SYSTEMS AND METHODS FOR IMPROVING WIRELESS MESH NETWORKS

Abstract

In a wireless mesh network comprising wireless communication nodes that are interconnected via wireless point-to-point and/or wireless point-to-multipoint links, at least some of the wireless communication nodes may additionally be installed with equipment that enables them to operate as blockchain nodes within a blockchain network, such as a computing system comprising hardware and software for operating as part of the blockchain network. This architecture enables such wireless communication nodes to serve a dual purpose of delivering both mesh-based applications and/or services to users, such as high-speed internet, as well as blockchain-based applications and/or services to users. For example, such wireless communication nodes may function to provide distributed, blockchain-based platforms for content storage (e.g., blockchain-based databases or distributed file storage platforms), content distribution, social media, gaming, and/or virtual experiences, among other possibilities.

Inventors:	**Ross; Kevin** (Lehi, UT), **Naim; Muhammad Ahsan** (Irving, TX)
Applicant:	**L3VEL, LLC** (Wilmington, DE)
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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application claims priority to and is a continuation of U.S. Non-Provisional patent application Ser. No. 17/590,608, filed on Feb. 1, 2022, and entitled "Systems And Methods For Improving Wireless Mesh Networks," which is a continuation-in-part of U.S. Non-Provisional patent application Ser. No. 17/345,914, issued as U.S. Pat. No. 11,246,180, filed on Jun. 11, 2021 and entitled "Systems And Methods For Improving Wireless Mesh Networks," which is a continuation of U.S. Non-Provisional patent application Ser. No. 16/680,457, issued as U.S. Pat. No. 11,044,617, filed on Nov. 11, 2019, and entitled "Systems and Methods for Improving Wireless Mesh Networks," which is a continuation-in-part of U.S. Non-Provisional patent application Ser. No. 16/590,217, issued as U.S. Pat. No. 11,102,834, filed on Oct. 1, 2019 and entitled "Systems and Methods for Improving Wireless Mesh Networks," which is a continuation-in-part of U.S. Non-Provisional patent application Ser. No. 16/508,289, issued as U.S. Pat. No. 10,966,266, filed Jul. 10, 2019 and entitled "Systems and Methods for Improving Wireless Mesh Networks," which claims priority to the following U.S. provisional applications: (i) U.S. Provisional App. No. 62/856,697, filed Jun. 3, 2019 and entitled "A METHOD FOR BUILDING WIRELESS MESH NETWORK NODES," (ii) U.S. Provisional App. No. 62/833,485, filed Apr. 12, 2019 and entitled "A METHOD FOR BUILDING WIRELESS MESH NETWORK NODES," (iii) U.S. Provisional App. No. 62/771,508, filed Nov. 26, 2018 and entitled "A METHOD FOR IMPROVING WIRELESS MESH NETWORK USING DIRECT OPTICAL-TO-RF AND DIRECT-RF-TO-OPTICAL CONVERSION MODULE," (iv) U.S. Provisional App. No. 62/753,885, filed Oct. 31, 2018 and entitled "METHODS OF BUILDING 60

GHZ MESH BASED NETWORK INFRASTRUCTURE FOR BLOCKCHAIN TECHNOLOGY BASED PLATFORMS," and (v) U.S. Provisional App. No. 62/696,688, filed Jul. 11, 2018 and entitled "METHODS FOR BUILDING WIRELESS MESH NETWORK." The contents of each of the foregoing patent applications are incorporated herein by reference in their entireties for all purposes.

BACKGROUND

[0002] 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.

[0003] Current wireless mesh networking systems exhibit many shortcomings, including failing to account for extra protection for point-to-point narrow beam wireless paths. 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.

[0004] Thus, there exists multiple needs in the art for improved systems and methods relating to wireless communication mesh network design and operation.

OVERVIEW

[0005] 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 mesh networking and related operations and techniques.

[0006] In accordance with one aspect of the present disclosure, wireless communication nodes that are configured to operate within a wireless mesh network (e.g., via wireless point-to-point and/or wireless point-to-multipoint millimeter-wave links) may additionally be installed with equipment that enables them to operate as blockchain nodes within a blockchain network. For instance, such a wireless communication node may be equipped to host a computing system comprising at least one processor, memory, stored digital content (which may include non-fungible tokens (NFTs) in some examples), software, etc., where that computing system is connected to a blockchain network and comprises a client that is capable of storing, validating, and/or relaying transactions in addition to the high-speed, low latency mesh networking capability of the wireless communication nodes.

[0007] This novel architecture enables wireless communication nodes within a communication system to serve a dual purpose of delivering both mesh-based applications and/or services to users, such as high-speed internet, as well as blockchain-based applications and/or services to users. Such a novel architecture provides various advantages over existing architectures where the communication nodes are only capable of serving one of these purposes. For instance, in the architecture disclosed herein, the blockchain nodes are capable of communicating wirelessly with one another via the mesh networking technologies disclosed herein, which may provide various advantages over existing architectures for interconnecting blockchain nodes, including high capacity (e.g., a bandwidth ranging from 20 gigabits per second to 100 gigabits per second bi-directionally) and low latency (e.g., less than 1 millisecond for point-to-point links and less than 4 milliseconds for point-to-multipoint links). Further, by enabling the wireless communication nodes of a wireless mesh network to also operate as blockchain nodes, this may reduce the need to separately deploy blockchain nodes in order to provide blockchain-based applications and/or services to users, which may provide various efficiencies with respect to installing, hosting, overseeing, and/or maintaining blockchain nodes, among other possible efficiencies. The novel architecture disclosed herein may provide other advantages as well.

[0008] The blockchain-based applications and/or services that can be provided by this novel

architecture may take any of various forms. As examples, wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may function to provide distributed, blockchain-based platforms for content storage (e.g., blockchain-based databases or distributed file storage platforms), digital content distribution (including distribution of NFTs in some examples), social media, gaming, and/or virtual experiences, among other possibilities.

[0009] Accordingly, in one aspect, disclosed herein is communication system comprising a set of wireless communication nodes that are configured to operate as part of a wireless mesh network (e.g., wireless communication nodes installed at private properties associated with customers of a service delivered by the wireless mesh network), where at least a subset of the wireless communication nodes in the set are further configured to operate as blockchain nodes within a blockchain network.

[0010] In at least some example embodiments, the subset of the wireless communication nodes that are configured to operate as blockchain nodes within the blockchain network may comprise wireless communication nodes that are configured to operate as part of any of a blockchain-based content distribution platform, a blockchain-based social media platform, a blockchain-based gaming platform, and/or a blockchain-based virtual experiences platform, among other possibilities.

[0011] Further, in at least some example embodiments, the subset of the wireless communication nodes that are configured to operate as blockchain nodes within the blockchain network may comprise wireless communication nodes that are configured to operate as blockchain-based distributed storage nodes and/or are configured to perform blockchain-based computations.

[0012] Further yet, in at least some example embodiments, each wireless communication node in the subset may be installed with respective equipment for operating as a blockchain node within the blockchain network, and each such wireless communication node's respective equipment may comprise a computer system that includes one or more processors, data storage, and software for operating as part of the blockchain network, among other possibilities.

[0013] Still further, in at least some example embodiments, each respective wireless communication node in the set may be configured to communicate with at least one other wireless communication node in the set via at least one bidirectional wireless millimeter-wave link that is established with the at least one other wireless communication node in the set.

[0014] In at least some example embodiments, the set of wireless communication nodes may also be arranged into: (i) a first layer comprising a mesh of bidirectional wireless point-to-point (ptp) links for providing a backhaul path for aggregated mesh traffic across a first grouping of wireless communication nodes in the set, where each respective bidirectional wireless ptp link in the mesh of bidirectional wireless ptp links is established between a respective pair of wireless communication nodes in the first grouping, and (ii) a second layer comprising a plurality of bidirectional wireless point-to-multipoint (ptmp) links that extend the mesh of wireless, bidirectional point-to-point links by providing access paths for individual mesh traffic between the first grouping of wireless communication nodes and a second grouping of wireless communication nodes in the set, where each of the plurality of bidirectional wireless ptmp links is established between a respective one of the wireless communication nodes in the first grouping and one or more of the wireless communication nodes in the second grouping. In such embodiments, the bidirectional wireless ptp links in the first layer may have any of various 3 dB-beam widths, including but not limited to a 3 dB-beam width of either less than 1 degree or between 0.5 and 5 degrees, and may also have any of various lengths, including respective lengths of less than 300 meters on average. Further, in such embodiments, the bidirectional wireless ptp links in the first layer and the bidirectional wireless ptmp links in the second layer may each operate on a same set of one or more carrier frequencies within a V-band range of frequencies.

[0015] Additionally, in at least some example embodiments, each respective wireless communication node in the subset is configured to: (i) receive, from a first other wireless

communication node in the subset via a first set of one or more bidirectional wireless links, a communication comprising a request to retrieve given digital content stored at a second other wireless communication node in the subset, (ii) relay the communication to the second other wireless communication via a second set of one or more bidirectional wireless links, (iii) receive, from the second other wireless communication via the second set of one or more bidirectional wireless links, the given digital content, (iv) store a copy of the given digital content at the respective wireless communication node, and (v) relay the given digital content to the first other wireless communication node in the subset via the first set of one or more bidirectional wireless links.

[0016] In such embodiments, each respective wireless communication node in the subset could also further be configured to: (vi) receive, from a third other wireless communication node in the subset via a third set of one or more bidirectional wireless links, a subsequent communication comprising a subsequent request to retrieve the given digital content stored at the second other wireless communication node in the subset, and (vii) in response to receiving the subsequent communication, transmit the copy of the digital content back to the third other wireless communication node in the subset via the third set of one or more bidirectional wireless links. In this respect, the third other wireless communication node could be the same as the first other wireless communication node and the third set of one or more bidirectional wireless links could be the same as the first set of one or more bidirectional wireless links. Further, the third other wireless communication node could be a communication node that originated the subsequent communication and the third set of one or more bidirectional wireless links could be one single bidirectional wireless link between the respective communication node and the third other wireless communication node.

[0017] 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. It should be understood that the specific examples disclosed herein may be readily utilized as a basis for modifying or designing other structures for carrying out the same operations disclosed herein. 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. It should be understood that the figures are provided for the purpose of illustration and description only.

[0018] One of ordinary skill in the art will appreciate these as well as numerous other aspects in reading the following disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] A further understanding of the nature and advantages the present disclosure may be realized by reference to the following drawings.

[0020] FIG. **1** depicts an example diagram relating to a wireless networking and communication system, in accordance with various aspects of this disclosure.

[0021] FIG. **2** depicts an example wireless communication node comprising a module, in accordance with various aspects of this disclosure.

[0022] FIG. **3** depicts an example antenna pattern of a module, in accordance with various aspects of this disclosure.

[0023] FIG. **4** depicts an example communication link between two wireless communication nodes, in accordance with various aspects of this disclosure.

[0024] FIG. **5** depicts example wireless communication nodes, in accordance with various aspects

of this disclosure.

[0025] FIG. **6** depicts example wireless communication nodes that are communicatively coupled, in accordance with various aspects of this disclosure.

[0026] FIG. **7** depicts another example wireless communication node comprising a module, in accordance with various aspects of this disclosure.

[0027] FIG. **8**. depicts yet another example wireless communication node comprising a module, in accordance with various aspects of this disclosure.

[0028] FIG. **9** depicts an example wireless communication node comprising two modules, in accordance with various aspects of this disclosure.

[0029] FIG. **10** depicts another example wireless communication node comprising two modules, in accordance with various aspects of this disclosure.

[0030] FIG. **11**A depicts an example wireless communication node at a given time that can dynamically change type of links between wireless communication nodes, in accordance with various aspects of this disclosure.

[0031] FIG. **11**B depicts an example wireless communication node at another given time that can dynamically change type of links between wireless communication nodes, in accordance with various aspects of this disclosure.

[0032] FIG. **12** depicts an example location of a communication network that can be a seed or an anchor home, in accordance with various aspects of this disclosure.

[0033] FIG. **13** depicts another example location of a communication network that can be a seed or an anchor home, in accordance with various aspects of this disclosure.

[0034] FIG. **14** depicts another example wireless communication node comprising a module, in accordance with various aspects of this disclosure.

[0035] FIG. **15** depicts an example of multiple modules connected to a tower, in accordance with various aspects of this disclosure.

