-1, 103-2, 103-3, 104-1 and 104-2 is that nodes 301 and 302 each contain 2 separate wide beam width wireless communication nodes in one single enclosure. For example, figure 26 shows the wide beam communication node 301 that contains the small cell 301-2 and the CPE 301-1. Small cell 301-2 can be a node capable of establishing and controlling communications with several CPEs and/or mobile units (not shown in the figure) simultaneously for sub 6Ghz frequencies (or at a low frequency spectrum where strict LOS conditions in not required). In one embodiment, small cell 301-2 can be 4G LTE/LTE-A based small cell. In other embodiments, small cell 301-2 can be a 2G/3G/4G/5G/6G small cell that can operate at various frequencies and can be based on various RAN technologies including TDMA, FDMA, CDMA, OFDMA, CSMA, WiFi, 5G NR, TDD-LTE, FDD-LTE etc. or a combination of these technologies. CPE 301-1 can be node capable of establishing communications with one small cell at one time (CPE 301-1 may have multiple communications links with multiple small cells but only one small cell can act as the master/controller for those multiple connections). In one embodiment, CPE 301-1 can be a 4G LTE/LTE-A based user equipment (UE). In other embodiments, CPE 301-1 can be

a 2G/3G/4G/5G/6G CPE that can operate at various frequencies and can be based on various RAN technologies including TDMA, FDMA, CDMA, OFDMA, CSMA, WiFi, 5G NR, TDD-LTE, FDD-LTE etc. or a combination of these technologies. In figure 26, wide beam width communication node 301 is shown to contain one small cell 301-2 and a single CPE 301-1. However, in general, wide beam width communication node 301 can have multiple small cells and/or multiple CPE. In addition, figure 26 also shows the wide beam communication node 302 that contains a small cell 302-2 and a CPE 302-1. Small cell 302-2 can be a node capable of establishing and controlling communications with several CPEs and/or mobile units (not shown in the figure) simultaneously for sub 6GHz frequencies (or at a low frequency spectrum where strict LOS conditions are not required). In one embodiment, small cell 302-2 can be 4G LTE/LTE-A based small cell. In other embodiments, small cell 302-2 can be a 2G/3G/4G/5G/6G small cell that can operate at various frequencies and can be based on various RAN technologies including TDMA, FDMA, CDMA, OFDMA, CSMA, WiFi, 5G NR, etc. or a combination of these technologies. CPE 302-1 can be node capable of establishing communications with one small cell at one time (CPE 302-1 may have multiple communications links with multiple small cells but only one small cell can act as the master/controller for those multiple connections). In one embodiment, CPE 302-1 can be a 4G LTE/LTE-A based user equipment (UE). In other embodiments, CPE 302-1 can be a 2G/3G/4G/5G/6G CPE that can operate at various frequencies and can be based on various RAN technologies including TDMA, FDMA, CDMA, OFDMA, CSMA, WiFi, 5G NR, TDD-LTE, FDD-LTE etc. or a combination of these technologies. In figure 26, wide beam width communication node 302 is shown to contain one small cell 302-2 and a single CPE 302-1. However, in general, wide beam width communication node 301 can have multiple

small cells and/or multiple CPE. Moreover, the entities 301-1, 301-2, 302-1 and 302-2 can also be logical entities in the sense that same hardware can be used for both CPE and small cell functions and they may not need to be on separate hardware boards, etc.

