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(54) **ADAPTIVE PERSONAL REPEATER**

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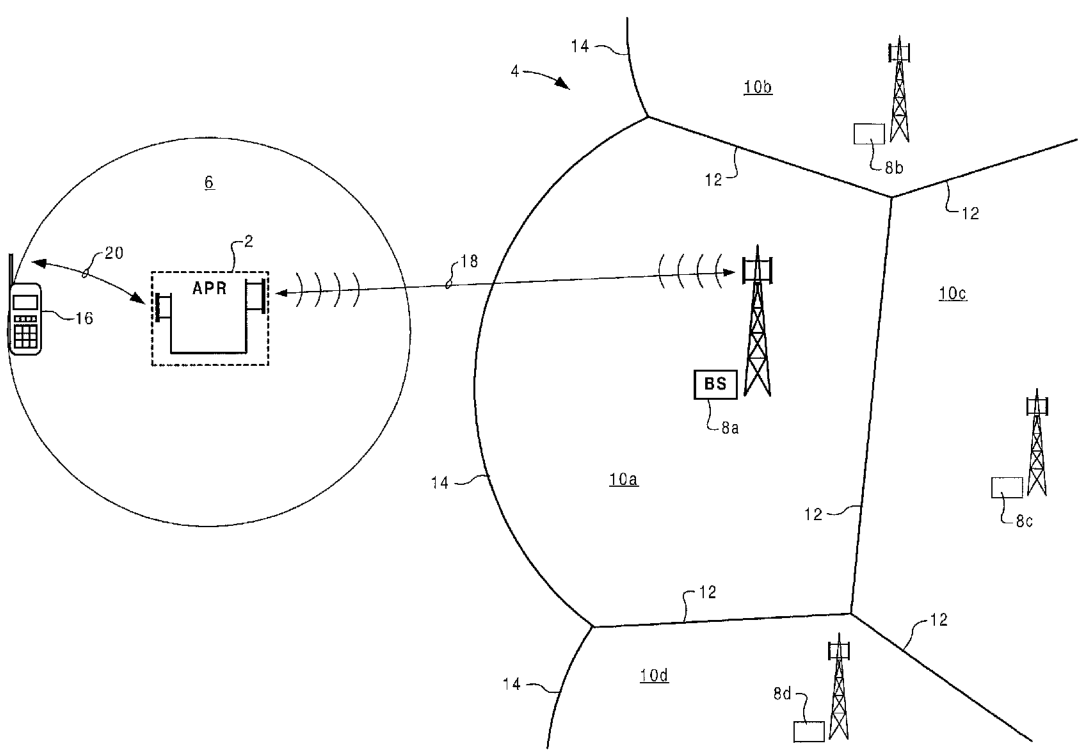
(57) **ABSTRACT**

An adaptive personal repeater transparently mediates signaling between a wireless communications device (WCD) and a wireless communications network. The repeater includes a Directional Donor Unit (DDU) and a Subscriber Coverage Unit (SCU). The DDU maintains a network link with a transceiver (base station) of the wireless communications network. The SCU maintains a local link with the WCD within a personal wireless space of the repeater. The SCU generally includes, means for detecting respective uplink and downlink channel frequencies of the wireless communications device, and control means for controlling at least the SCU to selectively receive and transmit signals within the detected uplink and downlink channel frequencies. Total system gain is divided between the DDU and the SCU, so that a separate gain and system control unit is not required. This division of system gain also enables high-performance on-frequency repeater functionality to be obtained without the use of high-cost components.