[0036] FIG. **16** depicts another example diagram relating to a wireless networking and communication system, in accordance with various aspects of this disclosure.

[0037] FIG. **17** depicts yet another example diagram relating to a wireless networking and communication system, in accordance with various aspects of this disclosure.

[0038] FIG. **18** depicts still another example diagram relating to a wireless networking and communication system, in accordance with various aspects of this disclosure.

[0039] FIG. **19** depicts an example communication module based on direct RF-to-Optical and direct Optical-to-RF conversion, in accordance with various aspects of this disclosure.

[0040] FIG. **20** depicts an example router/switch, in accordance with various aspects of this disclosure.

[0041] FIG. **21** depicts an example block diagram of a communication module, in accordance with various aspects of this disclosure.

[0042] FIG. **22** depicts an example block diagram of a ptmp radio module of a communication node, in accordance with various aspects of this disclosure.

[0043] FIG. **23** depicts an example block diagram of a ptp radio module of a communication node, in accordance with various aspects of this disclosure.

[0044] FIG. **24** depicts an example mesh network comprising a plurality of communication nodes, in accordance with various aspects of this disclosure.

[0045] FIG. **25**A depicts another example mesh network comprising a plurality of communication nodes, in accordance with various aspects of this disclosure.

[0046] FIG. **25**B depicts yet another example mesh network comprising a plurality of communication nodes, in accordance with various aspects of this disclosure.

[0047] FIG. **26** depicts an example modified version of a flexible millimeter wave radio box, in accordance with various aspects of this disclosure.

[0048] FIG. **27** depicts an example of a multi-layer wireless mesh network, in accordance with

various aspects of this disclosure.

[0049] FIG. **28** depicts another example of a multi-layer wireless mesh network, in accordance with various aspects of this disclosure.

[0050] FIG. **29** is a simplified block diagram of an example computing system, in accordance with the present disclosure.

DETAILED DESCRIPTION

[0051] Current wireless mesh networking systems exhibit many shortcomings, including failing to account for extra protection for a high reliability wireless path for carrying backhaul data that carries control signaling data along with user data for users in the network segment. Current wireless mesh networking systems use the same or similar beam transmission techniques for an 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.

[0052] To address these needs, disclosed herein are technologies for wireless mesh networks that serve as the basis for communication systems configured to provide various types of services to end users, including but not limited to telecommunication services such as high-speed internet. For instance, the wireless mesh network technologies disclosed herein may form the basis for a data communication system capable of providing multigigabit internet speeds through a mesh network of infrastructure nodes interconnected via wireless point-to-point (ptp) and/or point-to-multipoint (ptmp) links, such as the example communication network **100** illustrated in FIG. **1**. Communication network **100** in FIG. **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 a high bandwidth dark fiber capable of providing up to several hundred gigabits/second of data throughput. Tower/fiber access points **101** and **102** provide backhaul connectivity between a core network/data center (not shown in the FIG. **1** for the sake of simplicity) and a seed home of the communication network described below. Tower/Fiber access points **101** and **102** also host wireless point-to-point communication nodes **121** and **124**.

[0053] As shown, wireless communication nodes **121** and **124** are capable of reception and transmission of high bandwidth (multiple gigahertz) signals operating at very high frequency (6 Ghz˜100 Ghz such as 28 Ghz, V band, E band, etc.). Wireless communication nodes **121** and **124** each comprise a baseband/digital unit equipped with components including but not limited to a processor, memory, etc. Wireless communication nodes **121** and **124** also each comprise an RF unit and antenna unit. The antenna subsystem of wireless communication nodes **121** and **124** is capable of reception and transmission of directional signals where significant portion of the signal energy is concentrated within a few degrees around the antenna boresight (e.g., within a range of 0.5 degrees to 5 degrees), both in vertical and horizontal directions, in contrast to omni directional antennas where signal energy is close to evenly spread across 360° degrees.

[0054] As further shown in FIG. **1**, 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 rooftops. 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 (6 Ghz˜ 100 Ghz such as 28 Ghz, V band, E band, etc.).

[0055] Wireless communication nodes **122** and **123** comprise a baseband/digital unit equipped with components including but not limited to a processor, memory, etc. Wireless communication nodes **122** and **123** also comprise an RF unit and antenna unit. The antenna subsystem of wireless

communication nodes **122** and **123** is capable of reception and transmission of directional signals where a significant portion of the signal energy is concentrated within few degrees around the antenna boresight (e.g., within a range of 0.5 degrees to 5 degrees), both in vertical and horizontal directions, in contrast to omni directional antennas where signal energy is close to evenly spread across 360° degrees.

[0056] Wireless communication node **121** residing in Tower/fiber access point location **101** and wireless communication node **122** residing in seed home **111** work together to form a 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 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 together to form a 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**.

[0057] Seed home **111**, in addition to wireless communication node **122**, hosts a second wireless communication node **131**. Second wireless communication node **131** comprises 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 (6 Ghz~100 Ghz such as 28 Ghz, V band, E band, etc.). Each module of wireless communication node **131** comprises an independent baseband/digital unit equipped with components including but not limited to a processor, memory, etc. Each module in wireless communication node **131** also comprises an independent RF unit and independent antenna unit. The 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 (e.g., within a range of 0.5 degrees to 5 degrees), both in vertical and horizontal directions, in contrast to omni directional antennas where signal energy is close to evenly spread across 360° degrees.

[0058] Communication network **100** also includes multiple anchor homes **112**, **113** and **114**. Each of these anchor homes host a wireless communication node similar to wireless communication node **131** described above. However, unlike seed homes, a wireless communication node on an anchor home only provides wireless connectivity to one or more 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**. A first 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 together to form a 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, as another example, a second 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 together to form a bi-directional high bandwidth communication point-to-point data link **153** that provides connectivity between anchor home **112** and anchor home **113**. As yet another example, a third 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 together to form a bi-directional high bandwidth communication point-to-point data link **154** that provides connectivity between anchor home **112** and seed home **115**. As a further example, 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 together to form a bi-directional high bandwidth communication point-to-point data link **152** that provides connectivity between anchor home **114** and seed home **111**. As another example, 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 together to form a bi-directional high bandwidth communication point-to-point data link **156** that provides connectivity

between anchor home **114** and seed home **115**. Other examples are possible as well.

[0059] Bi-directional communication links **141**, **142**, **151**, **152**, **153**, **154** & **155** shown in FIG. **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), and/or 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 a set of communication nodes comprising two or more of **121**, **122**, **123**, **124**, **131**, **132**, **133**, **134**, and/or **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), and/or ultra-wide band (UWB) pulse modulation (pico-second pulses), etc.

[0060] In FIG. **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, it should be understood that communication network **100** can include a different number of Tower/fiber nodes, seed homes, anchor homes and/or communication links, which may depend on the specific layout of a particular instantiation of the communication network deployed in the field. Similarly, although, FIG. **1** shows four communication nodes **121**, **122**, **123** & **124** that provide connectivity between a Tower/fiber access point (e.g., Tower/fiber access points **101**, **102**) and a seed home, five communication nodes **131**, **132**, **133**, **134** & **135** that provide connectivity between two anchor homes or between an anchor and a seed home, the number of these communication nodes can vary from one communication network to another communication network, which may depend on the specific size and layout of a particular instantiation of the communication network. It should also be understood that communication network **100** may also contain other nodes (e.g., network switches/routers, etc.) that are omitted here for the sake of simplicity.

[0061] Referring to FIG. **2**, one possible embodiment of wireless communication node **131** of FIG. **1** is shown as wireless communication node **200**. Wireless communication node **200** in FIG. **2** comprises a module labelled as "Module A." As shown, Module A comprises a 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 a wired medium.

[0062] Module A also includes RF unit **202** which, among other things, performs processing of intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received via Module A. RF unit **202** is capable of operating over a wide range of frequencies (e.g., V band frequencies ranging from 57 Ghz to 71 Ghz).

[0063] Further, as shown, Module A also comprises 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** may be 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 unit **203** is capable of establishing point-to-point links with a different module residing in a different wireless communication node.

[0064] Referring to FIG. **3**, an example of an antenna pattern of Module A created by antenna unit **203** is shown. It can be seen from the antenna pattern in FIG. **3** that the beam width of antenna unit **203** of Module A is extremely narrow (less than a degree) and the side lobe power levels start to drop at a rapid rate. For instance, as shown, approximately 5-6 degrees from the main lobe, power levels may drop by more than 30 dB.

[0065] It should be understood that the antenna pattern of antenna unit **203** shown in FIG. **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 may be generated. Further, while Module A can be constructed using metamaterials described above, it should be understood that Module A can be constructed using a parabolic antenna or other types of antennas. However, it should be understood that the main characteristic of generation of extremely narrow antenna beam pattern is common to all the instances of Module A.

[0066] Referring to FIG. **4**, a point-to-point wireless communication link **400** established between two wireless communication nodes **401** and **402** is shown. Wireless communication nodes **401** and **402** each host a single communication module (i.e., "Module A") that may take the form similar to Module A depicted in FIG. **2** and described above. As shown in FIG. **4**, due to the antenna unit characteristics of Module A in wireless communication node **401** and **402**, the bi-directional point-to-point link **400** may have an extremely narrow beam. This transmission and reception capability of radio signals over an extremely narrow beam via point-to-point link **400** provides interference immunity in scenarios where there are a large number of wireless communication links established by multiple wireless communication nodes concentrated in a small area and operating in the same frequency.

[0067] In some implementations, Module A can additionally provide beam steerability characteristics in addition to the capability of transmitting and receiving data over extremely narrow beams as explained above and illustrated in the context of FIGS. **2-4**.

[0068] For example, referring to FIG. **5**, a wireless communication node **501** comprising Module A, a second wireless communication node **502** comprising Module A and a third wireless communication node **503** comprising Module A is shown. During time T1, Module A of wireless communication node **501** and Module A of wireless communication node **502** work together to establish an 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** may invoke the beam steering capability of the module and change the direction of the antenna transmission and reception beam towards wireless communication node **503** and work together with Module A of wireless communication node **503** to dynamically establish a bi-directional extremely narrow beam-based link **500** between wireless communication node **501** and wireless communication node **503** during time T2. The trigger for this beam steering can be due to changes in the link condition between wireless communication node **501** and wireless communication node **502** which may involve various factors, including but not limited to a change from a LOS path to a non-LOS path due to a change in environment, increased interference, a change in position of wireless communication node **502** with respect to wireless communication node **501**, and/or instructions from higher layers, etc.

[0069] In one embodiment, wireless communication node **503** can be different than wireless communication node **502**. In another embodiment, wireless communication node **503** can be the same as wireless communication node **502** but in a different physical location.

[0070] In some embodiments, wireless communication nodes defined above and discussed in the context of FIGS. **2-5** can host more than one module. 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 modules (e.g., multiple Module As) belonging to different wireless communication nodes working together.

[0071] As one example to illustrate, referring to FIG. **6**, wireless communication nodes **601** and **602** each host two Module As labeled "1" and "2," while wireless communication nodes **603** and **604** each host a single Module A. As shown, a 1.sup.st Module A of wireless communication node **601** and a 1.sup.st Module A of wireless communication node **602** work together to establish extremely narrow bi-directional beam-based link **600** to provide wireless connection between wireless communication node **601** and **602**. Similarly, a 2.sup.nd Module A of wireless

communication node **601** and **602** and a 1.sup.st (and only) Module A of wireless communication node **603** and **604** respectively work together to establish extremely narrow bi-directional beam-based links **610** and **620** to provide wireless connection between wireless communication nodes **601**-**603** and **602**-**604** respectively.

[0072] In one embodiment, the 1.sup.st and 2.sup.nd Module A of wireless communication nodes **601** and **602** can be inside the same physical enclosure and in other embodiments, the 1.sup.st Module A of wireless communication nodes **601** and **603** can be inside one physical enclosure and the 2.sup.nd Module A of wireless communication nodes **601** and **603** can be inside a different physical enclosure. In embodiments where different Module As belonging to the same wireless communication node are contained in separate physical enclosures, these Module As can be connected via a wired link as they are co-located in the same seed home or anchor home.

[0073] In FIG. **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, it should be understood that a wireless communication node can host more than two Module As and the maximum number of Module As that a wireless communication node can host may depend on the maximum total power available to the wireless communication node.

[0074] Further, it should be understood that in one embodiment, all Module As belonging to the same wireless communication node may operate on the same carrier frequencies of a frequency band, and in other embodiments, different Module As belonging to same wireless communication node may operate on different carrier frequencies of a frequency band.