[00078] It is to be noticed here that CPE belonging to a particular wide beam width communication node does not connect itself (over the air) to the small cell residing in the same enclosure but strictly connects itself to small cell(s) that are residing in different wide beam width communication node. CPEs can be connected through wired connection to small cells residing in the same wide beam communication node though. For example, in figure 26, let's assume CPE 301-1 is an LTE technology-based device. Hence, as previously explained, CPE 301-1 residing in wide beam width communication node 301 will use LTE technology protocol to connect its self to a small cell 302-2 over the air that belongs to a different wide beam width communication node 302 to establish a bi-directional link. CPE 301-1 can however still have connection with small cell 301-2 over a wired interface though. Similarly, let's assume CPE 302-1 is an LTE technology-based device. Hence, as previously explained, CPE 302-1 residing in wide beam width communication node 302 will use LTE technology protocol to connect is self to a small cell 301-2 over the air that belongs to a different wide beam width communication node 301 to establish a bi-directional link. CPE 302-1 can however still have connection with small cell 302-2 over a wired interface though.

[00079] Moving on to figure 27, communication network 100 is shown. As explained in the context of figure 25, due to an event links 10-12 and 10-14 lose connectivity and mesh node 101 gets disconnected from the rest of the mesh network including its immediate neighbor nodes 102 and 104. Figure 27 shows that mesh node 101 in addition to ptp/ptmp nodes 101-1 and 101-2 also hosts wide beam width

communication node 301-E. Node 301-E consists of a CPE 301-1 and a small cell 301-2 (in general, node 301-E can have multiple CPEs and small cells). Small cells 301-2 of wide beam width communication node 301-E has a coverage area 301-E1 where other CPEs that use compatible RAN protocols can connect over the air and get data connection via 301-2. Also, wide beam width communication node 301-E is connected via a wired interface to ptp/ptmp links 101-1 and 101-2. Figure 27 also shows that mesh node 103 in addition to ptp/ptmp nodes 103-1, 103-2 and 103-3 also hosts wide beam width communication node 303-E. Node 303-E consists of a CPE 303-1 and a small cell 303-2 (in general, node 303-E can have multiple CPEs and small cells). Small cells 303-2 of wide beam width communication node 303-E has a coverage area 303-E1 where other CPEs that use compatible RAN protocols can connect over the air and get data connection via 303-2. Also, wide beam width communication node 303-E is connected via a wired interface to ptp/ptmp links 103-1 and 103-2. In a preferred embodiment, CPE 301-1 residing at mesh node 101 can connect to small cell 303-2 residing at mesh node 103 over the air and can establish a link between mesh nodes 101 and 103. Hence nodes 101-1, 101-2, and 301-2 can all coordinate and transmit their data via the link established by 301-1 between mesh node 101 and 103. Hence, even in an event where direct ptp/ptmp links-based connectivity between mesh nodes is impacted, connectivity can be immediately restored by re-routing the traffic via link between CPE of the impacted node and small cell of the wide beam width communication node that provides connectivity to the CPE of the impacted node. In figure 27, wide beam width communication nodes are shown only at mesh node 101 and 103 however, wide beam width communication node can reside on any or all mesh nodes of the network. Moreover, figure 27 shows connectivity is restored with CPE 301-1 of mesh node 101 and small cell 303-2 of mesh

node 103, however, a different set of CPE and small cell can also establish a link if failure occurs at a different mesh node. For example, if ptp/ptmp link failure occurs at node 103 that break links 10-34 and 10-23, then CPE 303-1 of mesh node 103 can small cell 301-2 of mesh node 101 can coordinate to reestablish the connectivity between mesh nodes. In one embodiment, all the different collocated nodes including wide beam width communication node and multiple ptp/ptmp nodes can be in one box or enclosure. In other embodiments, collocated wide beam width communication nodes and ptp/ptmp nodes can be in separate boxes or enclosures