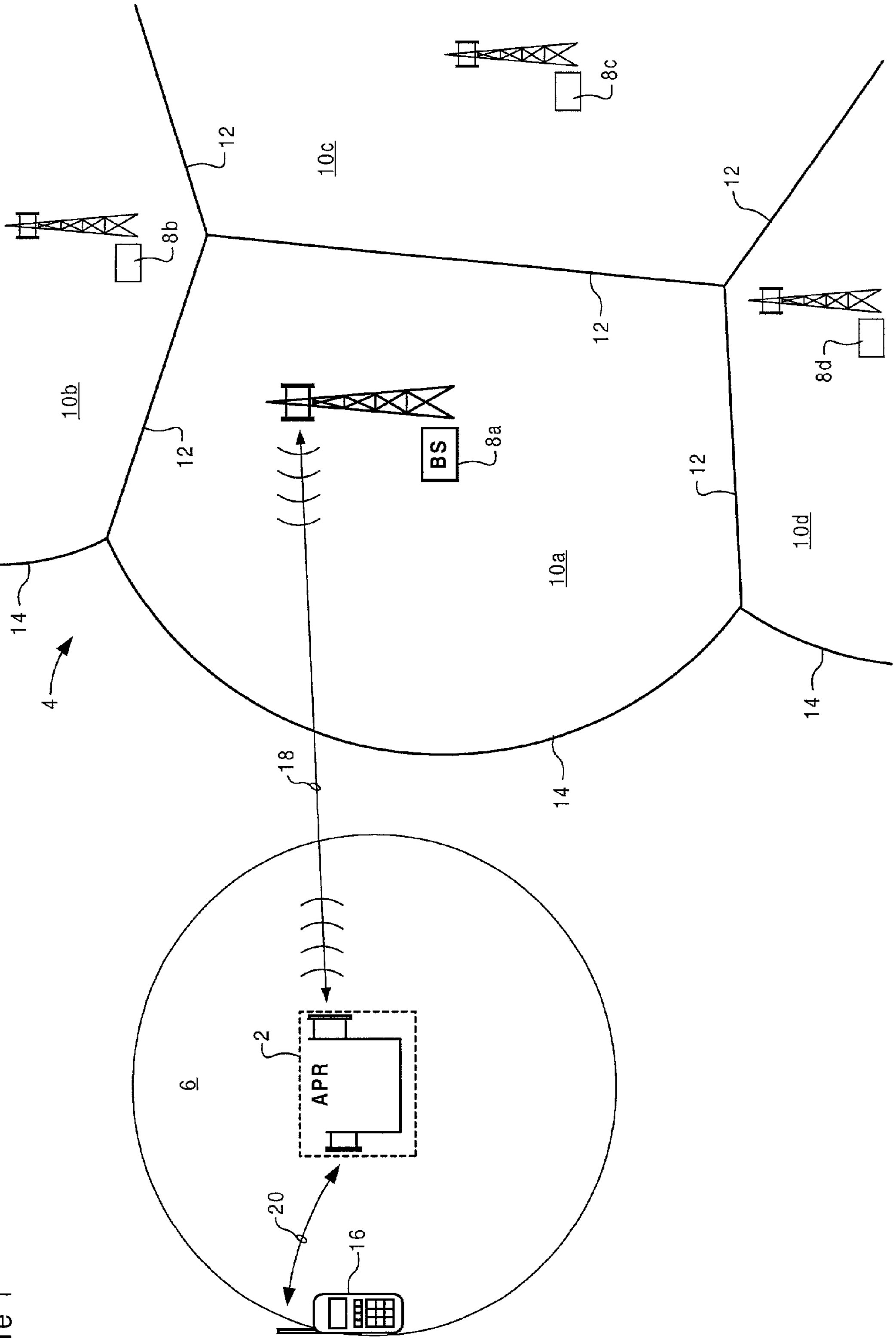


Figure 1