[0075] Referring to FIG. **7**, another embodiment of wireless communication node **131** of FIG. **1** is shown as wireless communication node **700**. Wireless communication node **700** in FIG. **7** comprises a single module labeled as "Module B." Module B comprises 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 the communication network that are external to the wireless communication node **700** via wired medium.

[0076] Module B also includes RF unit **702**, which among other things processes intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received with Module B. RF unit **702** is capable of operating over a wide range of frequencies (e.g., V band frequencies ranging from 57 Ghz to 71 Ghz).

[0077] Further, Module B comprises antenna unit **703**, which performs the transmission and reception of over the air radio signals. Antenna unit **703** may be an active antenna system (AAS) that comprises a phased array of transmitters and receivers that are capable of beamforming and creating multiple beams simultaneously in different directions. By virtue of the simultaneous creation of multiple beams in different directions, AAS 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.

[0078] As further shown in FIG. **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 the number of transmit and receive 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 the antenna pattern in FIG. **7** that the beam width of point-to-multipoint beams of antenna unit **703** of Module B are not extremely narrow (e.g. 3 dB beam width of 7~10 degree) and side lobes power levels do not start to drop at a rapid rate which is in contrast to the antenna pattern of the antenna unit belonging to Module A

described above and discussed in the context of FIGS. **2-6**.

[0079] Further, Module B of wireless communication node **700** also differs from Module A (discussed above in the context of FIGS. **2-6**) with respect to the limitation that the multiple bi-directional links operate in a single frequency range at a given time. For example, signal beams 1 to N that connect wireless communication node **700** to wireless communication nodes **710** to **7N0** respectively may only operate within the same frequency range at a given instant of time. It is to be noted that at a different 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 the same as the frequency range of all the other N−1 beams at a given instant of time. Hence, with respect to 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 FIG. **7**, an interference profile at the receiver side with such point-to-multipoint network is inferior to an interference profile of point-to-multipoint network where a wireless communication node hosts multiple Module As and creates multiple point-to-point links as shown in FIG. **6**, where wireless communication node **601** uses two Module As to connect to wireless communication node **602** and wireless communication node **603** simultaneously. The main reasons of high interference with Module B may be due to (1) individual phased antenna array-based beams that are not as narrow as extremely narrow beams generated by metamaterial-based antenna of Module A and/or (2) all beams of Module B belonging to one wireless communication unit that cannot operate at different frequency ranges unlike multiple point-to-point narrow beams of wireless communication node that host multiple Module As.

[0080] Referring to FIG. **8**, another possible embodiment of wireless communication node **131** of FIG. **1** is shown as wireless communication node **800** and wireless communication node **810**. Wireless communication node **800** in FIG. **8** comprises a module labeled as "Module C." Module C comprises a 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 interacts with other nodes of a communication network that are external to the wireless communication node **800** via wired medium.

[0081] Module C also includes an ultra-wide band antenna embedded with the baseband unit. Module C is capable of generation, transmission, and reception of extremely short duration pulses (few pico seconds long) and uses pulse modulation (and its variations such as pulse amplitude modulation, etc.) to transmit data at extremely high rates (e.g., greater than 100 Gbps) 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. One of ordinary skill in the art will appreciate that the range of frequencies used by pulses generated by Module C of wireless communication unit **800** can take a different range as well. Moreover, multiple module Cs can be placed together to create a 1, 2, or 3 dimensional array. Elements of this array (e.g., module C) are capable of performing a time synchronized transmission for beam forming. This allows the RF signal energy of the Pico second/UWB pulses to focus in a desired (receiver) direction and can also enable the creation of null or low RF signal energy of the Pico second/UWB pulse in other directions to avoid interference.

[0082] One fundamental difference between the characteristic of signals generated by Module C and signals generated by Module A and/or Module B is that these signals generated by Module C are ultra wide band (UWB) signals and their power spectral density over the entire range of frequencies is very low. In this respect, 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.

[0083] As further shown in FIG. **8**, Module C of wireless communication node **800** and Module C of wireless communication unit **810** establish a link **801** by working together. 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 FIG. **8**) such as wireless communication nodes with Module A or Module B that operate on a narrow band of frequencies compared 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.

[0084] In another preferred embodiment, in line with the discussion above, wireless communication node **131** in FIG. **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.

[0085] As one example to illustrate, referring to FIG. **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 together 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 (1) a module of wireless communication node **930** to establish bi-directional beam **902**, (2) a module of wireless communication node **940** to establish bi-directional beam **903**, (3) a module of wireless communication node **950** to establish bi-directional beam **904**, and (4) a 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** may all operate within the same range of carrier frequencies at a given time. In another embodiment, extremely narrow beam **901** may operate within a different range of frequencies compared to the range of frequencies used by the group of beams including **902**, **903**, **904** and **905** at a given time.

[0086] In one embodiment, Module A and Module B of wireless communication node **910** can be inside the same physical enclosure. In other embodiments, Module A and Module B of wireless communication node **910** can be inside two separate physical enclosures. In such embodiments where Module A and Module B belong to the same wireless communication node contained in separate physical enclosures, Module A and Module B can be connected via a wired link as they are co-located in the same seed home or anchor home.

[0087] In FIG. **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, it should be understood that wireless communication node **910** can host more than two modules (e.g., a combination of one or more Module As and one or more Module Bs) and the maximum number of total modules that a wireless communication node can host may depend on the maximum total power available to the wireless communication node. Further, it should be understood that in one embodiment, all modules belonging to same wireless communication node may operate on the same carrier frequencies of a frequency band but in other embodiments, different modules belonging to the same wireless communication node may operate on different carrier frequencies of a frequency band.

[0088] As noted above, wireless communication nodes **131** in FIG. **1** can host more than one type of module. This allows a wireless communication node to communicate simultaneously with multiple wireless communication nodes and with different interference profiles.

[0089] As another example to illustrate, referring to FIG. **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 together to establish extremely high data rate ultra-wide frequency and low power spectral density beam-based link **1001** to provide wireless connection between wireless communication nodes **1010** and **1020**. 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 (1) a module of wireless communication node **1030** to establish bi-directional beam **1002**, (2) a module of wireless communication node **1040** to establish bi-directional beam **1003**, (3) a module of wireless communication node **1050** to establish bi-directional beam **1004**, and (4) a module of wireless communication node **1060** to establish bi-directional beam **1005**.

[0090] In one embodiment, Module C and Module B of wireless communication node **1010** can be inside same physical enclosure. In other embodiments, Module C and Module B of wireless communication node **1010** can be inside two separate physical enclosures. In such an embodiment where Module C and Module B belong to the same wireless communication node contained in separate physical enclosures, Module C and Module B can be connected via a wired link as they are co-located in same seed home or anchor home.

[0091] In FIG. **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, it should be understood that wireless communication node **1010** can host more than two types of module (e.g., a combination of Module A, Module B and/or Module C) and the maximum number of total modules that a wireless communication node can host may depend on the maximum total power available to the wireless communication node. It should be also understood that in one embodiment, all modules belonging to same wireless communication node may operate on same carrier frequencies of a frequency band, while in other embodiments, different modules belonging to same wireless communication node may operate on different carrier frequencies of a frequency band.

[0092] In another preferred embodiment, wireless communication nodes **131** in FIG. **1** can host more than one type of module and dynamically change the type of link between wireless communication nodes. 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.

[0093] As one example to illustrate, referring to FIG. **11**A, wireless communication node **1110** hosts a Module C or Module A along with a Module B. During time T1, Module A/Module C of wireless communication node **1110** and communication module of wireless communication node **1010** work together to establish either an extremely high date 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**. At substantially 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 (1) a module of wireless communication node **1130** to establish bi-directional beam **1102**, (2) a module of wireless communication node **1140** to establish bi-directional beam **1103**, (3) a module of wireless communication node **1150** to establish bi-directional beam **1104**, and (4) a module of wireless communication node **1160** to establish bi-directional beam **1105**.

[0094] Referring to FIG. **11**B, at a different time T2, due to some trigger, Module A/Module C of wireless communication node **1110** may dynamically switch 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 a 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 **1113** 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**, which may involve various factors, including but not limited to change from a LOS path to a non-LOS path due to a change in environment, increased interference, a change in position of wireless communication node **1120** or **1140** with respect to wireless communication node **1110**, instructions from higher layers, etc.

[0095] As shown in FIGS. **11**A-B, dynamic link switching may occur between wireless communication nodes **1110**, **1120** and **1140**. However, it should be understood that dynamic switching can also occur between different communication nodes.

[0096] In some instances, one or more wireless communication nodes may leave the communication network. In such case, links between nodes may be dropped and the communication network may dynamically re-align itself by adjusting/switching link types between the remaining number of wireless communication nodes in the communication network to best suit the needs to the wireless communication nodes and the communication network.

[0097] In some embodiments, wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160** can host multiple modules of the same or different types. For example, one or more 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 a first communication module (e.g., Module A or C) of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then a second communication module (e.g., 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 link using its Module B with the first communication module (e.g., Module A or C) of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then the second communication module (e.g., 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.

[0098] As another example, one or more of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160** can host two Module As or Module Cs. Hence, when wireless communication node **1110** makes a point-to-point link using its Module A or Module C with the first Module A or C of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then the second 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 the first communication modules (Module A or C) of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then the second 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.

[0099] As yet another example, wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160** can host multiple Module As or Module Cs and a Module B. For instance, one or more of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160** can host two Module As or Module Cs and one Module B. Hence, when wireless communication node **1110** makes a point-to-point link using its Module A or Module C with a first Module A or C of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then a second 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 a third communication module (e.g., 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 link using its Module B with the first communication module (e.g., Module A or C) of wireless communication nodes **1120**, **1130**, **1140**, **1150** and **1160**, then the second communication module (e.g., 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 a third communication module (e.g., 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.

[0100] 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 users of a wireless communication mesh network. Hence links established by Module A or Module C can act as a wireless backhaul for a mesh network while links established with Module B can provide access to individual users of a communication network.

[0101] In one embodiment, an entire wireless mesh can be composed of point-to-point links where both links providing backhaul and access have interference immunity. Although such links are more expensive due to the requirement of separate modules to establish individual links, such links are suitable when certain high service quality or reliability is required to be ensured for all customers of the network.

[0102] For example, FIG. **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 cither Module A or Module C. Hence wireless communication node **1201** is capable of establishing six point-to-point links. As shown, wireless communication node **1201** uses a 1.sup.st and 4.sup.th Module A/Module C to establish connections with location **1210** and location **1260** that serve as backhaul links, while wireless communication node **1201** uses a 2.sup.nd, 3.sup.rd, 5.sup.th and 6.sup.th Module A/Module C to establish point-to-point links with location **1220**, **1230**, **1250** and **1240** to provide access links. In this respect, links between locations **1200** and **1220**, locations **1200** and **1230**, locations **1200** and **1240**, and locations **1200** and **1250** only carry data for individual users, whereas links between locations **1200** and **1260** and locations **1200** and **1210** carry signaling and data for all the locations including **1200**, **1210**, **1220**, **1230**, **1240**, **1250** and **1260**.

[0103] In another embodiment, an 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. Although such wireless mesh networks due to presence of point-to-multipoint links provide interference immunity to all the users of the communication network, such wireless mesh networks are less expensive due to the non-requirement of separate modules to establish individual links.

[0104] For example, FIG. **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 cither Module A/Module C or Module B. Hence this wireless communication node is capable of establishing two point-to-point links and two point-to-multipoint links. As shown, wireless communication node **1301** uses a 1.sup.st and 4.sup.th Module A/Module C to establish connections with location **1310** and location **1360** that serve as backhaul links, while wireless communication node **1301** uses a 2.sup.nd Module B to establish point-to-

multipoint links with locations **1320**, **1330** and uses a 3.sup.rd Module B to establish point-to-multipoint links with locations **1350** and **1340** to provide access links. In other words, links between locations **1300** and **1320**, locations **1300** and **1330**, locations **1300** and **1340** and locations **1300** and **1350** only carry data for individual users, whereas links between locations **1300** and **1360** and locations **1300** and **1310** carry signaling and data for all the locations including **1300**, **1310**, **1320**, **1330**, **1340**, **1350** and **1360**.

[0105] Referring to FIG. **14**, another possible embodiment of wireless communication node **131** of FIG. **1** is shown as wireless communication node **1400**. Wireless communication node **1400** comprises a single module labeled as "Module D." Module D comprises 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 the communication network that are external to the wireless communication node **1400** via wired medium.