[00080] For wide beam width communication node that carries single or multiple small cell and single or multiple CPEs, wireless communication operations can easily be performed if all CPE(s) and small cell(s) use different set of frequencies at one instant of time such that frequencies are far apart from each other so that no self-interference issues arise. For example, assume a wide beam width communication node has a single small cell and a single CPE. Since small cell and CPE are collocated in the same enclosure of the wide beam width communication node, they are required to operate at two different frequencies at one instant of time otherwise transmission and reception of small cell will be impacted by the transmission and reception of CPE and vice versa. More over these frequencies need to be separated in the spectrum band such that side lobes of one frequency become very weak at the other frequency. If the CPE(s) and small cell(s) of a wide beam width communication node can only operate on one (same) frequency then only entity, either CPEs or small cell(s) can operate and other entities are required to shut down the operations during that time. For example, consider figure 28. During the time instances when CPE 301-1 of wide beam width communication node 301-E performs communication with small cell 303-2 of wide beam width communication node 303-E,

small cell 301-2 of wide beam width communication node 301-E is required to shut down its operations in order to avoid causing an interference with the transmission and reception of CPE 301-1. This will impact the connectivity of other CPEs (not shown in figure 28) that are connected only with small cell 301-2 of wide beam width communication node. Hence, if simultaneous operation of multiple entities (small cell(s) and CPE(s)) of a wide beam width communication node involving at least one small cell and one CPE is required then other techniques or solutions is required which is discussed and explained in the following paragraphs.

[00081] Consider figure 29 which shows the communication network 100 that has been discussed in the context of figures 24 to 28 so far. Figure 29 additionally shows 2 CPEs i.e. 301-2-A and 301-2-B that are in the coverage area 301-E1 served by small cell 301-2 and are connected to the network via bi-directional communication links between the CPEs (301-2-A and 301-2-B) and the small cell 301-2 that belongs to the wide beam width communication node 301-E. As discussed earlier in the context of figure 28, if small cell 301-2 shuts down the operation at certain time instance (or interval) due to receiving and transmission operations of its collocated CPE 301-1, then connectivity services of the CPEs 301-2-A and 301-2-B get impacted during that time instance (or interval). In the following paragraphs, certain mechanisms are presented which enable the simultaneous operations of the small cell(s) and the CPE(s) that are collocated and associated with same wide beam width communication node.

[00082] Next, steps of operations entailing the proposed mechanisms are discussed with the aid of figures 30A and 30B. Figure 30A shows communication network 100 that has been described above in the context of figures 24 to 29. Wide beam width communication node 801-E and 803-E residing at mesh network nodes 101 and 103

respectively have characteristics described in the context of figure 26. During normal mesh network operations, when all ptp/ptmp nodes are functional, both small cells 801-2 and 803-2 as well as both the CPEs 801-1 and 803-1 operate at frequency f1 as shown by horizontal stripes in the coverage areas 801-E1 and 803-E1. During normal network operations, small cell 801-2 of wide beam width communication node 801-E is connected with CPEs 801-2-A and 801-2-B using frequency f1. In addition, small cell 803-2 of the wide beam width communication node 803-E is connected to CPE 801-1 residing in 801-E using frequency f1.

[00083] In the event of mesh network failure as discussed above, ptp/ptmp links 10-12 and 10-14 break and mesh node 101 loses connectivity with its neighbor nodes. As a consequence, the customer router of mesh node 101 and the small cell 801-2 of wide beam width communication node 801-E that are backhauled through ptp/ptmp links 10-12 and 10-14 lose their connectivity. In addition, CPEs 801-2-A and 801-2-B that are served by small cell 801-E are also impacted. As a result of such event, this disclosure proposes the following:

- a. Small cell 801-2 of the wide beam width communication node 801-E and mesh network node 101 (the impacted node) instructs all its connected CPEs (801-2-A and 801-2-B of figure 30A) to pause their uplink transmission for certain duration X (or until instructed by small cell 801-2 to resume uplink transmissions).
- b. CPE 801-1 residing in wide beam width communication node 801-E scans the network for best small cell operating at f1 and connects to that small cell 803-2 of the wide beam width communication box 803-E located at mesh node 103 as shown in figure 30A.

