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(54) IN-BUILDING RADIO FREQUENCY COMMUNICATIONS SYSTEM WITH AUTOMATIC FAILOVER RECOVERY

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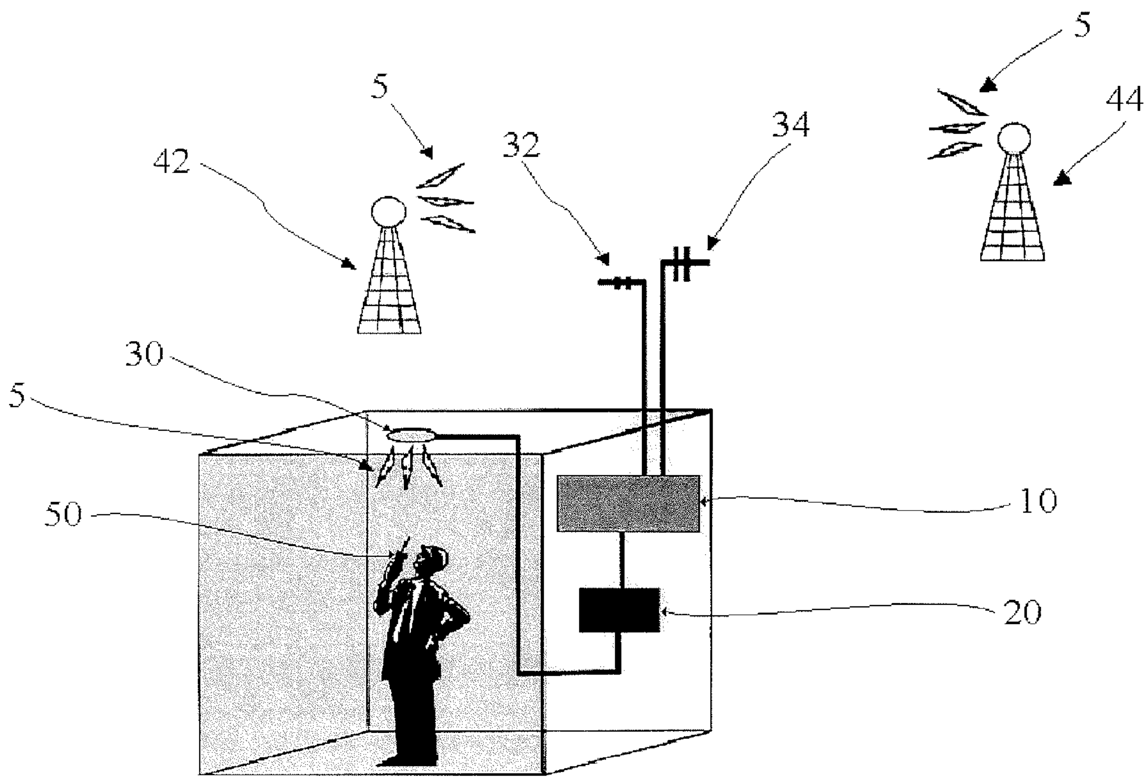
(57) ABSTRACT

An improved in-building radio frequency communications system with automatic failover recovery comprising a primary external antenna and one ancillary external antenna, each antenna directed to a primary transmission tower and to an ancillary transmission tower, respectively, and a diversity site donor system capable of monitoring the strength and/or quality of the radio frequency signals received from the primary transmission tower and switching communications between the primary transmission tower and the ancillary transmission tower based on the strength and/or quality of the radio frequency signals received from the primary transmission tower.