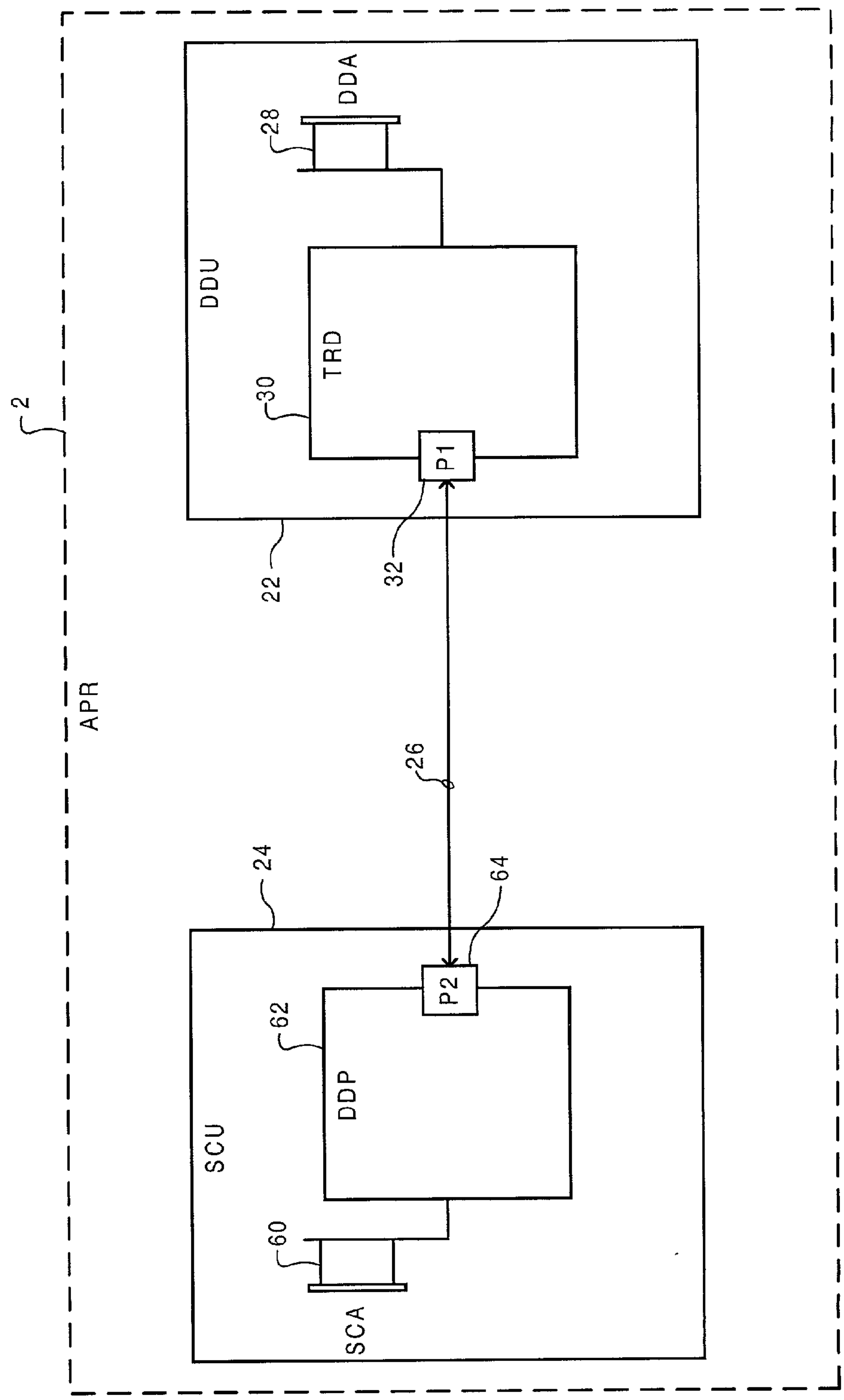
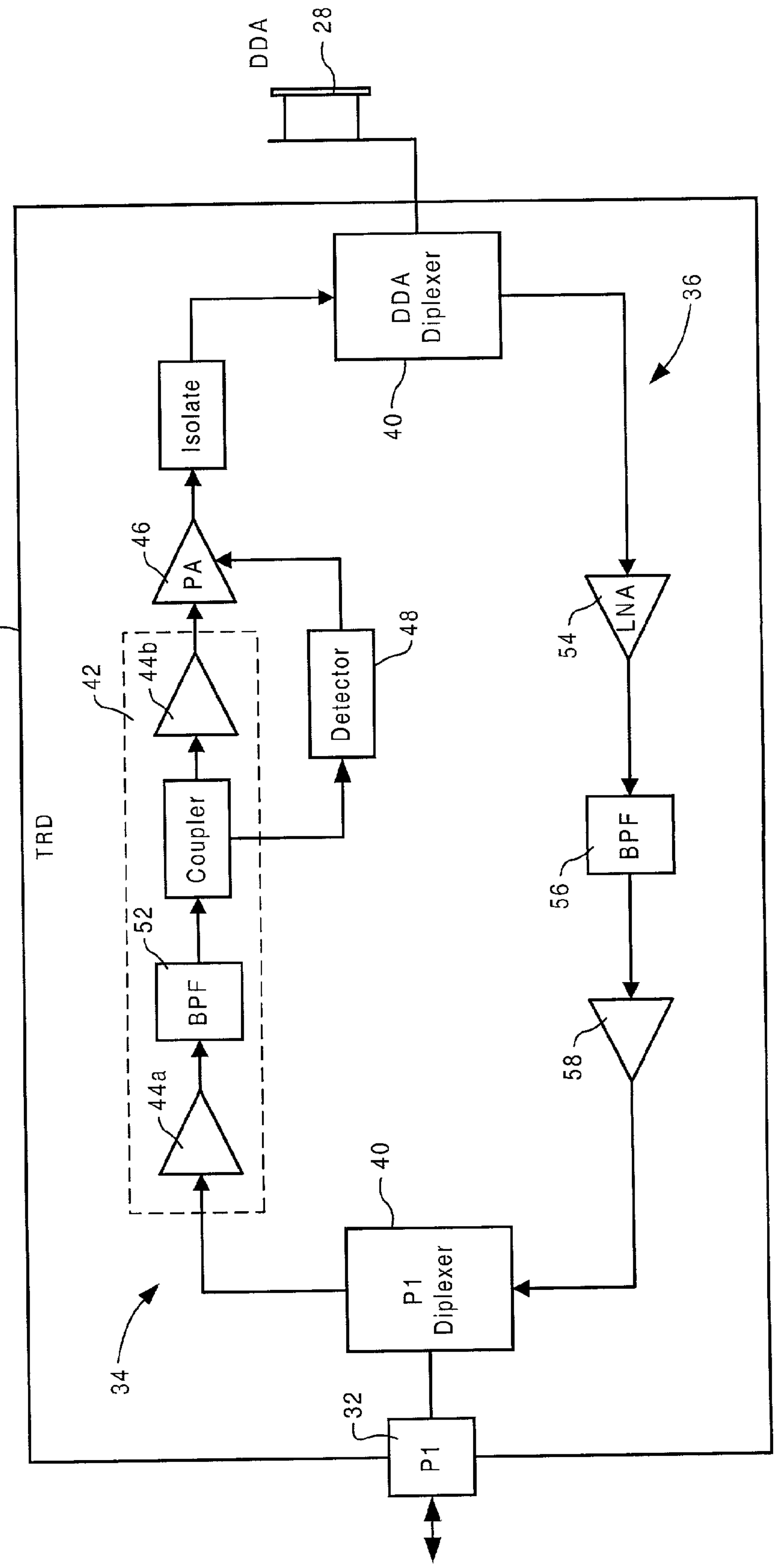