- c. At the impacted mesh node location (node 101 in this example), small cell 801-2, CPE 801-1 of wide beam width communication node 801-E, mmWptp/ptmp link nodes 101-1 and 101-2 coordinate with each other and CPE 801-1 operating at frequency f1 starts acting as gateway for communication between the network and end-users including the customer router linked with ptp/ptmp nodes (101-1, 101-2 in case of figure 30A), CPEs 801-2-A and 801-2-B associated with small cell 801-2. CPE 801-1 operating at frequency f1 coordinates with the controlling small cell 803-2 of the wide beam width communication node 803-E at mesh node location 103 and establishes different bearers and negotiates scheduling resources with small cell 803-2. In addition, CPE 801-1 located at impacted mesh node 101 pre-negotiates the uplink transmission time slots with its controlling small cell 803-2 where CPE 801-1 sends the uplink data to the network from all the impacted nodes and users.
- d. Once this is established, CPE 801-1 informs its collocated small cell 801-2 over wired interface that CPE 801-1 has successfully pre-negotiated uplink transmissions time slots with its controlling small cell 803-2. Once collocated small cell 801-2 receives that information, small cell 801-2 located at impacted mesh node 101 instructs its connected CPEs (801-2-A and 801-2-B of figure 30A) to resume their uplink transmissions but only in time slots that do not overlap with the time slots when CPE 801-1 of the wide beam width communication node performs its own transmission. CPE 801-1 acting as a gateway for impacted nodes and customers starts the bi-directional data transfer via small cell 803-2 residing in wide beam width

communication node 803-E of the unimpacted mesh node 103.

Specifically:

- i. for mmW customer(router) and ptp/ptmp node 101-1 and 101-2, CPE 801-1 uses high priority bearer and:

1. Receives the downlink data for mmW customer (router) on downlink channel of small cell 803-2 operating at frequency f1 and located at mesh node 103 and forwards the decoded (Layer 2) information over wired interface to mmW customer (router) located at mesh node 101.
2. Receives uplink (layer 2) information over the wired interface from mmW customer (router) located at mesh node 101 and uses uplink channel of small cell 803-2 operating at frequency f1 and located at mesh node 103 to transmit this information to the network.

- ii. For wide beam width customers CPEs 801-2-A and 801-2-B linked with small cell 801-2 at mesh node 101, CPE 801-1 uses lower priority bearer and:

1. Receives the downlink data for CPEs 801-2-A and 801-2-B associated with small cell 801-2 and wide beam width communication node 801-E on downlink channel operating at frequency f1 of small cell 803-2 located at mesh node 103 and forwards the decoded (layer 2) information over wired interface to small cell 801-2. Small cell 801-2 of wide beam width communication node 801-E transmits this

information to its associated CPEs 801-2-A and 801-2-B over frequency f1 using its downlink channel.

2. Receives uplink (layer 2) information of CPEs 801-2-A and 801-2-B over the wired interface from small cell 801-2 of wide beam width communication node 801-E at mesh node location 101 and uses uplink channel operating at frequency f1 of small cell 803-2 of wide beam width communication node located at mesh node 103 to transmit this information to the network.

[00084] The end state of the network after completion of the above steps is shown in figure 30B where coverage area 801-E1 is shown with vertical stripes indicating use of frequency f1 where uplink transmission happens only $(100-X)\%$ of times where X is the percentage of times pre-negotiated by CPE 801-1 with small cell 803-2 for its own uplink transmission, while coverage area 803-E1 is shown with horizontal stripes indicating uplink transmission from 801-1 occurs during certain pre-configured time slots $X\%$ percentage of times. So far, the mechanism in an event where one or multiple ptp/ptmp node failures to provide alternative communication path for the impacted customers (CPEs i.e. wide beam width communication node customers and mesh node customer router) is explained with an example scenario described in figures 30A and 30B. However, proposed mechanism described above is not limited to above example and explained more broadly with the help of figure 31. Figure 31 shows generic steps of mechanisms for providing alternate data paths in the event of single or multiple ptp/ptmp link failures. At step 901, all wide beam width communication is performed using frequency f1 100% of time slots. All collocated CPEs in a wide beam width