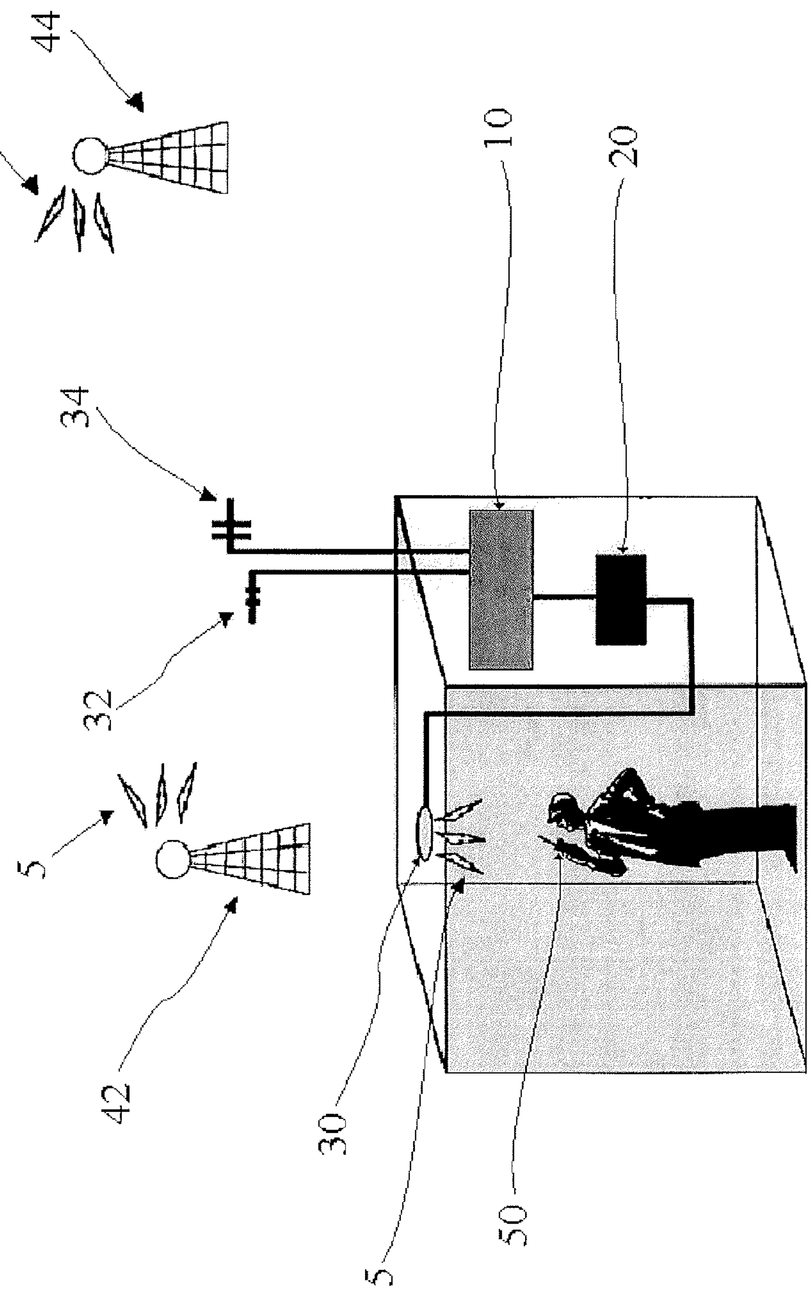


Fig. 1

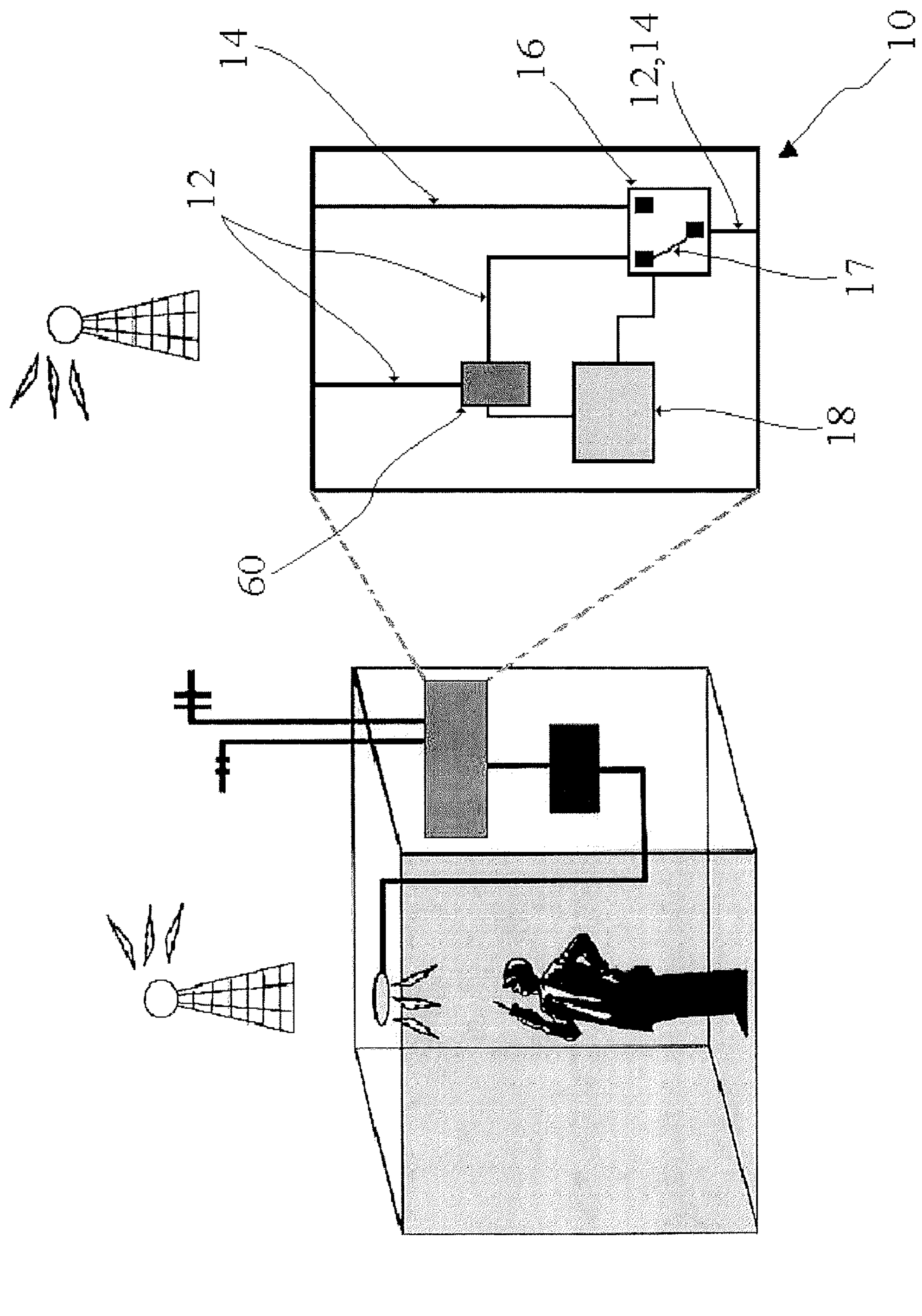


Fig. 2

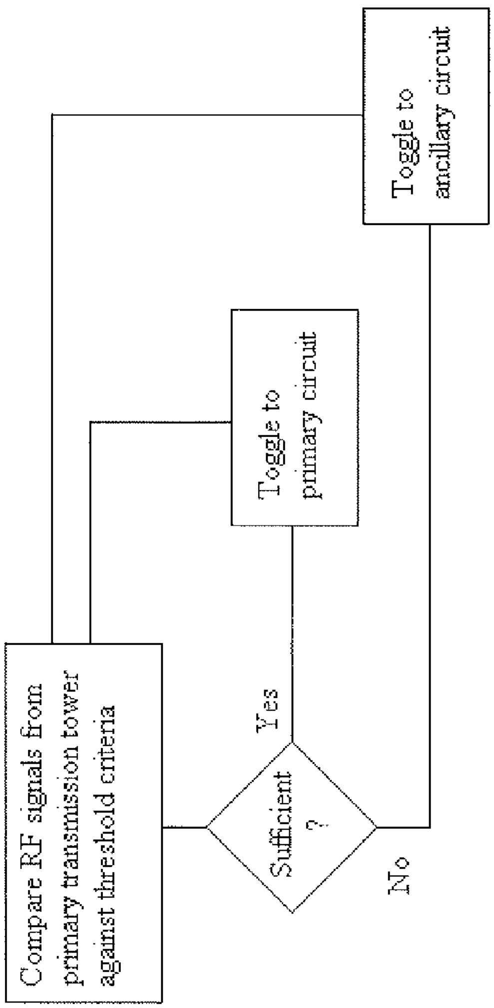

Compare RF signals from primary transmission tower against threshold criteria
Sufficient ?
Yes
No
Toggle to primary circuit
Toggle to ancillary circuit

Fig. 3

IN-BUILDING RADIO FREQUENCY COMMUNICATIONS SYSTEM WITH AUTOMATIC FAILOVER RECOVERY

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a divisional of U.S. Ser. No. 11/030,646, filed Jan. 4, 2005 and currently pending in Art Group 2617, entitled In-Building Radio Frequency Communications System With Automatic Failover Recovery, which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The invention relates to the field of in-building radio communication coverage enhancement. Specifically, the invention provides a solution to maintain radio communication coverage inside a facility when the primary radio transmission tower providing the radio communication signals to the in-building system fails or is taken out of operation for maintenance or service. The invention will detect that the signals from the primary transmission tower are not viable and automatically connect radio communication signals from an alternate transmission tower to the in-building system electronics and signal distribution system.