Figure 2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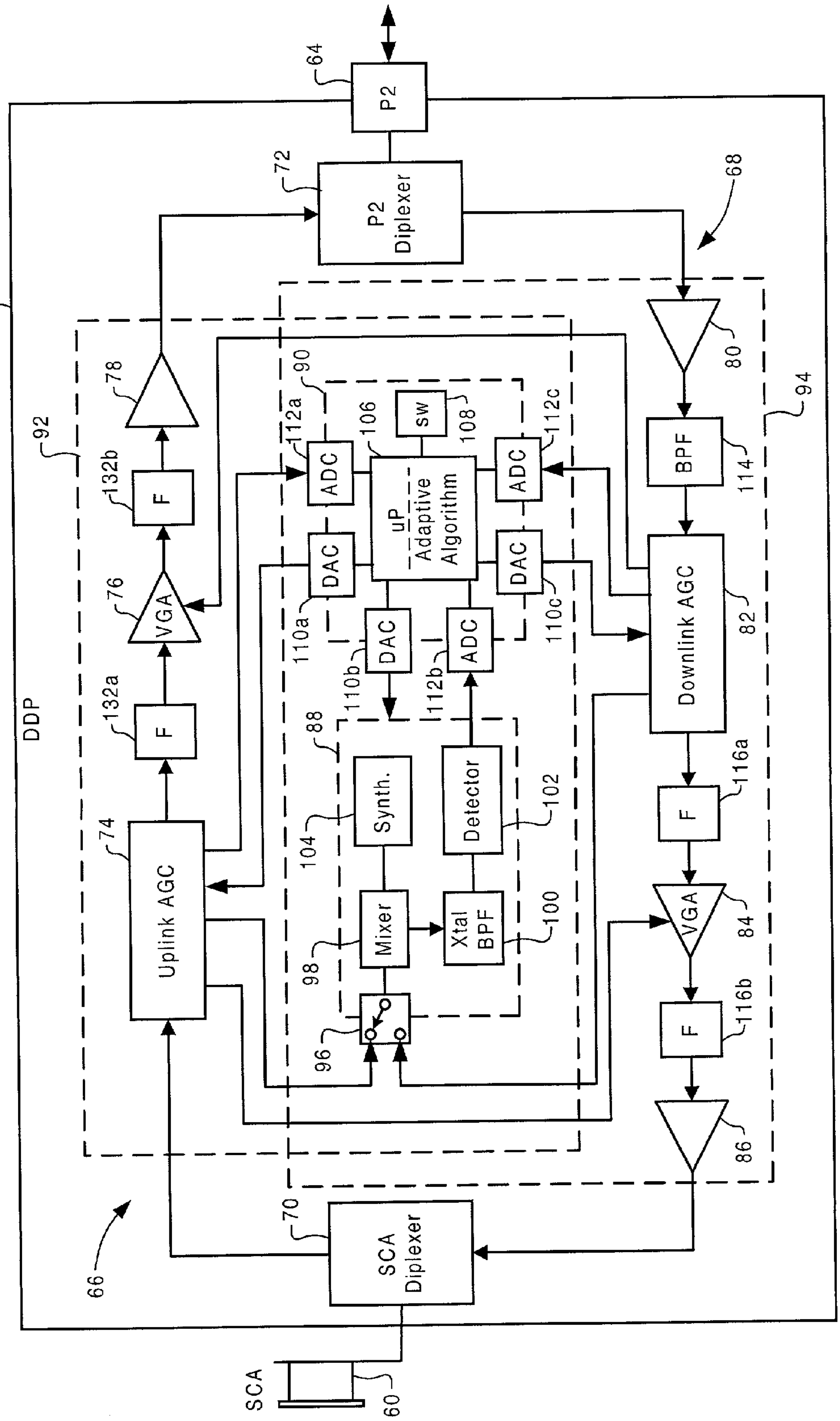
28
30
TRD
DDA Diplexer
40
36
Isolate
46
PA
48
Detector
42
44b
Coupler
52
BPF
44a
54
LNA
56
BPF
58
40
P1 Diplexer
34
32
P1

Figure 3



P2
64
P2
Diplexer
72
68
62
92
78
90
106
sw
108
112a
112c
ADC
uP
Adaptive
Algorithm
ADC
132b
F
80
BPF
114
94
DAC
DAC
76
VGA
110a
DAC
ADC
110c
Downlink AGC
82
110b
112b
DDP
132a
F
88
Synth.
Detector
102
104
116a
F
74
Uplink AGC
Mixer
Xtal
BPF
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98
VGA
84
96
116b
F
86
66
70
SCA
Diplexer
SCA
60