[0106] Module D also includes RF unit **1402**, which among other things processes intermediate frequency (IF) signals and defines the frequency range of the radio signals that can be transmitted or received with the Module D. RF unit **1402** is capable of operating over a wide range of frequencies (e.g., 5 Ghz band frequencies ranging from 5 Ghz to 6 Ghz).

[0107] Further, as shown, Module D also comprises 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** may be constructed with either 1-dimensional or 2-dimensional 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 unit **1403** is capable of establishing point-to-multipoint links with a 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 an integrated RF unit called RFIC.

[0108] Referring to FIG. **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 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 that can create multiple bi-directional narrow beam links simultaneously in all directions with 360 degrees of coverage area. In one embodiment, tower **1500** can operate in the 5 Ghz band including frequencies ranging from 5000 Mhz to 6000 Mhz. In other embodiments, tower **1500** and associated wireless communication nodes **1501**, **1502** and **1503** can operate within a different frequency band.

[0109] It should be understood that while FIG. **15** shows only one tower and three wireless communication nodes hosting Module D in the network, a given network can have multiple towers similar to tower **1500** and these towers can each be connected to a large number of wireless communication nodes hosting various other modules.

[0110] In accordance with the present disclosure, the route that a particular packet takes from a source to a destination may be dynamically selected based on factors including but not limited to link quality, loading, latency etc. For example, referring to FIG. **16**, communication system **1600** is shown that is similar to communication system **100** and has all the components described in the context of FIG. **1**. Additionally, system **1600** of FIG. **16** includes a tower **1610** which is similar to tower **1500** described in the context of FIG. **15**. In contrast to communication system **100** in FIG. **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 FIGS. **14-15** with tower **1610** using massive MIMO beamforming capabilities. Such links labeled 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.

[0111] In FIG. **16**, only one tower (i.e., tower **1610**) capable of massive MIMO point-to-multipoint communication is shown to be connected to five wireless communication nodes **131-135**. However, it should be understood that a communication system can also have more than one tower, each connected to multiple different wireless communication nodes hosting various other modules.

[0112] In areas within tower **1500**'s (and other towers of same type) coverage area, a given communication network can initially start in a point-to-multipoint manner, where tower **1500** (and other towers of same type) provides access to individual customers using sub 6 Ghz massive MIMO point-multipoint beams. Later, nodes in the given communication 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, the given communication network may evolve into a 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.

[0113] One of ordinary skill in the art will appreciate that a route a given packet takes from a source to a destination in this network may be optimized by considering various factors including latency, congestion, reliability etc. One of ordinary skill in the art will also appreciate that a given communication network can later add seed homes (e.g., seed homes **111** and **115** in FIG. **1**) along with tower/fiber access points **101** and **102** to provide alternate backhaul as per need basis.

[0114] 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 FIG. **17**, communication system **1700** is shown that is similar to communication system **100** and has all the components described in the context of FIG. **1**. Additionally, system **1700** of FIG. **17** includes a satellite **1710** which is capable of massive MIMO transmission and reception on frequencies including but not limited to 5-6 Ghz, similar to tower **1500** described in the context of FIG. **15**. In contrast to communication system **100** in FIG. **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 FIGS. **14-15** 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.

[0115] In FIG. **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, it should be understood that a communication system can also have more than one satellite, each connected to multiple different wireless communication nodes hosting various other modules.

[0116] In another embodiment, some of the wireless communication nodes that provide backhaul

functionality can be equipped with multiple communication modules that enable these wireless communication nodes to provide transport backhaul data between an end user and a network using multiple different types of communication links. For example, referring to FIG. **18**, communication system **1800** is shown that is similar to communication system **100** and has all the components described in the context of FIG. **1**. Additionally, system **1800** of FIG. **18** includes a satellite **1810** which is capable of massive MIMO transmission and reception on frequencies including but not limited to 5-6 Ghz, similar to tower **1500** described in the context of FIG. **15**. System **1800** also includes a massive MIMO cable tower **1820** which is also similar to tower **1500** described in the context of FIG. **15**.

[0117] In contrast to communication system **100** in FIG. **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 FIGS. **14-15** with satellite **1810** and tower **1820** using massive MIMO beamforming capabilities. Such links labeled as **1801**, **1802**, **1803** and **1804** can provide an 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 in the line-of-sight profile of a millimeter wave link between two wireless communication nodes. Specifically, satellite **1810** in FIG. **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.

[0118] In one embodiment, seed home **115** using wireless communication node **135** at a given 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 link coupled to tower/fiber access point **102**. Such trigger may include latency, bandwidth, packet loss requirements, etc. of a particular application.

[0119] FIG. **18** also shows an 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 though point to point/point-multi-point connections using millimeter wave through towers **101** or **102** via seed homes **111** and **115** respectively, among other options.

[0120] In one embodiment, wireless communication node **132** can dynamically switch its connection link to route data to and from end user home **113**. For example, due to some trigger similar to the 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**.

[0121] It should be understood that 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. It should also be understood that satellite links **1802** and **1804** can use the same frequency range of communications or can operate in different frequency ranges. Further, while FIG. **18** shows only one satellite (i.e., satellite **1810**) capable of massive MIMO point-to-multipoint communication that is connected to two wireless communication nodes **132** and **135**, it should be understood that a communication system can also have more than one satellite, each connected to multiple different wireless communication nodes hosting various other modules.

[0122] As further shown in FIG. **18**, tower **1820** 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** with options 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**.

[0123] 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 a given 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 link coupled to tower/fiber access point **101**. Such trigger may include latency, bandwidth, packet loss requirements, etc. of a particular application.

[0124] In FIG. **18**, only one tower (i.e., tower **1820**) capable of massive MIMO point-to-multipoint communication is shown to be connected to two wireless communication nodes **131** and **134**. However, it should be understood that a communication system can also have a different number of massive MIMO towers, each connected to multiple different wireless communication nodes hosting various other modules.

[0125] In another embodiment, one or more wireless communication nodes described above and discussed with respect to FIGS. **1-18** may additionally be an edge computing node by hosting a processor (separate or shared), memory, digital contents, software, and storage, among other components for computing, 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 a given communication system to provide cloud services in a distributed manner closer to an end user as wireless communication nodes are distributed across the network and provide an interface between the network and an end-user. This memory unit can store a copy of local digital contents and can additionally store portions of digital content that that are not local. The non-local digital contents among other things can include digital content belonging to other nodes. This provides content redundancy in a communication system. Hence, when an end user of a communication system requests for digital content, then this edge computing mechanism allows a request to be fulfilled in a variety of different ways, including a request processed by a local node and/or remote node based on various criteria including but not limited to latency, network congestion, etc. of the application making the request.

[0126] In accordance with the present disclosure, the wireless mesh network node equipment (point-to-point link modules, point-to-multipoint link modules, multiple point-to-point link modules, combination of multiple point-to-point and point-to-multipoint links, antennas for cellular small cells/CPEs and mm Wave equipment, cable, mounts, power supply boxes, etc.) that gets deployed and installed on a rooftop of a private infrastructure such as a single-family home can be consumer financed. For instance, in case of a customer meeting a certain credit score threshold (or any other credit checking criteria), the equipment required to add a millimeter wave mesh node at the customer's premises (i.e., to add the customer to the wireless mesh network) and provide high speed internet service may be financed by a bank on the behalf of the customer, and the customer may agree with the financing bank to re-pay the amount financed by the bank over a certain time period by making periodic (e.g. monthly) payments based on the terms and conditions of the agreement. This way, the customer becomes owner of the equipment (a wireless mesh network node) once the full financed amount is made to the financing bank. This customer can in one embodiment lease back the wireless mesh network node equipment installed on its property to the wireless mesh network operator that installed the wireless mesh network equipment on its property and provide high speed internet data service. In another embodiment, this customer can lease back the wireless mesh network node equipment installed on its property to the wireless mesh network operator that installed the wireless mesh network equipment on its property and provide high speed internet data service for a certain term (e.g., 18 months, 24 months, 36 months, etc.).

[0127] In some instances, this customer may be required to lease back the equipment to only that

operator which originally installed the equipment at the customer location and provided high speed internet data services. In other instances, this customer can lease back the equipment to any wireless internet network operator. In another instance, lease back of the equipment to an operator other than the operator which originally installed the network equipment at the customer location may only occur with the permission of the wireless internet network operator that originally installed that equipment at customer location. In yet another instance, such lease back to a different wireless internet network operator may only occur after expiration of the lease term with the original wireless internet network operator.

[0128] For a wireless internet network operator building and operating a wireless mesh network, the type of customer financing-based network deployment described above becomes a crowd sourcing or crowdfunding-based infrastructure roll out mechanism, where instead of one or few large entities, CAPEX is sourced from a pool of individuals who in some instances are the customers of the wireless mesh network operator. Such customers can get high speed internet data service from the wireless mesh network operator (operating using ptp/ptmp modules, other communication nodes and equipment and various variations discussed earlier in this disclosure) at a subsidized/discounted rate. In certain cases, such customers may get two separate bills periodically, one for the high-speed internet data service and other for the equipment financing from bank. In another case, customers can get a single consolidated bill from a wireless mesh operator.

[0129] In some instances, all customers of a wireless mesh operator can be based on consumer financing explained above in a neighborhood or market where wireless mesh operator offers its high-speed internet data service. In other instances, wireless mesh network's customers in a market or neighborhood can be financed through a variety of different ways including operator financing where wireless mesh operator pays for the equipment of the wireless mesh node, financed through bundling with a private utility or service that has a relatively smaller market size (e.g. home security/automation, solar energy, etc.) compared to market size of the high speed internet where a bundled service is offered and wireless mesh operator uses the marketing/sales commission received from the private utility or service provider to fund the wireless mesh node equipment, financed through the revenue generated from running blockchain platform based services on the wireless mesh network nodes along with the consumer/customer based financing that is explained earlier in the disclosure.

[0130] Further, in accordance with the present disclosure, the communications equipment including various types of ptp/ptmp modules, cellular small cell, etc. that were described above can be used to establish multiple point-to-point and/or point-to-multiple links where both network nodes of a wireless link, one from where a link originates and the second from where a link terminates (in general, nodes can switch roles dynamically between link originator and link terminator based on the direction of data flow), are located at the different customer locations and providing high speed internet service to the dwellers of the property where wireless mesh network node is deployed and installed. In some cases, one of the two nodes of the link can be at a location where the deployed equipment provides high speed internet service to the dwellers of the property at that location. In other instances, both nodes of the link may be at a location where the deployed equipment does not provide high speed internet service to the dwellers of the property at that location.

[0131] It should be understood that the length of the communication links of a wireless mesh network describe above may vary. For instance, the length of the communication links of a wireless mesh network established with the help of the various communication modules and equipment described above may be less than 300 meters on average. Alternatively, the length of the communication links of a wireless mesh network can be greater than 300 meters on average as well.

[0132] In accordance with the present disclosure, further disclosed herein are communication modules that employ direct RF (microwave/millimeter wave)-to-optical and direct Optical-to-RF

(microwave/millimeter wave) conversion. In one example implementation, the high-speed photo detectors can be used that directly translate an optical signal into a microwave signal. One of ordinary skill in the art will appreciate that 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. One of ordinary skill in the art will appreciate that 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.

[0133] FIG. **19** shows a communication module based on direct RF-to-Optical and direct Optical-to-RF conversion. Communication module of FIG. **19** contains a single direct RF-to-Optical sub-module and a single Optical-to-RF sub-module. However, communication module of FIG. **19** can host any integer number of direct RF-to-Optical sub-modules greater than or equal to zero and any integer number of direct Optical-to-RF sub-modules greater than or equal to zero. In one example embodiment, this direct RF-to-Optical and direct Optical-to-RF conversion technology can be implemented is an integrated Circuit (IC) or chip.

[0134] Based on the above explanation with respect to the example communication module of FIG. **19**, in an example 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 example embodiment, a standard 8-port×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 FIG. **20**. One of ordinary skill in the art will understand that the router/switch can have a different number of ports as well.

[0135] These multiple distributed locations can be determined in advance 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 a roof's eaves and in other embodiments, these end points can be placed above a roof's caves. In some other embodiments, some of the Optical-to-RF or RF-to-Optical end points can be placed below a roof's eaves and some can be placed above a roof's eaves and actual placement may depend upon the line-of-sight profile of the location/site.