BACKGROUND OF THE INVENTION

[0003] Wireless communication devices, such as cell phones and two-way radios, are becoming ever more popular. Such devices typically receive and transmit radio frequency (RF) signals from and to remote RF signal transmission towers, such as cell towers. While RF signals are capable of penetrating solid objects, the strength and quality of those signals degrade as more barriers are present between the transmission tower and the wireless communication device. Signal degradation is especially acute within structures, such as office buildings or factories, which offer multiple barriers between the transmission tower and the wireless communication device.

[0004] In-building radio frequency communications systems have been developed to improve performance of wireless communication devices within structures. These systems typically use a strategically located and directed antenna, which typically is located on the exterior of the structure (roof or side wall), providing a communications link with a RF signal transmission tower. The directed antenna is focused at a specific RF signal transmission tower (primary RF signal donor site) in an effort to maximize desired signal levels from the donor site to the in-building system. In addition, the directed antenna will minimize the level of non-desired and interference producing signals that arrive at angles, relative to the direction that the external antenna is focused, outside the horizontal beamwidth of the external antenna. The desired effect of the directed antenna is to isolate the in-building system from all RF signals other than those used at the primary donor site. They also use one or more low profile antennas located within the interior of the structure, strategically placed to provide coverage in areas where the RF signal levels and/or quality are not adequate to support reliable transmissions. The internal antennas are linked together by an infrastructure comprised of coaxial, fiber optic and/or network cables and power splitters. The infrastructure is typically connected with the external antenna through a bi-directional amplifier (BDA), a device that increases the strength of the signal passing through it, either as the signal is received from the transmission tower to be transmitted to the wireless communication device (the signal downlink) or as the signal is received from the wireless communication device to be transmitted to the transmission tower (the signal uplink). In such a system, the RF signals are 1) received from the transmission tower by the external antenna and connected to the BDA; 2) amplified by the BDA; 3) distributed via the system infrastructure to the internal antennas, whose quantity and location inside the facility are appropriate to meet system requirements; and 4) radiated at a sufficient level to support reliable radio communications. The net effect is to allow the signals to pass between the transmission tower and the external antenna and between the wireless communication device and the internal antennas with relatively few intervening barriers. This minimization of intervening barriers, together with the signal amplification provided by the BDA greatly improves in-building performance of wireless communication devices.

[0005] In-building radio frequency communications systems are well known in the prior art, and may be implemented in any number of ways. See, e.g., Point-To-Multipoint Digital Radio Frequency Transport, U.S. Pat. No. 6,704,545 (Wala), issued Mar. 9, 2004; Communication System Comprising An Active-Antenna Repeater, U.S. Pat. No. 5,832,365 (Chen, et al.), issued Nov. 3, 1998; Method Of Locating A Mobile Station In A Mobile Telephone, U.S. Pat. No. 5,634,193 (Ghisler), issued May 27, 1997. However, while these systems are designed to handle the communications within a building, they all depend on reliable signals from the radio frequency transmission tower to support in-building transmissions. Thus, in-building signal enhancement tends to be susceptible to failure if there is an interruption or degradation of service at the external radio frequency transmission tower. This may result from a mechanical failure, a planned maintenance shutdown, environmental factors such as a lightning strike, or other causes, most of which are beyond the control or even awareness of the end use of the wireless communications device. In-building radio frequency communications systems known in the prior art are unable to recover from such interruptions and thus fail to provide the level of quality and reliability desired by end users.

[0006] One class of in-building frequency communications system known in the art does exemplify some failure recovery properties. Where an omni-directional antenna is used as the external antenna for an in-building system, by design the omni-directional antenna sends and receives RF signals equally in the horizontal plane, compared to a directional antenna, which will focus RF energy from approximately 15° to 100° of the horizontal plane. When an omni-directional antenna is used as the external antenna for an in-building system, there may be some degree of radio frequency transmission site diversity due to the inherent ability of the omni-directional antenna to transmit/receive RF signals equally in the horizontal plane. Under this scenario, signals from more than one radio frequency transmission tower may be connected into the in-building system and if signals from one radio frequency transmission tower fail, signals from a different radio frequency tower may be available to provide a level of coverage inside the facility. However, this configuration does not allow for specific redirection for precise control over alternative RF signal sources. The present invention, by placing such control with the system designer, is an improvement over in-building systems that have been designed to provide radio frequency transmission tower diversity through the use of an omni-directional external antenna.