Figure 4

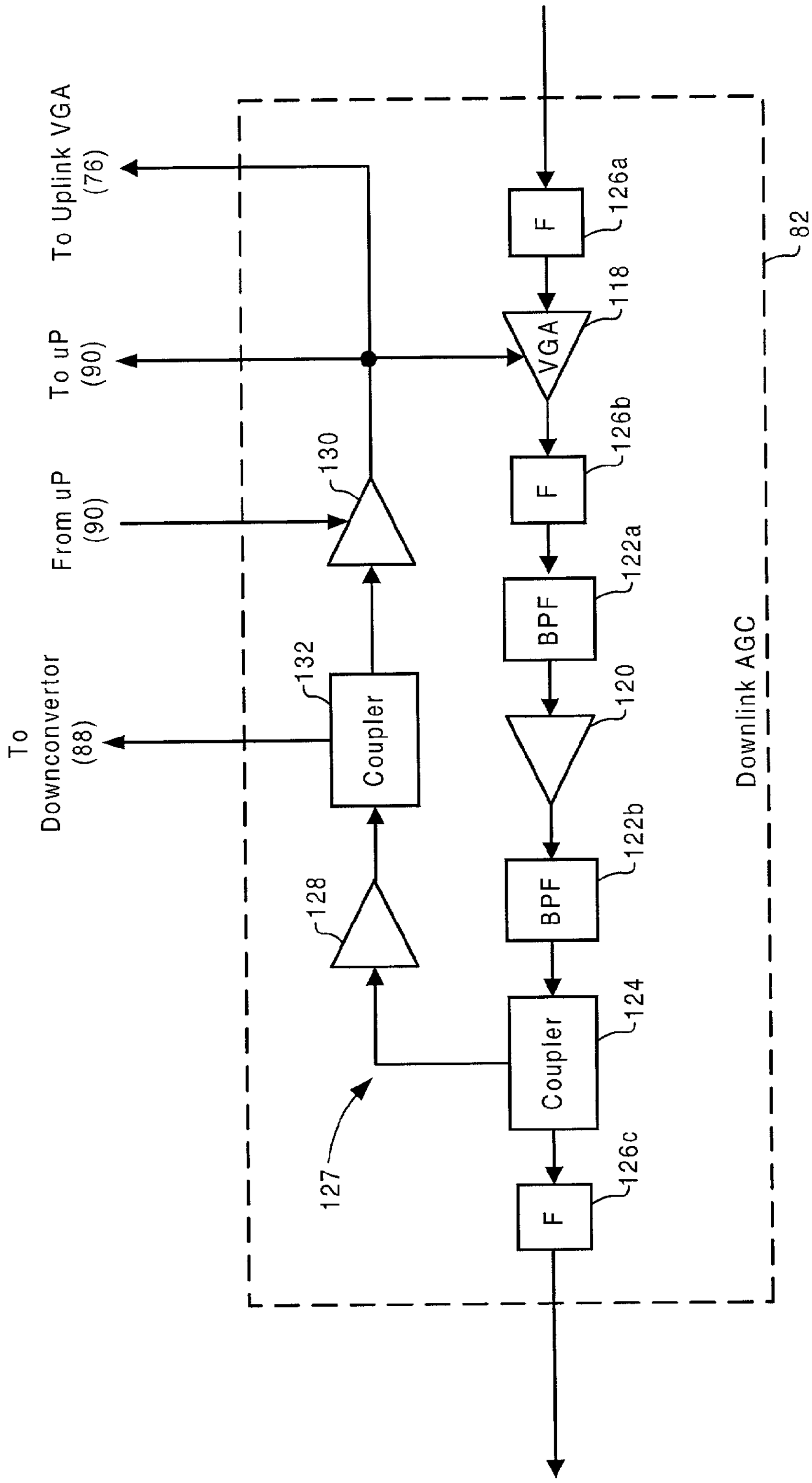
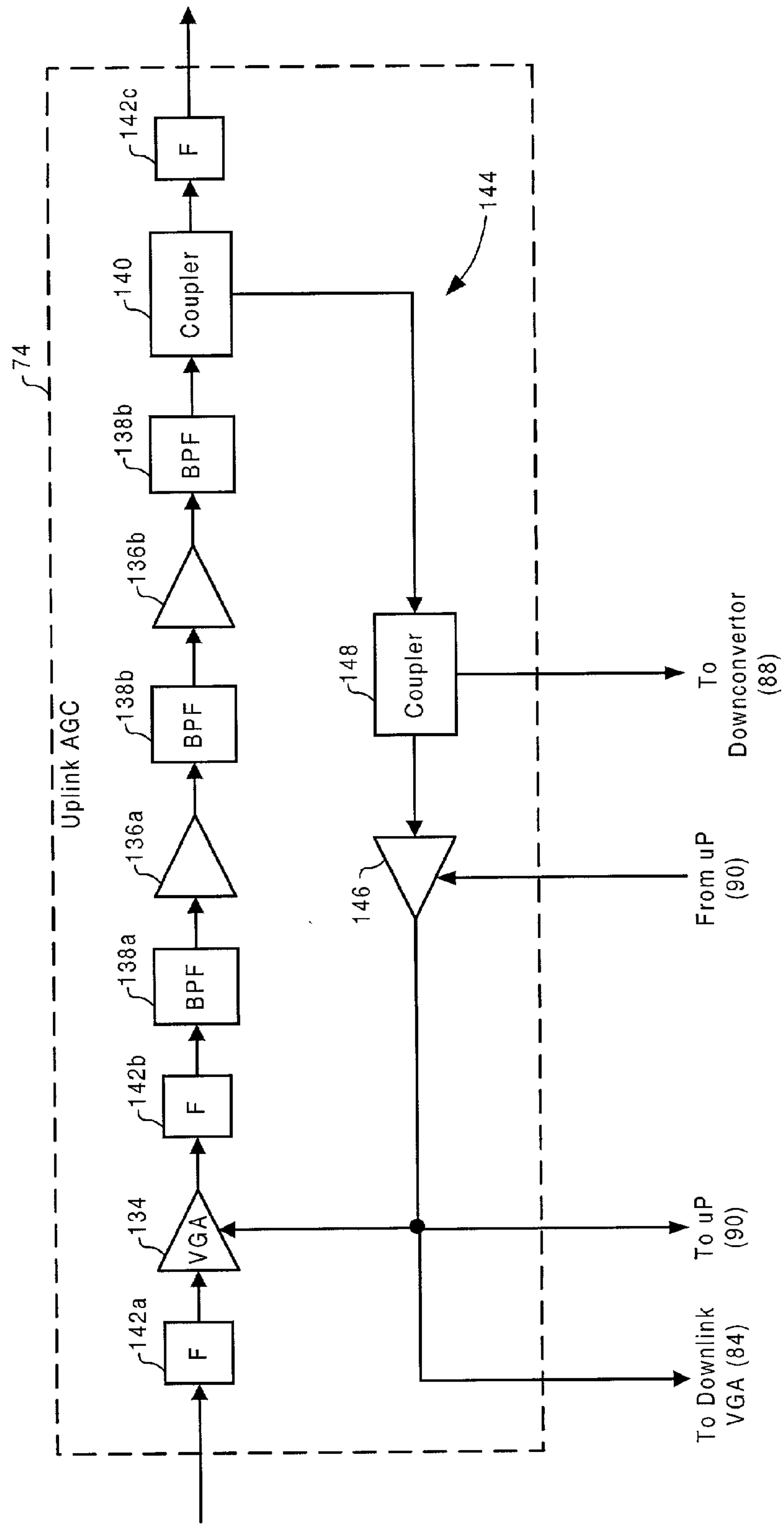