[0136] It should be understood that the example communication module discussed in the context of FIGS. **19**-**20** can be implemented in other communication modules that were discussed in the context of FIGS. **1**-**18**. For instance, the modules discussed in the context of FIGS. **1**-**18** can have direct RF-to-Optical and direct Optical-to-RF technology embedded such that the narrow beam, extremely narrow beam, and/or ptp/ptmp/multiple ptp links can be established without the need for ADC/DAC mixed signal circuitry that consumes a high amount of power and requires to be connected individually with each antenna.

[0137] In accordance with the present disclosure, a modified version of the communication nodes discussed earlier for building a wireless mesh network will now be discussed. In one embodiment, a communication node can be a flexible millimeter wave radio equipment capable of establishing multiple point-to-point and/or point-to-multipoint links operating over millimeter wave frequencies

and can comprise 3 different sub-modules: (1) digital/network module, (2) point-to-point radio module, and (3) point-to-multipoint radio module. A digital/network module is responsible for interfacing the above millimeter wave radio box (communication node) with a backhaul or fiber network. Specifically, it provides switching capability to direct traffic between the point-to-point or point-to-multipoint radio modules of the millimeter wave radio box (communication node) and the fiber or backhaul network. The connectivity between a single or multiple point-to-point and/or point-to-multipoint radio modules of the millimeter wave radio box and the backhaul or fiber network can be based over a variety of interfaces including but not limited to PCI/PCI express bus interface and ethernet.

[0138] In one embodiment, PCI/PCIe can be used when a point-to-point or point-to-multi-point radio that needs to be connected is enclosed in the same box with a digital/network module and separation between the digital/network module and the point-to-point module is limited to few inches such as 3-6 inches or less.

[0139] In one embodiment, a digital/network module provides connectivity to a single point-to-point or point-to-multipoint module over a single PCI/PCIe bus interface. In a different embodiment, a digital/network module provides connectivity to 3 point-to-point or 3 point-to-multipoint or a combination of 3 point-to-point/point-to-multipoint modules over three separate PCI/PCIe bus interfaces. In another embodiment, a digital/network module provides connectivity to N point-to-point or N point-to-multipoint or a combination of N point-to-point/point-to-multipoint modules over N separate PCI/PCIe bus interfaces, where N is a positive integer number greater than zero.

[0140] An ethernet interface such as an RJ45 port with multi-gigabit support, including but not limited to 1 Gb, 2.5 Gb, 5 Gb, 10 Gb, etc., can be used to connect point-to-point or point-to-multipoint radio modules with a digital/network module. In one embodiment, an ethernet interface can be used when the point-to-point or point-to-multi-point radio that needs to be connected is not enclosed in the same box with a digital/network module and separation between digital/network module and the point-to-point module is greater than 3-6 inches. In some embodiments, the length can be 10 meters or more.

[0141] In one embodiment, a digital/network module provides capability of connecting up to 4 point-to-point/point-to-multipoint radios or up to 3 point-to-point/point-to-multipoint radio and a small cell over 4 ethernet interfaces. In a different embodiment, a digital/network module provides capability of connecting up to N point-to-point/point-to-multipoint radios or up to N−1 point-to-point/point-to-multipoint radio and a small cell over N ethernet interfaces, where N is a positive integer number greater than zero. Digital/network module also contains SFP/SFP+ interface or any other interface to connect digital/network module with fiber/backhaul network.

[0142] The point-to-multipoint radio module of the communication node discussed above is responsible for establishing point-to-multipoint millimeter wave based bi-directional links to connect to peer millimeter wave radios in the network. point-to-multipoint radio module comprises a baseband sub-module and RF module. Baseband module handles the baseband processing and among other aspects is responsible for baseband processing related to beamforming. RF module contains phased antenna array that works in conjunction with baseband module to generate point-to-multipoint millimeter wave beams.

[0143] The point-to-point radio module of the communication node described above is responsible for establishing point-to-point millimeter wave based bi-directional links to connect to a peer millimeter wave radio in the network. The point-to-point radio module comprises a baseband sub-module, RF module and beam narrowing module. The baseband module handles the baseband processing and, among other aspects, is responsible for baseband processing related to beamforming. RF module contains phased antenna array that works in conjunction with baseband module to generate point-to-point millimeter wave beam. A beam narrowing module is responsible for narrowing the beam by focusing most of the radiated signal energy in the desired direction and

lowering the antenna side lobes to minimize the interference in a mesh network.

[0144] In one embodiment, the beam narrowing module can be a lens antenna integrated with an RF module. In another embodiment, the beam narrowing module can be a parabolic antenna integrated with an RF module. In yet another embodiment, the beam narrowing module could be a module other than a lens or parabolic antenna and rely on a different approach to narrow the beam originating from a phased array based RF module.

[0145] Referring to FIG. **21**, a logical block diagram of the communication module described above is shown. As explained earlier, a flexible millimeter wave radio node contains within an enclosure (typically outdoor) a digital/network module that has a network processing unit and is configured to provide network switch operations between the fiber optic backhaul interface and the point-to-point or point-to-multipoint radio modules either connected via PCI/PCIe interface or via multi gigabit ethernet ports. A flexible millimeter wave radio module also contains within the enclosure 3 point-to-point or point-to-multipoint radios. For providing mesh network deployment flexibility, a node can also be connected to external ptp/ptmp radios via ethernet ports. A node can be solar powered or can be powered via electric power outlet of the home where the node is installed. FIG. **21** also shows that this flexible millimeter wave radio node may only need a single network processing unit (NPU) that controls all the point-to-point or point-to-multipoint RF modules either connected via a PCI/PCIe interface or via a multi gigabit ethernet interface. Hence this example flexible millimeter wave radio node removes the need for using a dedicated NPU for each ptp/ptmp RF module.

[0146] FIG. **22** shows a block diagram of a ptmp radio module of the communication node described above. As shown, this radio module contains a baseband module and a RF module that has the phase antenna array for providing beamforming capability.

[0147] FIG. **23** shows a block diagram of the ptp radio module of the communication node discussed above. This radio module contains a baseband module, an RF module that has the phase antenna array for providing beamforming capability, along with a beam narrowing module. The beam narrowing module, based on various techniques discussed earlier, narrows the beam generated by the phase antenna array of the RF module.

[0148] Referring to FIG. **24**, various different use cases of the communication node described above and explained in the context of FIGS. **21-23** is shown. FIG. **24** shows a mesh network comprising 5 communication nodes **3700**. Communication nodes **3700** may each be a flexible millimeter wave communication node that has been discussed earlier.

[0149] At "Site A" of the mesh network, a communication node **3700** may be solar powered and mounted on the pole. This node **3700** at Site A may have 3 ptp links generated by 3 ptp radio modules integrated with the digital/network module. At "Site B," a communication node **3700** may be powered with an electric power outlet of the home and may have one ptp link via a single integrated ptp radio module and 2 ptmp links via two ptmp radio modules that are not integrated with a digital/network module but instead connected via ethernet interface to the communication node. Similarly, at "Site C," a communication node **3700** may be powered with an electric power outlet of the home and may have two ptp links via two integrated ptp radio module and one ptmp radio module integrated with a digital/network module. At "Site E," a communication node **3700** may be powered with an electric power outlet of the home and may have two ptp links via two integrated ptp radio module. Further, at "Site D," a communication node **3700** may be powered with an electric power outlet of the home and may have two ptp links via two integrated ptp radio module and one ptmp radio module integrated with the digital/network module.

[0150] Referring to FIG. **25**A, another use case of the communication node described above is shown. In particular, FIG. **25**A shows an example mesh network that includes communication nodes **3700** at the 5 sites previously described with respect to FIG. **24**, as well as an additional communication node **3700** at "Site A2." Similar to communication node **3700** at "Site A," communication node **3700** at "Site A2" may be mounted on a pole (among other possibilities).

[0151] Based on the preceding disclosure (e.g., the disclosure in connection with FIGS. **5-7**, **9-11**, **13**, and **16-18**), one of ordinary skill in the art will appreciate that each communication node **3700** at a given site may have the capability to communicate with multiple other communication nodes at multiple other sites. For instance, communication node **3700** at "Site B" may have the capability to communicate with the respective communication nodes **3700** at both "Site A" and communication node **3700** at "Site A2." Similarly, the respective communication node **3700** at each of "Site C," "Site D," and "Site E" may have the capability to communicate with the respective communication nodes **3700** at both of "Site A" and "Site A2."

[0152] Furthermore, based on the preceding disclosure (e.g., the disclosure in connection with FIGS. **5**, **11**, and **18**), one of ordinary skill in the art will appreciate that each communication node **3700** at a given site (e.g., communication node **3700** at "Site B") may have the capability to dynamically switch its active communication link from a first communication node **3700** at a first site (e.g., communication node **3700** at "Site A") to a second communication node **3700** at a second site (e.g., communication node **3700** at "Site A2") based on some trigger that is similar to the triggers described above (e.g., changes in link condition such as a change from a LOS path to a non-LOS path due to a change in environment, increased interference, instructions from higher layers, latency, bandwidth, and/or packet loss requirements of a particular application, etc.).

[0153] For instance, in the scenario shown in FIG. **25**A, the respective communication node **3700** at each of "Site B," "Site C," "Site D," and "Site E" may initially be configured to actively communicate with the communication node **3700** at "Site A" (which may function to route backhaul traffic to and/or from such other sites). However, at some later point in time, the communication node **3700** may dynamically switch its active communication link from the communication node **3700** at "Site A" to the communication node **3700** at "Site A2" (which may also function to route backhaul traffic to and/or from such other sites) due to some trigger similar to the triggers described above. Such a scenario is shown in FIG. **25**B.

[0154] It should be understood that FIGS. **24-25** are described in such a manner for the sake of clarity and explanation and that the example mesh networks described in FIGS. **24-25** may take various other forms as well. For instance, the example mesh networks may include more or less communication nodes, and a given communication node may take various other forms and may be mounted in various other manners and/or mounted on various other objects as well (e.g., mounted on a pedestal). Further, in line with the preceding disclosure, one or more of the communication nodes (e.g., the communication nodes **3700** at "Site A" and "Site A2) may be mounted to an object that is at or near a fiber access point. Further yet, the example mesh networks may have various different configurations of ptp or ptmp modules either integrated or connected via an ethernet interface and powered via various different power options.

[0155] Another important aspect of communication node **3700** is that the integrated radio modules can be pluggable. In other words, based on a specific use case, the number and types of radio modules integrated with a digital/network module via PCI/PCIe interface can easily be changed by plugging in the desired number and type of radio modules with full flexibility instead of having one specific configuration.

[0156] So far the modified version of communication nodes discussed above and also described in the context of FIGS. **21-25** assumes that the point-to-point or point-to-multipoint modules connected to a digital/network module with an NPU via a high speed interface (e.g., PCI/PCIc/Thunderbolt) are also located inside a same enclosure. It should be understood that the point-to-point or point-to-multipoint modules connected to a digital/network module via high speed interface can also be located outside the digital/network module with the NPU and inside an independent box/enclosure connected via an outdoor cable supporting the PCI/PCIc/Thunderbolt high speed communication protocol to the enclosure of the digital/network module.

[0157] As one example, FIG. **26** depicts a modified version of a flexible millimeter wave radio box, where the point-to-point or point-to-multipoint RF modules are located outside a digital/network

module with NPU enclosure and inside separate independent box/enclosure and connected via an outdoor wired cable capable of supporting high speed communication interface (e.g., PCI/PCIc/Thunderbolt Interface). As shown, 3 point-to-point or point-to-multipoint modules are connected via PCIc/Thunderbolt interfaces to the digital/network module with the NPU using a compatible outdoor cable.

[0158] In general, it should be understood that N number of point-to-point or point-to-multipoint modules in separate independent enclosures can be connected via a PCIc/Thunderbolt compatible outdoor cable, where N is an integer greater than zero. It should also be understood that the length of the outdoor cable compatible with high speed communication protocol, such as PCIc/thunderbolt, depends on the maximum limit defined by the technology. In one embodiment, PCIc/thunderbolt cable can be up to 3 meters. In other embodiments, the length of the outdoor PCI/PCIc/thunderbolt compatible cable can be less than or greater than 3 meters.