communication node of the network connect to the best possible non-allocated small cell. Next, at 902, due to single or multiple ptp/ptmp link failures, a mesh node site is disconnected from rest of mesh node network. In general, multiple sites can get disconnected due to ptp/ptmp link failures. At step 903, small cell(s) enclosed in wide beam width communication node at impacted mesh node instructs all its connected CPEs over the air to pause their uplink transmission. Next at step 904, at the impacted mesh node, collocated CPE of the wide beam width communication node coordinates with its collocated small cell, mesh network customer router and ptp/ptmp nodes and start acting as a gateway for all the bi-directional (UL/DL) traffic for end users including ptp/ptmp customers and wide beam width communication node's small cell customers using wired link between collocated CPE, small cell, mesh node customer and ptp/ptmp nodes. At step 905, at the impacted mesh node, collocated CPE of the wide beam width communication node coordinates with its controlling non-allocated small cell and 1)pre-negotiates some time slots for its uplink transmission and 2)establishes higher priority bearer for mesh node customer and lower priority bearers for wide beam width communication node small cells customers and 3)informs the collocated small cell about its pre-negotiated uplink transmission time slots. At step 906, the small cell at the impacted node instructs all its over-the-air connected CPE(s) to resume uplink transmission during time slots that do not overlap with uplink transmission time slots of collocated CPE (gateway). Lastly, at step 907, once all impacted ptp/ptmp links get fixed, network communication operations go back to step 901 configuration. These steps 901 to 907 are not always required to be in the same order. In some embodiments, order of these steps can change and in some other embodiments, some of these steps can be skipped or repeated. CPE at step 905 can in general establish both high, low or equal

priority data bearers for both mesh node customer and wide beam width communication node customers.

[00085] So far in the above discussion, it is assumed that collocated CPE and small cells belonging to the wide beam width communication node mitigate the uplink interference by coordinating the uplink transmission of collocated CPE and the CPEs that are connected over the air with collocated small cell in non-overlapping time slots. In general, similar procedure can be adopted for downlink transmissions. However, in certain scenarios, continuous downlink transmission is required and collocated small cells of the wide beam width communication node is unable to shut down its downlink transmissions during the time slots when collocated CPE is receiving downlink information from the non-collocated small cell. In such scenarios, other mechanisms can be introduced that can help mitigate downlink interference between collocated CPE and small cell of the wide beam width communication node as discussed in the following.

[00086] Referring to figure 32, a mesh network node 101 is shown. Mesh node 101 hosts two ptp/ptmp communication nodes 101-1 and 101-2. Mesh node 101 also hosts a wide beam width communication node 101-E that contains a small cell 301-2 and collocated CPE 301-1. In case mesh node 101 gets impacted due to some events that are described above in this disclosure, both nodes 301-1 and 301-2 are required to operate at the same frequency. Figure 32 shows the antenna patterns of the collocated CPE and small cell that shows that both antenna patterns have uncorrelated gains in one direction. At the bore sight of CPE antenna, gain of the collocated small cell is negligible and similarly at the bore sight of small cell antenna, collocated CPE's antenna gain is negligible. As a result, small cell transmission signals are directed in a different (opposite in figure 32) direction compared to CPE which collects the received signal energy from

the transmission signals of non-located small cell in a different (opposite in figure 32) direction. As a result, both small cells (collocated and non-located) can have continuous down link transmissions without impacting the downlink reception of the collocated CPE at the impacted mesh node i.e. 301-1 in figure 32. Antenna patterns for collocated CPE and small cells in figure 32 represent one embodiment of the proposed invention in this disclosure. There can be variety of different antenna patterns that can mitigate downlink interference as long as collocated CPE and small cells have uncorrelated directional antenna patterns.