To Uplink VGA (76)
To uP (90)
From uP (90)
To Downconvertor (88)
F
126a
82
VGA
118
126b
130
F
BPF
122a
132
Coupler
120
Downlink AGC
BPF
122b
128
Coupler
124
127
F
126c

Figure 6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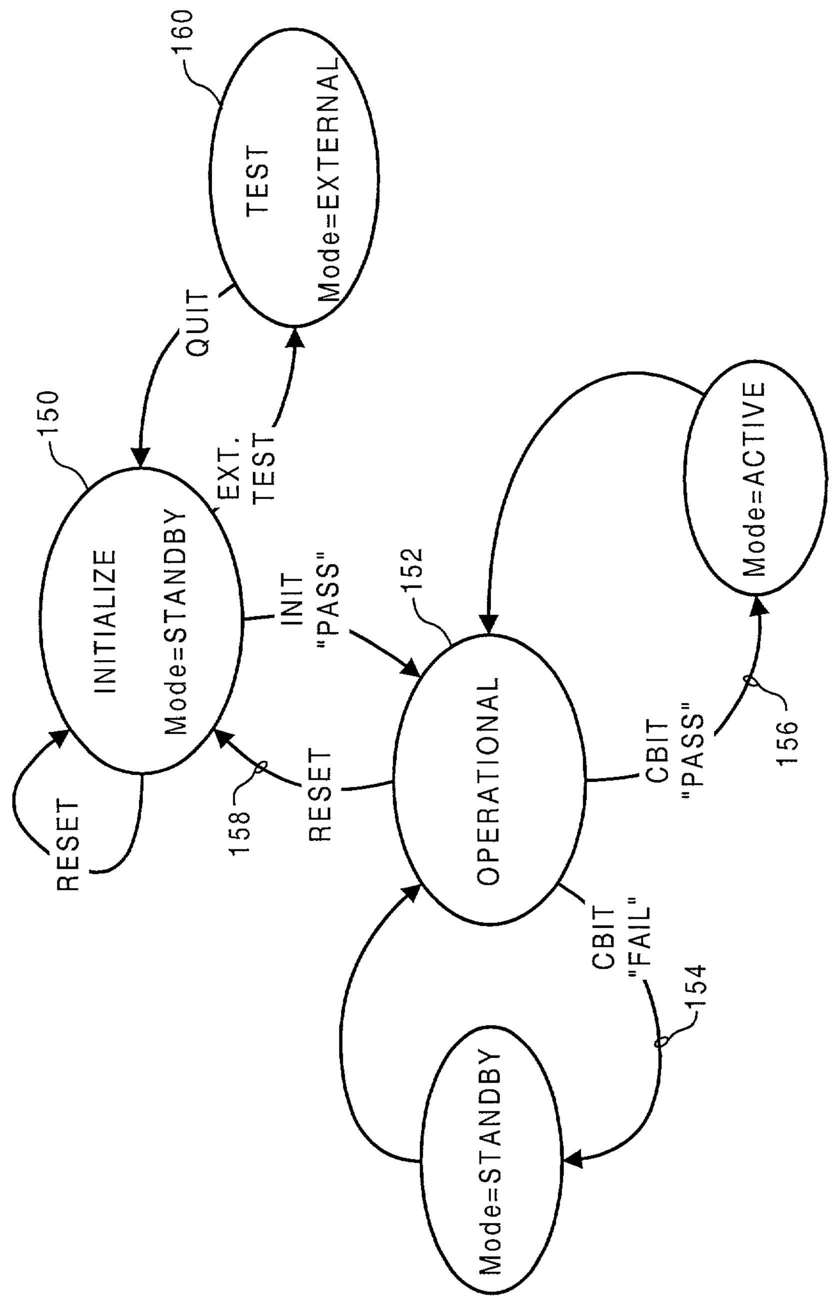
Uplink AGC
142a
F
134
VGA
142b
F
138a
BPF
136a
138b
BPF
136b
138b
BPF
140
Coupler
142c
F
144
148
Coupler
146
To Downconvertor (88)
From uP (90)
To uP (90)
To Downlink VGA (84)