[0159] In yet another embodiment of the present disclosure, a wireless mesh network may include ultra-high-capacity nodes that are capable of establishing ultra-high-capacity links (e.g., point-to-point or point-to-multipoint bi-directional communication links) using a millimeter wave spectrum, including but not limited to 28 Ghz, 39 Ghz, 37/42 Ghz, 60 Ghz (including V band), or E-band frequencies, as examples. These ultra-high-capacity links may have a larger range as compared to other point-to-point or point-to-multipoint links, including but not limited to point-to-point or point-to-multipoint links of the type discussed above with reference to FIGS. **1**-**26**.

[0160] For instance, as one possibility, a point-to-point or point-to-multipoint link of the type discussed above with reference to FIGS. **1**-**26** may have an average range of up to 100 meters, whereas an ultra-high-capacity link may have a range of more than 100 meters. As another possibility, a point-to-point or point-to-multipoint link of the type discussed above with reference to FIGS. **1**-**26** may have an average range of up to 500 meters, whereas an ultra-high-capacity link may have a range of more than 500 meters. As yet another possibility, a point-to-point or point-to-multipoint link of the type discussed above with reference to FIGS. **1**-**26** may have an average range of up to 1000 meters, whereas an ultra-high-capacity link may have a range of more than 1000 meters.

[0161] However, in other implementations, it is possible that the length of an ultra-high-capacity link may be similar to the length of a point-to-point or point-to-multi-point links of the type discussed above with reference to FIGS. **1**-**26**, but may nevertheless provide higher capacity such that a fewer number of ultra-high-capacity nodes/links may be used (as compared to the point-to-point or point-to-multipoint nodes/links of the type discussed above with reference to FIGS. **1**-**26**) to build a main high capacity backbone through the mesh (i.e., the ultra-high-capacity nodes/links may be more sparse).

[0162] The higher capacity and/or extended range of these ultra-high-capacity nodes/links may be achieved via various advanced signal processing techniques, including but not limited to multiple input multiple output (MIMO) such as 2×2 MIMO, 4×4 MIMO, 8×8 MIMO or an even higher order MIMO, use of vertical and horizontal polarization (V & H), higher switch capacity of the digital network module due to higher processing power such as support of 8×25 Gbps port (200 Gbps aggregate traffic flow), higher order modulation including 16QAM, 64QAM, 256QAM, 512 QAM, 1024 QAM, orbital angular momentum (OAM) multiplexing, and/or higher antenna gains, among other possibilities. Further, in some implementations, the higher capacity and/or extended range of these ultra-high-capacity nodes/links can be achieved using a subset of the advanced signal processing techniques mentioned above.

[0163] These ultra-high-capacity nodes/links may be used in conjunction with other point-to-point and/or point-to-multipoint links, including but not limited to point-to-point or point-to-multipoint links of the type discussed above with reference to FIGS. **1**-**26**, to design a multi-layer wireless mesh network.

[0164] To illustrate with an example, FIG. **27** shows one example of a multi-layer wireless mesh

network in which triple-compound links represent the ultra-high-capacity links described above, double-compound rings represent point-to-point links of the type discussed above with reference to FIGS. **1-26**, and single-line links represent point-to-multipoint links of the type discussed above with reference to FIGS. **1-26**.

[0165] As shown in FIG. **27**, longer ultra-high-capacity links may be used bring a high level of capacity to the wireless mesh network, which can then be delivered to an end user/customer via a shorter point-to-point or point to multi point link (which may not be ultra-high-capacity). It should also be understood that while the point-to-multipoint links may primarily serve to provide flexibility in building the wireless mesh network due to the capability of beam steering and ability to establish multiple links from a single radio, these point-to-multipoint links may also be used to indirectly connect two point-to-point links via multiple point-to-multipoint link hops that can add additional reliability to the network.

[0166] Further, it should be understood that a multi-layer wireless mesh network such as the one illustrated in FIG. **27** can be deployed in various manners. For instance, in one implementation, different layers of the multi-layer mesh network can be deployed in parallel. In another implementation, different layers of the multi-layer wireless mesh network can be deployed in different phases. For example, a deployment approach for a multi-layer wireless mesh network may involve first building a core network backbone (e.g., an ultra-high-speed network) using ultra-high-capacity nodes/links and then densifying the network during one or more subsequent phases using other types of point-to-point or point-to-multipoint nodes/links, including but not limited to point-to-point or point-to-multipoint radio links of the type discussed above with reference to FIGS. **1-26**. In another example, a deployment approach for a multi-layer wireless mesh network may involve first building a network of point-to-point nodes/links that are not ultra-high capacity and then later upgrading capacity by adding ultra-high-capacity nodes/links. A multi-layer wireless mesh network can be deployed in other manners as well.

[0167] One variation of the multi-layer mesh architecture described above is that the ultra-high-capacity links can be designed to create specific paths based on a traffic requirement and/or some other criteria defined by the operator. To illustrate with an example, FIG. **28** shows another example of a multi-layer wireless mesh network in which some of the preexisting, non-ultra-high-capacity point-to-point links included in the example multi-layer wireless mesh network of FIG. **27** are replaced by ultra-high-capacity links (shown as triple-compound links) to provide ultra-high capacity to specific segments of the wireless mesh network. This can be done either by supplementing the hardware of the preexisting, non-ultra-high-capacity nodes at the customer location with new hardware (e.g., a new radio or other associated hardware) capable of establishing ultra-high-capacity links or by replacing the hardware of the preexisting, non-ultra-high-capacity nodes at the customer location with new hardware (e.g., a new radio or other associated hardware) capable of establishing ultra-high-capacity links.

[0168] Another variation of the multi-layer mesh architecture described above is that different layers of the wireless mesh network may be deployed at different heights, which may create physical-link separation by allowing re-use of the available frequency spectrum. For instance, in one implementation, a multi-layer wireless mesh network can have at least 2 layers of ultra-high-capacity links operating in the same frequency range, but at different heights. To illustrate with an example, a first layer of ultra-high-capacity links can be deployed at a lower height, such as by installing the required hardware at a lower height within a structure hosting the wireless mesh hardware (e.g., on a lower floor of a building), and a second layer of the ultra-high-capacity links can be deployed at a higher height, such as by installing the required hardware at a higher height of the structure hosting the wireless mesh hardware (e.g., at higher floor of the building). In this respect, the deployment of these different layers of ultra-high-capacity links at different heights may serve to increase the capacity of the multi-layer wireless mesh network.

[0169] While the foregoing example involves the deployment of multiple different layers of ultra-

high-capacity links at multiple different heights, it should be understood that this example is merely provided for purposes of illustration, and that multiple layers of wireless mesh links of any type may be deployed at different heights in order to enhance the overall capacity of the multi-layer wireless mesh network, including but not limited to layers of ultra-high-capacity links, non-ultra-high-capacity point-to-point links, and/or non-ultra-high-capacity point-to-multipoint links.

[0170] Yet another variation of the multi-layer mesh architecture described above is that the point-to-multipoint links that are not ultra-high capacity (which are shown in FIGS. **27** and **28** as single-line links) may be replaced by wired links, such as a coaxial wire loop, fiber loop or some other type of wired link. To illustrate with an example, a multi-layer mesh network may include wired links that comprise the coaxial portion of the HFC (Hybrid Fiber Coax) used by the cable companies, in which case this coaxial portion of the HFC may bring mesh network connectivity to end users while the fiber portion of the HFC may bring the high-speed internet to the neighborhood. In this respect, the wireless mesh links consisting of ultra-high-capacity links (which are shown in FIGS. **27** and **28** as triple-compound links) and/or non-ultra-high-capacity point-to-point links may play the role of the fiber equivalent portion of the HFC by bring high capacity from a fiber POP to the neighborhood.

[0171] In accordance with yet another aspect of the present disclosure, some of the wireless communication nodes described above (e.g., wireless communication nodes operating as part of a wireless mesh network) may additionally be installed with equipment that enables them to operate as blockchain nodes. For instance, such a wireless communication node may be equipped to host a computing system comprising at least one processor, memory, stored digital content (which may include non-fungible tokens (NFTs) in some examples), software, etc., where that computing system is connected to a blockchain network and comprises a client that is capable of storing, validating, and/or relaying transactions in addition to the high-speed, low latency networking capability that has already been described above.

[0172] For instance, as discussed above, a communication system that is based on the wireless mesh network technologies disclosed herein may include different tiers of sites that are installed with wireless communication equipment for operating as different tiers of nodes within a wireless mesh network-including wireless communication nodes at fiber POP sites (i.e., fiber PoP nodes), seed homes (i.e., seed nodes), and anchor homes (i.e., anchor nodes)—and these different tiers of sites/nodes may be interconnected together via wireless point-to-point and/or point-to-multipoint links (e.g., millimeter-wave links) in order to form the wireless mesh network. In accordance with this aspect of the present disclosure, some or all of these sites could then additionally be installed with equipment for operating as blockchain nodes within a blockchain network, where the additional equipment installed at each such node may take the form of a blockchain-enabled computing system comprising hardware and associated software for performing functions related to any of various types of Blockchain-based applications and/or services.

[0173] In some implementations, the blockchain-enabled computing systems that are installed at the different tiers of nodes of the wireless mesh network may also have different levels of processing power. For instance, the blockchain-enabled computing systems installed at fiber PoP nodes of a wireless mesh network may generally have the highest level of processing power within the communication system, the blockchain-enabled computing systems installed at seed nodes of the wireless mesh network may generally have the second highest level of processing power within the communication system, and the blockchain-enabled computing systems installed at anchor nodes of the wireless mesh network may generally have the third highest level of processing power within the communication system. In this respect, the processing power of the edge computer systems may be defined based on various factors, examples of which may include clock speed, memory size, number of processing cores, and/or total number of physical computers/servers, among other possibilities.

[0174] Various other implementations of the blockchain-enabled computing systems are possible as

well.

[0175] This novel architecture enables wireless communication nodes within a communication system to serve a dual purpose of delivering both mesh-based applications and/or services to users, such as high-speed internet, as well as blockchain-based applications and/or services to users. Such a novel architecture provides various advantages over existing architectures where the communication nodes are only capable of serving one of these purposes. For instance, in the architecture disclosed herein, the blockchain nodes are capable of communicating wirelessly with one another via the mesh networking technologies disclosed herein, which may provide various advantages over existing architectures for interconnecting blockchain nodes, including high capacity (e.g., a bandwidth ranging from 20 gigabits per second to 100 gigabits per second bi-directionally) and low latency (e.g., less than 1 millisecond for point-to-point links and less than 4 milliseconds for point-to-multipoint links). Further, by enabling the wireless communication nodes of a wireless mesh network to also operate as blockchain nodes, this may reduce the need to separately deploy blockchain nodes in order to provide blockchain-based applications and/or services to users, which may provide various efficiencies with respect to installing, hosting, overseeing, and/or maintaining blockchain nodes, among other possible efficiencies. The novel architecture disclosed herein may provide other advantages as well.

[0176] The blockchain-based applications and/or services that can be provided by this novel architecture may take any of various forms.

[0177] For instance, as one possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may provide an ideal platform for blockchain databases, enterprise blockchain databases, permissioned/private blockchains, hybrid and other similar types of databases given that (1) file/data/record storage space is inherently distributed as wireless communication nodes are distributed across the geographical coverage area and (2) low latency communication between the nodes and across the network due to high-speed wireless links that enable improved latency and improve the transaction throughput of the blockchain based databases. As another possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may function to provide a distributed, blockchain-based content distribution platform, of which one example is a peer-to-peer media streaming platform. In such a blockchain-based content distribution platform, the blockchain nodes may be configured to retrieve, transmit, and store created digital content (which may include NFTs in some examples) from other blockchain nodes in the blockchain network. In this respect, each blockchain node operating in the content distribution platform may perform various functions.

[0178] As one possibility, a blockchain node operating within the content distribution platform may be configured to perform functions related to content creation. In this respect, the blockchain node may facilitate the addition and management of content on the blockchain network. For example, a user may capture or upload media content to the blockchain node. Upon upload of the media, the blockchain node may function to award the user with a digital certificate that can subsequently be used to verify that the user was the author of the media content. The blockchain node may then function to assign the media content a unique identifier, such as an ID associated with the Entertainment Identifier Registry (EIDR). The unique identifier may facilitate the management of the created content in that it provides the content developer the ability to trace all transactions related to the created content over the blockchain network. This may be advantageous in that it eliminates the piracy and misappropriation of the created content by allowing the content developer to control the number of copies that are created and trace all transactions involving the created content.