[0007] The present invention is directed to an in-building radio frequency communications system with the capability to automatically transfer RF signals to the in-building system from multiple radio frequency transmission towers. As such, it offers improved RF signal access reliability over known systems.

[0008] It is an object of this invention to provide a fault tolerant in-building radio frequency communications system which minimizes disruptions due to failure of the RF signals from the primary radio frequency transmission tower.

[0009] It is a further object of this invention to provide a donor site diversity system which continuously detects the strength and quality of RF signals from a primary radio frequency transmission tower in order to automatically switch an in-building radio frequency communications system to an ancillary radio frequency transmission tower whenever the strength and quality of RF signals from a primary radio frequency transmission tower fall below an acceptable threshold.

[0010] Other objects of this invention will be apparent to those skilled in the art from the description and claims which follow.

SUMMARY

[0011] The present invention is directed to an in-building radio frequency communications system with fault tolerant capability when RF signals from the primary radio frequency transmission tower are compromised or fail. Specifically, the invention relates to an improved system which incorporates into an in-building radio frequency communications system a primary external antenna and an ancillary external antenna, with the primary external antenna oriented to receive and transmit RF signals from and to a primary transmission tower, and the ancillary external antenna oriented to receive and transmit RF signals from and to the ancillary transmission tower.

[0012] The present invention further integrates an RF signal detection and switching mechanism into the in-building radio frequency communications system, the said detection and switching mechanism having two functions: 1) the detection mechanism constantly monitors the strength and quality of the RF signals received from the primary transmission tower; and 2) whenever the strength and/or quality of those RF signals deteriorates below a certain threshold, the switching mechanism redirects communications for the in-building radio frequency communications system to the ancillary transmission tower. The redirection of communication signals is achieved by toggling a switch within the switching mechanism, resulting in the circuit between the in-building system and the primary external antenna being interrupted and the circuit between the in-building system and the ancillary external antenna being completed, thereby establishing communications with the ancillary transmission tower. When the switching mechanism detects sufficient signal quality and/or strength in the RF signals received from the primary transmission tower, the switch is toggled to complete the circuit between the in-building system and the primary external antenna and to interrupt the circuit between the in-building system and the ancillary external antenna, thereby re-establishing communications with the primary transmission tower.

[0013] The above-described improvements to in-building radio frequency communications systems increase the reliability of communications in the event of disruptions from the primary transmission tower. By automatically redirecting the RF signal to a different transmission tower having sufficient performance criteria, the invention minimizes communications interruptions to in-building users of the system, achieving high levels of overall fault tolerance in the system.

[0014] Other features and advantages of the invention are described below.

DESCRIPTION OF THE DRAWINGS

[0015] FIG. **1** is a schematic drawing depicting the basic components of the present invention, including a donor site diversity system.

[0016] FIG. **2** is a schematic drawing depicting the basic components of the present invention, together with detail of the components comprising the donor site diversity system.

[0017] FIG. **3** is a flowchart showing the process for determining which RF signal transmission tower should be used when the in-building radio frequency communication system comprises a primary external antenna and a single ancillary external antenna.

DESCRIPTION OF THE INVENTION

[0018] The invention is an improvement on known in-building radio frequency communications systems designed to be installed and used within structures, such as office buildings, power generation plants, correctional facilities, etc. The basic in-building system is comprised of the following components: a primary external antenna **32**, an ancillary external antenna **34**, an internal antenna **30**, a donor site diversity system **10**, and a bi-directional amplifier **20**. These components are networked together to form the in-building radio frequency communications system. In one embodiment, the donor site diversity system **10** is connected with the primary external antenna **32** and with the ancillary external antenna **34** by coaxial cables and/or fiber optic cables, and the bi-directional amplifier **20** is connected with the donor site diversity system **10** and with the internal antenna **30** by coaxial cables and/or fiber optic cables. This configuration is shown in FIG. **1**.