[00087] In another embodiment, downlink signal isolation between collocated CPE's reception and collocated small cell's transmission can be achieved through physical separation between antennas as shown in figure 33. Ptp/ptmp nodes 101-1 and 101-2 can in addition to mmW communication modules also host antennas for the collocated CPE (or small cell) of the wide beam width communication node 101-E that is connected via antenna cable to the wide beam width communication node 101-E as shown in the figure 33 while small cell's (or CPE) antenna is placed within the enclosure of wide beam width communication node 101-E. If more isolation is needed, then if possible, wide beam width communication node 101-E can be move to a location that is at further distance from ptp/ptmp nodes (for example, moving to a different side of the roof, or at different height or combination of both) to get the desired signal level separation.

[00088] As another aspect, disclosed herein are new types of communication modules that employ direct RF (microwave/millimeter wave)-to-optical and direct Optical-to-RF(microwave/millimeter wave) conversion. In some embodiments, high-speed photo detectors can be used that directly translate an optical signal into a

microwave signal. In other embodiments, other approaches can be used for direct optical-to-RF conversion. Similarly, a dipole antenna directly coupled to a plasmonic modulator allows direct conversion from the RF to the optical world. In other embodiments, different approaches can be used for direct conversion of RF signals to optical signals. This direct optical-to-RF and direct RF-to-Optical conversion modules eliminate the need of the use of analog to digital and digital to analog (ADC/DAC) modules that are required by traditional modem implementations. These mixed signal components i.e. ADC/DAC consume high amount of power and also increase the cost as each antenna is required to be connected to a separate ADC/DAC modules.

[00089] Figure 34 shows a communication module based on direct RF-to-Optical and direct Optical-to-RF conversion. Communication module of figure 34 contains a single direct RF-to-Optical sub-module and a single Optical-to-RF sub-module. However, communication module of figure 34 can host any integer number of direct RF-to-Optical sub-modules greater than and equal to zero and any integer number of direct Optical-to-RF sub-modules greater than and equal to zero. In a preferred embodiment, this direct RF-to-Optical and direct Optical-to-RF conversion technology can be implemented is an integrated Circuit (IC) or chip.

[00090] Based on the above explanation of module based on direct conversion of RR-to-Optical and direct Optical-to-RF signal conversion, in a preferred embodiment, the core of the wireless mesh network can be a wireline optical or wired router/switch where each port is mapped, either through a direct connection or over optical / wired line, to an individual direct conversion Optical-to-RF or RF-to-Optical chip that then focuses, on both receiver and transmitter side, all RF energy into a high gain narrow beam that can be both fixed or steerable. In one preferred embodiment, a standard 8-port x 10G

router/switch could be used, with one port being used as a data drop to local building/site and the other 7 ports being connected over a fiber optic cable to various Optical-to-RF or RF-to-Optical end points that are located at multiple distributed locations external (and/or internal) on/in the building / site as shown in figure 35. In other embodiments, router/switch can have a different number of ports.

[00091] These locations can be determined in advanced based on the use of connection potentiality optimization algorithms, where the algorithm understands the relationship between end point placement and potentially connection partners. Also, the individual ptp beams can be dynamically steered among potential ptp connection partners to facilitate path optimization algorithms and/or to respond to network congestion and/or network element failures. In one embodiment, these Optical-to-RF or RF-to-Optical end points that establish ptp/ptmp beams can be placed below the roof's eaves and in other embodiments, these can be placed above the roof eaves. In some other embodiments, some of the Optical-to-RF or RF-to-Optical end points can be placed below the roof's eaves and some can be placed above the roof's eaves and actual placement is dependent upon the lone-of-sight profile of the location/site.