[0179] As another possibility, a blockchain node operating within the content distribution platform may be configured to perform functions related to content contribution. In this respect, the blockchain node may facilitate the contribution to content previously created on the blockchain

network. For example, a user may be assigned a task from a content developer that involves editing a video that has already been added to, or will soon be added to, the content distribution platform. In return, the content developer may be willing to share a certain percentage of the total value of the created content. Thus, if the task is sufficiently completed, the content developer may assign a percentage of ownership to the created content and pay the contributor a previously agreed upon amount. To this end, the contribution may be assigned a transaction identifier. The transaction identifier is then stored on the blockchain network to create a record of the contribution agreement, which may assist in solving any future disputes related to ownership of the created content.

[0180] As yet another possibility, a blockchain node operating within the content distribution platform may be configured to perform functions related to accessing content on the content distribution platform. In this respect, the blockchain node may facilitate the accessing of content that was previously created and available on the blockchain network. For example, an end user may register with the content distribution platform and access a list of content that is available. In some implementations, the content distribution platform may provide a search functionality to the end user that provides the end user the ability to search a list of content that is available on the content distribution platform. When the end user has located the content they wish to access, the end user may be able to request to buy and/or rent a license to access and view the desired content. The price may be set by the content's creator, or the end user may make an offer that can be accepted or rejected by the content creator. Once an agreement is reached, the end user may remit payment to the content creator. In some implementations, the end user may remit payment using a cryptocurrency associated with the blockchain network. Once payment is remitted, the end user may have access to the purchased content. To access the purchased content, the blockchain node that is associated with the end user may function to request, retrieve, and stream and/or download the content for the end user to view. Similar to above, this transaction may be stored on the blockchain network such that the content creator can view the purchase when managing the media content and the end user has proof of purchase.

[0181] Each blockchain node operating on the content distribution platform may perform various other functions as well, including but not limited to functions that are related to creation or distribution of NFTs.

[0182] As an illustrative example, referring to FIG. **1**, communication nodes **133**, **134**, and **135** may form a blockchain-based content distribution platform. In this example, communication node **133** may perform functions related to content creation, communication node **134** may perform functions related to content contribution, and communication node **135** may perform functions related to accessing the created content. In this example, a content developer may create content that is stored at communication node **133** and assigned a unique identifier that is stored on the peer-to-peer network. The content developer may want the content to be reviewed and edited and submits a request for contribution that is advertised on the blockchain-based content distribution platform. A content contributor may see the request and place a bid to provide the contribution. Upon acceptance by the content developer and completion of work by the contributor, the contributor is compensated in accordance with the agreement. As a result, the transaction is assigned an identifier that is stored on the blockchain network, which is subsequently stored on and accessible by each of communication nodes **133**, **134**, and **135**. Next, an end user may desire to access and view the created content. The end user may purchase rights to access and view the created content from the content developer using a cryptocurrency associated with the blockchain network. Upon remittance of payment, the end user may be able to access and view the content via the communication node **135**. It should be understood that while the example above is described with respect to each communication node performing specific functions in relation to the creation and access of content on the content distribution platform, each communication node is capable of performing any or all of the described functions. For instance, a communication node may function to perform functions related to content creation and functions related to accessing created content.

[0183] As another possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may function to provide a blockchain-based social media platform in which users' personal information and content can be stored and verified. In such a platform, each blockchain node may be capable of storing information related to users' social media profiles and facilitate payments between users. In this respect, each blockchain node in the network can perform various functions.

[0184] As one possibility, a blockchain node in a blockchain-based social media platform may be configured to perform functions related to securely storing a user's information. For instance, in a traditional social media platform, the information of all its users is stored at a centralized location and in many cases, this information is sold to advertisers. However, in a blockchain-based social media network, the information is stored across the network of blockchain nodes. For instance, when a user creates a social media profile on the blockchain-based social media platform, the user's profile is stored at the blockchain node where the user's profile was created and is then made accessible to other blockchain nodes operating on the social media platform. This may be advantageous as it prevents one entity from storing the information and thus being susceptible to selling users' personal information to the highest bidder.

[0185] As another possibility, a blockchain node in a blockchain-based social media platform may be configured to perform functions related to facilitating access to user content. For instance, once a user creates a profile to be shared on the blockchain-based social media platform, the profile may be accessible by other users via other blockchain nodes. In this respect, a blockchain node may be configured to request access to the user's profile. If accepted, the blockchain node may be provided with access to the user's profile. Further, the request and acceptance may be stored on blockchain nodes within the blockchain-based social media platform such that the request and acceptance can be accessed and reviewed in the future. This may be advantageous as this creates a record for the request, should it need to be viewed or disputed at a later time. Further, the record of the request and acceptance may function to reduce the number of artificial accounts on the network by serving as authentication that the user's profile is not artificial. This may be beneficial as it may lead to more accurate social media engagement statistics.

[0186] As another possibility, a blockchain node in a blockchain-based social media platform may be configured to perform functions related to advertising. In this respect, if a user advertises a particular product on their blockchain-based social media profile, the product owner can compensate the user.

[0187] As yet another possibility, a blockchain node in a blockchain-based social media platform may be configured to perform functions that facilitate the purchase and sale of products. In this respect, the blockchain-based social media network may provide an associated marketplace where users can offer for sale and purchase any variety of items. When a user agrees to sell, and another user agrees to purchase, a particular item, the transaction details may be stored on the blockchain network to keep a record of the transaction.

[0188] As still yet another possibility, a blockchain node in a blockchain-based social media platform may be configured to perform functions that facilitate compensation to users for continued use of the blockchain-based social media platform. In this respect, different blockchain-based social media networks may compete for users by offering compensation to users for participation in their blockchain-based social media platform. This may be advantageous to users in that they receive compensation for using a particular blockchain-based social media platform and may be advantageous to blockchain-based social media platform operators as it increases their market share when users actively use their blockchain-based social media platform.

[0189] Further, one aspect of each of the above functionalities is that users can send and receive payment through a cryptocurrency that is associated with the blockchain-based social media platform. As one example, when a blockchain node is configured to perform functions related to advertising, the advertiser may compensate the user promoting the product with an amount of

cryptocurrency that is associated with the blockchain-based social media platform. As another example, when a blockchain node is configured to perform functions that facilitate the purchase and sale of products, the purchaser may remit payment to the seller with an amount of cryptocurrency that is associated with the blockchain-based social media platform. Further, in this example, the transaction may be recorded and stored on the blockchain network to serve as proof of sale and purchase.

[0190] Each blockchain node in the blockchain-based social media network can perform various other functions as well.

[0191] As yet another possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may function to provide a blockchain-based gaming platform (e.g., the ROBLOX™ gaming platform) that can be accessed by users through client devices such as personal computers, smartphones, game consoles, and/or virtual reality (VR) headsets, among other possibilities. In such a platform, each blockchain node in the network can perform various functions.

[0192] As one possibility, blockchain nodes within a blockchain-based gaming platform may be configured to perform functions related to facilitating the creation of gaming-related virtual content. The created virtual content may take various forms. As one example, the created virtual content may take the form of a video game itself. In this respect, the blockchain node may function similarly to a blockchain node that is configured to facilitate content creation as described above with respect to blockchain nodes operating in a blockchain-based content distribution system. As another example, the created virtual content may take the form of a virtual world within a video game. As yet another example, the created virtual content may take the form of virtual items related to a video game (e.g., in-game assets such as avatars, skins, abilities, tools, etc.). The created virtual content may take other forms as well.

[0193] Once the virtual content is created, the virtual content may be added to the blockchain-based gaming platform and stored at various blockchain nodes therein. Further, instead of creating virtual content within the blockchain-based gaming platform, a user may create virtual content outside of the blockchain-based gaming platform and then upload that created virtual content to the blockchain-based gaming platform.

[0194] Upon creation or upload of virtual content by a user, a given blockchain node may function to award the user with a digital certificate that can subsequently be used to verify that the user was the author of the virtual content. The blockchain node may then function to assign the virtual content a unique identifier, such as an ID associated with the EIDR. The unique identifier may facilitate the management of the created virtual content in that it provides the content developer the ability to trace all transactions related to the created virtual content over the blockchain network. This may be advantageous in that it eliminates the piracy and misappropriation of the created virtual content by allowing the content developer to control the number of copies that are created and trace all transactions involving the created virtual content.

[0195] As another possibility, blockchain nodes within a blockchain-based gaming platform may be configured to perform functions that facilitate a user's ability to participate in a gaming-based virtual economy, such as by purchasing, selling, and/or trading virtual content within a video game. In this respect, blockchain nodes within a blockchain-based gaming platform may enable a purchaser of virtual content within a video game to remit payment to a seller of the virtual content in the form of cryptocurrency, tokens, or the like. Further, the blockchain nodes may record and store transactions within a virtual economy on the blockchain network to serve as proof of such transactions.

[0196] As yet another possibility, blockchain nodes within a blockchain-based gaming platform may be configured to perform functions related to controlling user access to video games within the blockchain-based gaming platform, such as by requiring users to transfer cryptocurrency to the creator of a video game and/or purchase certain types of tokens before the users are provided with

access to the video game.

[0197] As still another possibility, blockchain nodes within a blockchain-based gaming platform may be configured to perform functions related to compensating users for playing certain video games within the blockchain-based gaming platform, such as by issuing cryptocurrency and/or tokens to users for playing such video games.

[0198] As a further possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may function to provide a blockchain-based virtual experiences platform that enables users to access and enjoy other virtual experiences via client devices such as personal computers, smartphones, game consoles, and/or VR headsets, among other possibilities.

[0199] For instance, as one possibility, blockchain nodes within a blockchain-based virtual experiences platform may be configured to perform functions related to providing users with virtual access to a live event, such as a sporting event or a concert. In this respect, the blockchain nodes within such a blockchain-based virtual experiences platform may be configured to perform functions related to controlling and providing the users' virtual access to the live event, such as by requiring users to transfer cryptocurrency to an organization hosting the live event and/or to purchase certain types of tokens before the users are provided with virtual access to live media content.

[0200] In still another possible implementation, the wireless communication nodes in a wireless mesh network that are configured to operate as blockchain nodes may additionally be installed with equipment that enables them to act as blockchain-based distributed data storage nodes, such as by adding dedicated or shared storage capacity capability to these nodes, which may enable such blockchain nodes to function as part of a distributed, blockchain-based storage platform for user files and other data. One key advantage of implementing blockchain-based distributed data storage on a given communication system and the wireless communication nodes described in this disclosure is that storage nodes are inherently distributed, and due to the low latency and high bandwidth of the wireless communication links between the wireless communication node described above and the proximity of the storage location nodes to an end-user, accessing the data content can be faster compared to other approaches.

[0201] The wireless communication nodes disclosed herein may function to provide various other types of blockchain-based applications and/or services as well.

[0202] In embodiments where certain wireless communication nodes in a wireless mesh network are additionally configured to operate as blockchain nodes within a blockchain network, the wireless communication nodes may be configured to facilitate the retrieval and access of data stored at other wireless communication nodes. In this respect, the wireless communication nodes are capable of leveraging the blockchain network to facilitate the delivery of digital content (which may include NFTs in some examples) to one or more additional wireless communication nodes and/or validation of such digital content. The wireless communication nodes may utilize this functionality in various ways, which may include storing copies of digital content that is transmitted across multiple wireless communication nodes in a distributed manner.

[0203] For instance, referring to FIG. **1**, a user at anchor home **113** may desire to access given digital content (which may include an NFT in some examples) that is stored and/or accessible at communication node **124** installed at tower/fiber access point **102**. As such, the user may submit a request to access the given digital content that is initially received by communication node **133**.

[0204] In turn, communication node **133** may establish a connection with communication node **124** through a chain of wireless point-to-point links (which, as noted above, may comprise millimeter-wave links) with other intermediary communication nodes, such as communication nodes **132** and **135**/**123**. Once the connection is established, communication node **133** at anchor home **113** may send a communication to communication node **124**, using the chain of wireless point-to-point links, where that communication comprises a request to retrieve the given digital content from

communication node **124** that is based on the user's request to access the given digital content. In this respect, intermediary communication nodes **132** and **135/123** may each function to relay the communication from communication node **133** to the next communication node along the chain of wireless point-to-point links until that communication reaches communication node **124** (e.g., from node **132** to node **135/123** and then from node **135/123** to node **124**).