[0019] The primary external antenna **32** must be configured to receive and transmit RF signals **5**, which are used for communications with cell phones, two-way radios, and the like. The primary external antenna **32** typically should be located on the exterior of a structure where it can be directed to a primary RF signal transmission tower **42**, such that the primary external antenna **32** is capable of transmitting and receiving RF signals **5** to and from the primary RF signal transmission tower **42**. In the preferred embodiment, the primary external antenna **32** is located on the roof of the structure, or other location with an unobstructed path to the primary RF signal transmission tower **42**. The primary RF signal transmission tower **42** is selected as providing the strongest and/or highest quality RF signal **5** available to connect with the in-building radio frequency communications system.

[0020] The ancillary external antenna **34** must also be configured to receive and transmit RF signals **5**. The ancillary external antenna **34** typically should be located on the exterior of the structure where it can be directed to an ancillary RF signal transmission tower **44**, such that the ancillary external antenna **34** is capable of transmitting and receiving RF signals

5 to and from the ancillary RF signal transmission tower **44**. Because the ancillary external antenna **34** is directed to an ancillary RF signal transmission tower **44** generating RF signals **5** which when received are of a lower strength and/or quality than the RF signals **5** generated by the primary RF signal transmission tower **42**, the ancillary external antenna **34** may be required to be of higher gain and greater directivity; for example, the ancillary external antenna **34** may be a parabolic grid-type antenna, whereas the primary external antenna **32** may be of lower gain and directivity, such as a corner reflector or yagi type antenna. Other types of higher gain and greater directivity antennas may also be used. Use of a higher gain and greater directivity ancillary external antenna **34** increases the likelihood that the RF signals **5** received from the ancillary RF signal transmission tower **44** and passed on to the bi-directional amplifier **20** will be of comparable strength and quality as those received from the primary RF signal transmission tower **42**. In the preferred embodiment, the ancillary external antenna **34** is located on the roof of the structure. The ancillary RF signal transmission tower **44** is selected as providing the next strongest and/or highest quality RF signal **5** available to the in-building radio frequency communications system, after the primary RF signal transmission tower **42**.

[0021] The internal antenna **30** must be configured to receive and transmit RF signals **5**. The internal antenna **30** is typically a low-profile antenna with a power output significantly less than that of the primary **42** and secondary **44** radio transmission towers. The internal antenna(s) **30** typically is located within the interior of the structure where it is capable of transmitting and receiving RF signals **5** to and from wireless communication devices **50** located within the structure. In the preferred embodiment, multiple internal antennas **30** are located within the structure, with each internal antenna **30** configured to receive and transmit RF signals **5**. The multiple internal antennas **30** are distributed throughout the interior of the structure so as to provide the greatest practical coverage within the structure, such that each of the internal antennas **30** is capable of transmitting and receiving RF signals **5** to and from nearby wireless communication devices **50**. Each of the internal antennas **30** is connected with the bi-directional amplifier **20**, either directly or indirectly via a network of cables. In the preferred embodiment, the network connecting the internal antennas **30** is comprised of coaxial cables, although other infrastructure configurations exist, such as fiber optic and network (CAT5/6) cable type systems.

[0022] The bi-directional amplifier **20** may be any type of RF signal amplifier known in the art capable of increasing the strength of RF signals **5**. The bi-directional amplifier **20** must be capable of increasing the strength of RF signals **5** downlinked from RF signal transmission towers to be transmitted to personal communications devices, and capable of increasing the strength of RF signals **5** uplinked from wireless communication devices to be transmitted to RF signal transmission towers. The bi-directional amplifier **20** is connected with the donor site diversity system **10**, from which it receives the downlinked RF signals **5** and to which it sends uplinked RF signals **5**, and is connected with the internal antenna **30**, from which it receives the uplinked RF signals **5** and to which it sends downlinked RF signals **5**. In the preferred embodiment, the bi-directional amplifier **20** is located proximate to the donor site diversity system **10**.

[0023] The donor site diversity system **10** is connected with the primary external antenna **32** and with the ancillary external antenna **34**. The donor site diversity system **10** monitors the strength and quality of the RF signals **5** received by the primary external antenna **32** from the primary RF signal transmission tower **42**. The donor site diversity system **10** is further capable of switching the communication connection between the primary RF signal transmission tower **42** and the ancillary RF signal transmission tower **44**, based on the strength and quality of the RF signals **5** received from the primary RF signal transmission tower **42**.