Figure 6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TEST
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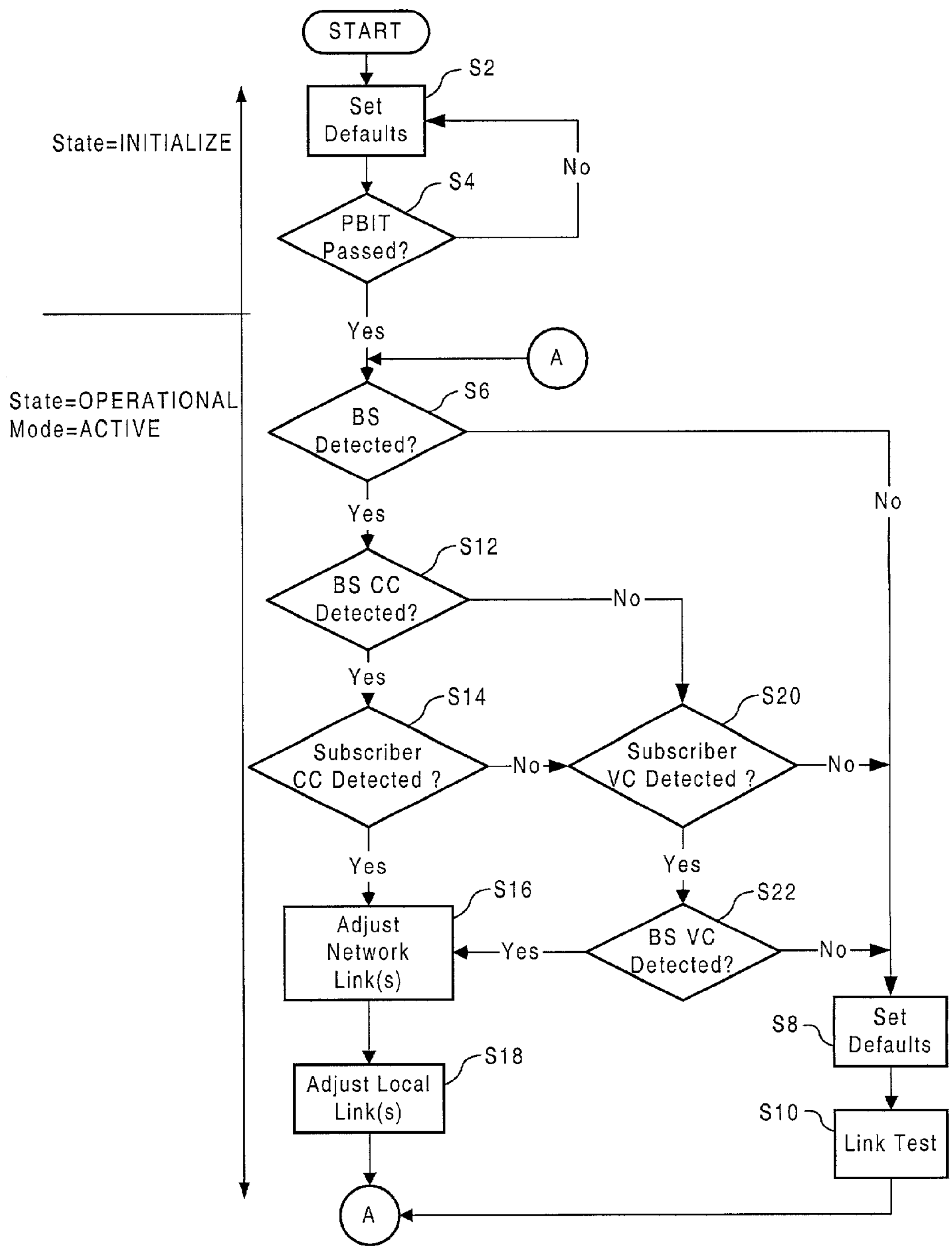
QUIT
EXT.
TEST
150
INITIALIZE
Mode=STANDBY
RESET
INIT
"PASS"
152
OPERATIONAL
RESET
158
CBIT
"PASS"
156
Mode=ACTIVE
CBIT
"FAIL"
154
Mode=STANDBY

Figure 7

Figure 8



START
Set Defaults
S2
State=INITIALIZE
PBIT Passed?
S4
No
Yes
A
State=OPERATIONAL
Mode=ACTIVE
BS Detected?
S6
No
Yes
BS CC Detected?
S12
No
Yes
Subscriber CC Detected ?
S14
No
Subscriber VC Detected ?
S20
No
Yes
Yes
Adjust Network Link(s)
S16
BS VC Detected?
S22
Yes
No
Set Defaults
S8
Adjust Local Link(s)
S18
S10
Link Test
A

ADAPTIVE PERSONAL REPEATER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is the first application filed for the present invention.

MICROFICHE APPENDIX

[0002] Not Applicable.

TECHNICAL FIELD

[0003] The present application relates to wireless access networks, and in particular to an adaptive personal repeater for enabling a wireless subscriber to improve wireless services within a personal wireless space.

BACKGROUND OF THE INVENTION

[0004] In the modern communications space, wireless access networks are increasingly popular, as they enable subscribers to access communications services without being tied to a fixed, wireline communications device. Conventional wireless access network infrastructure (e.g., base stations) is typically "built out", by a network services provider, using a network-centric approach. Thus the build-out normally begins with major Metropolitan Service Areas (MSAs) using base stations located at the center of overlapping coverage areas or "cells". The build-out, and corresponding wireless communications services, subsequently migrates outward from the MSAs to areas of lower population/service densities (e.g., urban to suburban to rural, etc.). At some point, usually dictated by economics, the build-out slows and/or becomes spotty leaving many individual wireless subscribers with unreliable or non-existent service.

[0005] On-frequency repeaters are known in the art for improving wireless services within defined regions of a wireless network (e.g. within a building or a built-up area). Such on-frequency repeaters are typically provided by the wireless network provider in order to improve signal quality in high noise or attenuation environments, where signal levels would otherwise be too low for satisfactory quality of service. In some cases, a wireless network provider may install a repeater in order to improve service in an area lying at an edge of the coverage area serviced by a base station, thereby effectively extending the reach of the base-station.