[00092] The above communication module discussed in the context of figure 34 and 35 can be implemented in other communication modules that are discussed in the context of figures 1 to 33. In other words, the modules discussed in the context of figure 1 to figure 33 can have direct RF-to-Optical and direct Optical-to-RF technology embedded such that all the narrow beam, extremely narrow beam ptp/ptmp/multiple ptp links, etc. can be established without the need for ADC/DAC mixed signal circuitry that consumes high amount of power and required to be connected individually with each antenna.

[00093] The foregoing concepts have been disclosed in an illustrative manner, and it is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation. Obviously, many modifications and variations of the disclosed concepts are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the claims (to be added later), the disclosed concepts may be practiced otherwise than as specifically described. The invention will ultimately be defined by the claim(s).

ABSTRACT:

[00094] Methods, apparatuses, and systems relating to narrow beam communications and wireless networking are disclosed. Exemplary methods for wireless networking and communications are shown where mesh network node complexity may be reduced by using direct RF-to-Optical and direct Optical-to-RF conversion modules.

Provisional Application for Patent Cover Sheet This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)					
Inventor(s)					
Inventor 1					Remove
Given Name	Middle Name	Family Name	City	State	Country j
Kevin		Ross	Lehi	UT	US
Inventor 2					Remove
Given Name	Middle Name	Family Name	City	State	Country j
Muhammad	Ahsan	Naim	South Jordan	UT	US
All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the Add button.					Add
Title of Invention		A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module			
Attorney Docket Number (if applicable)		Naim-00016			
Correspondence Address					
Direct all correspondence to (select one):					
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Customer Number			130085		
The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.					
☒ No.					
Yes, the invention was made by an agency of the United States Government. The U.S. Government agency name is:					
Yes, the invention was under a contract with an agency of the United States Government. The name of the U.S. Government agency and Government contract number are:					

Entity Status**Applicant asserts small entity status under 37 CFR 1.27 or applicant certifies micro entity status under 37 CFR 1.29**

- ☒ Applicant asserts small entity status under 37 CFR 1.27
- ☐ Applicant certifies micro entity status under 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
- ☐ No

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Signature

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Signature	Rory P. Shea/		Date (YYYY-MM-DD)	2018-11-26
First Name	Rory P.	Last Name	Shea	Registration Number (If appropriate)
				60529

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **This form can only be used when in conjunction with EFS-Web. If this form is mailed to the USPTO, it may cause delays in handling the provisional application.**

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7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2:

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

Inventor	1				Remove	
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	Kevin		Ross			
Residence Information (Select One) • US Residency Non US Residency Active US Military Service						
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Address 2						
City	Lehi	State/Province	UT			
Postal Code	84043	Country i	US			
Inventor	2				Remove	
Legal Name						
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	Muhammad	Ahsan	Naim			
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Address 2						
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All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button.						

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		

☐ An Address is being provided for the correspondence information of this application.

Customer Number	130085		
Email Address	ls3_docketing@cardinal-ip.com	Add Email	Remove Email

Application Information:

Title of the Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		
Attorney Docket Number	Naim-00016	Small Entity Status Claimed ☒	
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	36	Suggested Figure for Publication (if any)	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:
☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

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

Representative Information:

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

Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)
Customer Number	130085		

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
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Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. ☐ NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.
--

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

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A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

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☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		

Applicant Information:

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

Applicant	1	Remove
If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.		
Clear		
Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.		Person who shows sufficient proprietary interest
If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:		
Name of the Deceased or Legally Incapacitated Inventor:		
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Prefix	Given Name	Middle Name	Family Name	Suffix
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Assignee Information including Non-Applicant Assignee Information:

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	Naim-00016
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Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module	

Assignee	1
-----------------	---

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

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Signature	/Rory P. Shea/		Date (YYYY-MM-DD)	2018-11-26
First Name	Rory P.	Last Name	Shea	Registration Number
				60,529

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	Naim-00016
		Application Number	
Title of Invention	A Method for Improving Wireless Mesh Network Using Direct Optical-to-RF and Direct RF-to-Optical Conversion Module		

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

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1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
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5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.