[0024] In one embodiment, the donor site diversity system **10** comprises a primary circuit **12**, an ancillary circuit **14**, a RF signal switch **16**, and a RF signal detector/sensor **18**. This configuration is shown in FIG. **2**.

[0025] The primary circuit **12** is configured to establish a communications connection between the primary external antenna **32** and the bi-directional amplifier **20** such that RF signals **5** may travel between the primary external antenna **32** and the bi-directional amplifier **20**. The ancillary circuit **14** is configured to establish a communications connection between the ancillary external antenna **34** and the bi-directional amplifier **20** such that RF signals **5** may travel between the ancillary external antenna **34** and the bi-directional amplifier **20**. The primary circuit **12** and the ancillary circuit **14** are mutually exclusive; that is, when the primary circuit **12** is active, the ancillary circuit **14** is inactive, and RF signals **5** are received by and sent from the in-building radio frequency communications system solely through the primary circuit **12**; and when the ancillary circuit **14** is active, the primary circuit **12** is inactive, and RF signals **5** are received by and sent from the in-building radio frequency communications system solely through the ancillary circuit **14**.

[0026] The RF signal switch **16** is configured to activate and deactivate the primary circuit **12** and to activate and deactivate the ancillary circuit **14**. In the preferred embodiment, the RF signal switch **16** toggles an interlink **17** between the primary circuit **12** and the ancillary circuit **14**, such that the ancillary circuit **14** is interrupted when the interlink **17** is toggled to and completes the primary circuit **12**, and the primary circuit **12** is interrupted when the interlink **17** is toggled to and completes the ancillary circuit **14**.

[0027] The RF signal detector/sensor **18** is configured to monitor the strength and quality of the RF signals **5** received from the primary RF signal transmission tower **42**. In one embodiment, the RF signal detector/sensor **18** comprises a monitoring means and a logic processor appropriate to the target RF signals **5** enhancing the in-building environment. The monitoring means is configured to monitor the strength and quality of the RF signals **5** received from the primary RF signal transmission tower **42**. In the preferred embodiment, the monitoring means is configured to continuously monitor the strength and quality of the RF signals **5** received from the primary RF signal transmission tower **42**. The logic processor of the RF signal detector/sensor **18** is connected with the RF signal switch **16**, and is configured to determine the sufficiency of the strength and quality of the RF signals **5** received from the primary RF signal transmission tower **42**. The threshold criteria for determining the sufficiency of the strength and quality of the RF signals **5** may be preset, or altered by the user, or dynamically altered automatically depending on environmental criteria. The logic processor compares the sufficiency of the strength and quality of the RF signals **5** against the threshold criteria, and communicates a positive signal to the RF signal switch **16** if the sufficiency of the strength and quality of the RF signals **5** meets or exceeds the threshold criteria, and communicates a negative or ground signal to the RF signal switch **16** if the sufficiency of the strength and quality of the RF signals **5** fails to meet or exceed the threshold criteria. The RF signal switch **16** in turn toggles the interlink **17** to complete the primary circuit **12** when a positive signal is received, thereby interrupting the ancillary circuit **14**, and toggles the interlink **17** to complete the ancillary circuit **14** when a negative signal is received, thereby interrupting the primary circuit **12**. This process is shown in FIG. **3**.