[0205] In response to receiving the request, communication node **124** may then retrieve and send the requested digital content to communication node **133** through the same chain of wireless point-to-point links (albeit in the opposite direction). In this respect, intermediary communication nodes **132** and **135/123** may each function to relay the requested digital content from communication node **124** to the next communication node along the chain of wireless point-to-point links until that communication reaches communication node **133** (e.g., from node **135/123** to node **132** and then from node **132** to node **133**). In some implementations, while relaying the digital content from communication node **124** to communication node **133** through the series of wireless point-to-point links, one or more of intermediary communication nodes **132** or **135/123** may also store a copy of the digital content (or at least a portion thereof) such that the one or more of intermediary communication nodes **132** or **135/123** may use the stored copy of the digital content when receiving a subsequent request for retrieval of the same digital content (e.g., based on a request from another user). In this respect, if one of intermediary communication nodes **132** or **135/123** receives a subsequent communication comprising a subsequent request for retrieval of the same digital content (either directly from the communication node that originated the communication or through another intermediary communication node), that intermediary communication node may be able to send its copy of the digital content (or at least a portion thereof) back to the originating communication node without needing to involve the communication node **124** at the tower/fiber access point **102** or any other communication nodes in between.

[0206] For instance, if communication node **132** stores a copy of the given digital content during the course of relaying it from communication node **124** to communication node **133** based on a first user's request, communication node **132** may then be capable of providing that copy of the given digital content in response to receiving a subsequent communication comprising a subsequent request for retrieval of the same given content. In this respect, the subsequent communication that is received by communication node **132** could be a communication originated by one of the communication nodes that is directly connected to communication node **132** via a single point-to-point link (e.g., communication nodes **133**, **135/123**, or **131/122**) or could be a communication originated by another communication that is connected to communication node **132** via a chain of multiple point-to-point links (e.g., communication node **134**).

[0207] In line with the discussion above, it should also be understood that the wireless communication nodes of FIG. **1** could be connected via point-to-multipoint links instead of point-to-point links (which, as noted above, may also comprise millimeter-wave links).

[0208] This functionality of storing copies of digital content at intermediary communication nodes may be advantageous in that it may reduce the number of wireless point-to-point links and communication nodes that are involved delivering requested digital content, which may in turn result in lower network usage and faster time to deliver the digital content. Additionally, this functionality of storing copies of digital content at intermediary communication nodes may also be advantageous in that retrieving requested digital content from one or more of the intermediary communication nodes may help to balance the network load across a blockchain network, instead of having all network communication flowing through the tower/fiber access point.

[0209] Turning now to FIG. **29**, a simplified block diagram is provided to illustrate some structural components that may be included in an example computing system **2900** that may be installed at an example wireless communication node of a wireless mesh network (e.g., one of the wireless communication nodes described above) in order to enable that wireless communication node to also operate as a blockchain node within a blockchain network. At a high level, example computing

system **2900** may generally comprise one or more physical computing devices (e.g., one or more personal computers, servers, or the like), and these one or more computing devices may collectively include at least a processor **2902**, data storage **2904**, and a communication interface **2906**, all of which may be communicatively linked by a communication link **2908** that may take the form of a system bus, a communication network, or some other connection mechanism.

[0210] Processor **2902** may comprise one or more processing components, such as one or more general-purpose processors (e.g., a single- or a multi-core central processing unit (CPU)), special-purpose processors (e.g., a graphics processing unit (GPU), application-specific integrated circuit, and/or digital-signal processor (DSP) such as a tensor processor), programmable logic devices (e.g., a field programmable gate array), controllers (e.g., microcontrollers), and/or any other processor components now known or later developed. In line with the discussion above, it should also be understood that processor **2902** could comprise processing components that are distributed across a plurality of physical computing devices connected via a network.

[0211] In turn, data storage **2904** may comprise one or more non-transitory computer-readable storage mediums that are collectively configured to store (i) program instructions that are executable by processor **2902** such that example computing system **2900** is configured to perform functions related to operating within a blockchain network and/or providing blockchain-based applications and/or services, among other possible functions, and (ii) data that may be received, derived, or otherwise stored by example computing system **2900** in connection with the disclosed functions (e.g., in one or more databases, file systems, object stores, or the like), including but not limited to digital content related to a blockchain-based application and/or service. In this respect, the one or more non-transitory computer-readable storage mediums of data storage **2904** may take various forms, examples of which may include volatile storage mediums such as random-access memory, registers, cache, etc. and non-volatile storage mediums such as read-only memory, a hard-disk drive, a solid-state drive, flash memory, an optical-storage device, etc. In line with the discussion above, it should also be understood that data storage **2904** may comprise computer-readable storage mediums that are distributed across a plurality of physical computing devices connected via a network. Data storage **2904** may take other forms and/or store data in other manners as well.

[0212] Communication interface **2906** may be configured to facilitate wireless and/or wired communication with the wireless communication equipment disclosed herein. Additionally, in an implementation where example computing system **2900** comprises a plurality of physical computing devices connected via a network, communication interface **2906** may be configured to facilitate wireless and/or wired communication between these physical computing devices. As such, communication interface **2906** may take any suitable form for carrying out these functions, examples of which may include an Ethernet interface, a serial bus interface (e.g., Firewire, USB 2.0, etc.), a chipset and antenna adapted to facilitate wireless communication of any suitable type (e.g., WiFi communication, cellular communication, short-range wireless communication, etc.), and/or any other interface that provides for wireless and/or wired communication. Communication interface **2906** may also include multiple communication interfaces of different types. Other configurations are possible as well.

[0213] Although not shown, example computing system **2900** may additionally include or have an interface for connecting to user-interface components that facilitate user interaction with example computing system **2900**, such as a keyboard, a mouse, a trackpad, a display screen, a touch-sensitive interface, a stylus, a virtual-reality headset, and/or speakers, among other possibilities.

[0214] It should be understood that example computing system **2900** is one example of a computing system that may be used with the embodiments described herein. Numerous other arrangements are possible and contemplated herein. For instance, other computing systems may include additional components not pictured and/or more or fewer of the pictured components.

CONCLUSION

[0215] Example embodiments of the disclosed innovations have been described above. At noted above, it should be understood that the figures are provided for the purpose of illustration and description only and that various components (e.g., modules) illustrated in the figures above can be added, removed, and/or rearranged into different configurations, or utilized as a basis for modifying and/or designing other configurations for carrying out the example operations disclosed herein. In this respect, those skilled in the art will understand that changes and modifications may be made to the embodiments described above without departing from the true scope and spirit of the present invention, which will be defined by the claims.

[0216] Further, to the extent that examples described herein involve operations performed or initiated by actors, such as humans, operators, users or other entities, this is for purposes of example and explanation only. Claims should not be construed as requiring action by such actors unless explicitly recited in claim language.

Claims

1. A wireless communication node comprising: equipment for communicating with at least one other wireless communication node of a wireless mesh network via at least one bidirectional wireless millimeter-wave link that is established with the at least one other wireless communication node of the wireless mesh network; and equipment for operating as a blockchain node within a blockchain network.

2. The wireless communication node of claim 1, wherein the wireless communication node is configured to: receive, from a first other wireless communication node in the wireless mesh network via a first set of one or more bidirectional wireless links, a communication comprising a request to retrieve given digital content stored at a second other wireless communication node in the wireless mesh network; relay the communication to the second other wireless communication via a second set of one or more bidirectional wireless links; receive, from the second other wireless communication via the second set of one or more bidirectional wireless links, the given digital content; store a copy of the given digital content at the wireless communication node; and relay the given digital content to the first other wireless communication node in the wireless mesh network via the first set of one or more bidirectional wireless links.

3. The wireless communication node of claim 1, wherein the wireless communication node is configured to operate as part of a blockchain-based content distribution platform.

4. The wireless communication node of claim 1, wherein the wireless communication node is configured to operate as part of a blockchain-based social media platform.

5. The wireless communication node of claim 1, wherein the wireless communication node is configured to operate as part of a blockchain-based gaming platform.

6. The wireless communication node of claim 1, wherein the wireless communication node is configured to operate as part of a blockchain-based virtual experiences platform.

7. The wireless communication node of claim 1, wherein the wireless communication node is configured to operate as a blockchain-based distributed storage node.

8. The wireless communication node of claim 1, wherein the wireless communication node is configured to perform blockchain-based computations.

9. The wireless communication node of claim 1, wherein the wireless communication node is installed at a private property associated with a customer of a service delivered by the wireless mesh network.

10. The wireless communication node of claim 1, wherein the equipment for operating as the blockchain node within the blockchain network comprises a computer system that includes one or more processors, data storage, and software for operating as part of the blockchain network.

11. The wireless communication node of claim 1, wherein the wireless communication node and the at least one other wireless communication node of the wireless mesh network are

communication nodes in a set of wireless communication nodes that are configured to operate as part of the wireless mesh network, wherein at least a subset of the wireless communication nodes in the set are further configured to operate as blockchain nodes within the blockchain network, wherein the subset includes the wireless communication node, and wherein each respective wireless communication node in the set is configured to communicate with at least one other wireless communication node in the set via at least one bidirectional wireless millimeter-wave link that is established with the at least one other wireless communication node in the set.

12. A wireless communication node comprising: equipment for operating as part of a wireless mesh network; and equipment for operating as a blockchain node within a blockchain network, wherein the wireless communication node is configured to: receive, from a first other wireless communication node in the wireless mesh network via a first set of one or more bidirectional wireless links, a communication comprising a request to retrieve given digital content stored at a second other wireless communication node in the wireless mesh network; relay the communication to the second other wireless communication via a second set of one or more bidirectional wireless links; receive, from the second other wireless communication via the second set of one or more bidirectional wireless links, the given digital content; store a copy of the given digital content at the wireless communication node; and relay the given digital content to the first other wireless communication node in the wireless mesh network via the first set of one or more bidirectional wireless links.

13. The wireless communication node of claim 12, wherein: the equipment for operating as part of the wireless mesh network comprises equipment for communicating with at least one other wireless communication node of a wireless mesh network via at least one bidirectional wireless link that is established with the at least one other wireless communication node of the wireless mesh network; and wherein the equipment for operating as the blockchain node within the blockchain network comprises a computer system that includes one or more processors, data storage, and software for operating as part of the blockchain network.

14. The wireless communication node of claim 12, wherein the wireless communication node is further configured to: receive, from a third other wireless communication node in the wireless mesh network via a third set of one or more bidirectional wireless links, a subsequent communication comprising a subsequent request to retrieve the given digital content stored at the second other wireless communication node; and in response to receiving the subsequent communication, transmit the copy of the digital content back to the third other wireless communication node in the wireless mesh network via the third set of one or more bidirectional wireless links.

15. The wireless communication node of claim 14, wherein the third other wireless communication node is the same as the first other wireless communication node and the third set of one or more bidirectional wireless links is the same as the first set of one or more bidirectional wireless links.

16. The wireless communication node of claim 14, wherein the third other wireless communication node comprises a communication node that originated the subsequent communication and the third set of one or more bidirectional wireless links comprises one single bidirectional wireless link between the wireless-communication node and the third other wireless communication node.

17. The wireless communication node of claim 12, wherein the wireless communication node is installed at a private property associated with a customer of a service delivered by the wireless mesh network.

18. The wireless communication node of claim 12, wherein the wireless communication node is configured to one or more of: operate as part of a blockchain-based content distribution platform; operate as part of a blockchain-based social media platform; operate as part of a blockchain-based gaming platform; operate as part of a blockchain-based virtual experiences platform; operate as a blockchain-based distributed storage node; and perform blockchain-based computations.

19. A method carried out by a wireless communication node that is (i) configured to operate as part of a wireless mesh network and (ii) to operate as a blockchain node within a blockchain network,

the method comprising: receiving, from a first other wireless communication node in the wireless mesh network via a first set of one or more bidirectional wireless links, a communication comprising a request to retrieve given digital content stored at a second other wireless communication node in the wireless mesh network; relaying the communication to the second other wireless communication via a second set of one or more bidirectional wireless links; receiving, from the second other wireless communication via the second set of one or more bidirectional wireless links, the given digital content; storing a copy of the given digital content at the wireless communication node; and relaying the given digital content to the first other wireless communication node in the wireless mesh network via the first set of one or more bidirectional wireless links.

20. The method of claim 19, wherein the wireless communication node is configured to communicate with at least one other wireless communication node in the wireless mesh network via at least one bidirectional wireless link that is established with the at least one other wireless communication node in the set.