[0028] In one embodiment, the donor site diversity system **10** further comprises a signal splitting means for directing RF signals **5** to both the RF signal detector/sensor **18** and the RF signal switch **16**. In the preferred embodiment the signal splitting means comprises an unequal power signal splitter **60**, a two-way power divider **64**, and a variable attenuator **68**. The unequal power signal splitter **60** further has an input port **61**, a high power output port **62**, and a low power output port **63**. The two-way power divider **64** further has an input port **65**, a first equal power distribution output port **66**, and a second equal power distribution output port **67**. The unequal power signal splitter **60** is located in-line with the primary circuit **12**, whereby the unequal power signal splitter **60** is in connection with the primary external antenna **32** through the input port **61** of the unequal power signal splitter **60**, the unequal power signal splitter **60** is in connection with the RF signal switch **16** through the high power output port **62** of the unequal power signal splitter **60**, and the unequal power signal splitter **60** is in connection with the two-way power divider **64** through the low power output port **63** of the unequal power signal splitter **60** and into the input port **65** of the two-way power divider **64**. RF signals **5** from the primary external antenna **32** enter the unequal power signal splitter **60** through its input port **61** and are directed simultaneously to the RF signal switch **16** and the two-way power divider **64**. The two-way power divider **64** in turn is in connection with a test port through the first equal power distribution output port **66** of the two-way power divider **64** and with the variable attenuator **68** through the second equal power distribution output port **67** of the two-way power divider **64**. The variable attenuator **68** is in connection with the RF signal detector/sensor **18**. The variable attenuator **68** is used to adjust the threshold level of the RF signal detector/sensor **18**. RF signals received by the primary external antenna **32** are transmitted along the primary circuit **12** to the unequal power signal splitter **60**, whereby the RF signals **5** are then split between the RF signal switch **16** and the RF signal detector/sensor **18** (the latter by way of the two-way power divider **64** and variable actuator **68**). In using the combination of the unequal power signal splitter **60** and the two-way power divider **64** to send RF signals **5** to the RF signal switch **16** and the RF signal detector/sensor **18**, the monitoring means of the donor site diversity system **10** can monitor the strength and/or quality of the RF signals **5** received from the primary RF signal transmission tower **42** on a continuous basis. The RF signal detector/sensor **18** then directs the RF signal switch **16** to toggle between the primary circuit **12** and the ancillary circuit **14** as appropriate.

[0029] Modifications and variations can be made to the disclosed embodiments of the invention without departing from the subject or spirit of the invention as defined in the following claims.

I claim:

1. An in-building radio frequency communications system comprising

a primary external antenna, suitably configured to receive and transmit radio frequency signals, said primary external antenna located on an exterior of a structure and oriented towards a primary radio frequency signal transmission tower such that the primary external antenna is capable of transmitting and receiving radio frequency signals to and from the primary radio frequency signal transmission tower;

an ancillary external antenna, suitably configured to receive and transmit radio frequency signals, said ancillary external antenna located on the exterior of the structure and oriented towards an ancillary radio frequency signal transmission tower such that the ancillary external antenna is capable of transmitting and receiving radio frequency signals to and from the ancillary radio frequency signal transmission tower;

a donor site diversity system, in connection with the primary external antenna and with the ancillary external antenna, said donor site diversity system suitably configured to monitor the strength and quality of the radio frequency signals received from the primary radio frequency signal transmission tower and capable of switching between the primary radio frequency signal transmission tower and the ancillary radio frequency signal transmission tower based on the strength and quality of the radio frequency signals received from the primary radio frequency signal transmission tower;

an internal antenna, suitably configured to receive and transmit radio frequency signals, said internal antenna located within an interior of the structure such that the internal antenna is capable of transmitting and receiving radio frequency signals to and from one or more wireless communication devices located within the structure; and

a bi-directional amplifier, in connection with the donor site diversity system and with the internal antenna, said bi-directional amplifier suitably configured to increase the strength of radio frequency signals received from the radio frequency signal transmission towers through the external antennas and received from the one or more wireless communication devices through the internal antenna;

wherein the primary external antenna and the ancillary external antenna are suitably configured such that both the primary external antenna and the ancillary external antenna are capable of operating independently from the other, where at any given time only one of said primary and ancillary external antennas is receiving or transmitting radio frequency signals for the purpose of providing a communications link between one of the radio frequency signal transmission towers and the one or more wireless communication devices, while the other of said primary and ancillary external antennas is in stand-by mode whereby it is not providing a communications link between either of the radio frequency signal transmission towers and the one or more wireless communication devices.

2. The in-building radio frequency communications system of claim **1** wherein the donor site diversity system is connected with the primary external antenna and with the ancillary external antenna by coaxial cables and/or fiber optic cable, and the bi-directional amplifier is connected with the donor site diversity system and with the internal antenna by coaxial cables and/or fiber optic cable.

3. The in-building radio frequency communications system of claim **1** further comprising multiple internal antennas, each internal antenna suitably configured to receive and transmit radio frequency signals, with the multiple internal antennas distributed throughout the interior of the structure, such that each of the internal antennas is capable of transmitting and receiving radio frequency signals to and from wireless communication devices located within the structure, and with each of the internal antennas in connection with the bi-directional amplifier;

wherein the multiple internal antennas are suitably configured such that each of the multiple internal antennas is capable of operating independently from each other of the multiple internal antennas for the purpose of providing a communications link between one of the radio frequency signal transmission towers and the one or more wireless communication devices.

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