[0006] Prior art repeaters are part of a network-centric view of the wireless network space, in that they are comparatively large systems provided by the network provider in order to improve wireless service to multiple subscribers within a defined area. As such, they form part of the network "build-out plan" of the network provider. These systems suffer the disadvantage in that an individual subscriber cannot benefit from the improved services afforded by the repeater unless they happen to be located within the coverage area of the repeater. However, there are many instances in which wireless subscribers may reside or work in areas where the coverage area of the wireless network is unreliable. Typical examples include mobile subscribers, and subscribers located in suburban and rural areas. Also, in-building coverage can be unreliable even within MSAs, depending on the size, location and construction of buildings and/or other obstacles. In such cases, it may be uneconomical for a network provider to build-out the network to provide adequate coverage area, thereby leaving those subscribers with inadequate wireless services.

[0007] Accordingly, a method and apparatus that enables an individual subscriber to cost-effectively access high quality wireless communications services, independently of the location of the subscriber, remains highly desirable.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide an apparatus that enables an individual subscriber to cost-effectively access high quality wireless communications services, independently of a location of the subscriber.

[0009] Accordingly, an aspect of the present invention provides a repeater adapted to transparently mediate signaling between a wireless communications device and a wireless communications network. The repeater comprises a Directional Donor Unit (DDU) and a Subscriber Coverage Unit (SCU). The DDU is adapted to maintain a network link with a transceiver (base station) of the wireless communications network. The SCU is adapted to maintain a local link with the wireless communications device within a personal wireless space of the repeater. The SCU generally includes, means for detecting respective uplink and downlink channel frequencies of the wireless communications device, and control means adapted to control at least the SCU to selectively receive and transmit signals within the detected uplink and downlink channel frequencies.

[0010] The DDU and SCU are preferably provided as highly integrated antenna/amplifier units coupled together by a bi-directional signal path, such as a coaxial cable. In this arrangement, the total APR gain can be divided between the DDU and the SCU, so that a separate gain and system control unit is not required. Additionally, division of system gain between the DDU and SCU also enables high-performance on-frequency repeater functionality to be obtained without the use of high-cost components, and at the same time facilitates isolation between the system antennas.

[0011] Another aspect of the present invention provides a method by which a network service provider can provide wireless communications services to a subscriber or a co-located group of subscribers located in an area that is poorly serviced by a wireless communications network. Rather than build-out the network with high-cost equipment, in accordance with the present invention, the network service provider can provide the subscriber(s) with a personal repeater adapted to transparently mediate signaling between wireless communications devices of the subscriber(s) and a base station of the wireless communications network. This provides the network service provider with a cost-effective means of addressing service quality issues on an individual subscriber basis, in areas where network build-out is uneconomical.

[0012] Another aspect of the present invention provides a method by which a third-party vendor can enable subscribers located in an area that is poorly serviced by a wireless communications network to access wireless communications services of the wireless communications network. Thus the third-party vendor can provide the subscriber(s) with a personal repeater adapted to transparently mediate signaling between a wireless communications device of the subscriber and a base station of the wireless communications network. Because the personal repeater is transparent to both the wireless communications network and the subscriber's wireless communications device, the subscriber(s) can install and operate the personal repeater independently of the network service provider, without any adverse impact on operation of the base station.

[0013] The APR of the present invention represents a Subscriber-Centric Technology (SCT), in that it complements existing wireless communications networks (such as cellular and PCS networks) by providing a cost-effective product solution for the individual subscriber who has inadequate or non-existent wireless coverage. The Adaptive Personal Repeater (APR) of the present invention allows the wireless subscriber or collocated group of subscribers to access the wireless communications network by reaching back from the outside of the reliable network without the need for any further network-centric build out. Thus the APR provides the subscriber with a means to address poor or non-existent coverage when, and where, they need it, and thereby empowers the individual subscriber to manage their own "personal wireless space".

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[0015] **FIG. 1** is a block diagram schematically illustrating an Adaptive Personal Repeater in accordance with an embodiment of the present invention;

[0016] **FIG. 2** is a block diagram schematically illustrating principle elements of the Adaptive Personal Repeater of **FIG. 1**;

[0017] **FIG. 3** is a block diagram schematically illustrating principle elements of an exemplary directional donor unit (DDU) usable in the embodiment of **FIG. 2**;

[0018] **FIG. 4** is a block diagram schematically illustrating principle elements of an exemplary subscriber coverage unit (SCU) usable in the embodiment of **FIG. 2**;

[0019] **FIG. 5** is a block diagram schematically illustrating principle elements of an exemplary downlink AGC usable in the SCU of **FIG. 4**;

[0020] **FIG. 6** is a block diagram schematically illustrating principle elements of an exemplary uplink AGC usable in the SCU of **FIG. 4**;

[0021] **FIG. 7** is a state diagram illustrating exemplary states and state transitions traversed during operation of the Adaptive Personal Repeater of **FIG. 1**; and

[0022] **FIG. 8** is a flow chart illustrating principle operations of an exemplary adaptive control algorithm during initialization and operation of the Adaptive Personal Repeater of **FIG. 1**.

[0023] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0024] The present invention provides an Adaptive Personal Repeater (APR) **2**, which enables cost-effective delivery of high quality wireless communications services to subscriber(s) located outside a reliable coverage area of an existing wireless communications network **4**. In general, the APR **2** operates to create a personal wireless space **6** encompassing the subscriber's wireless communications device(s), and "reaches back" into the reliable coverage area of the wireless communications network **4** in order to access wireless communications services. **FIG. 1** is a block diagram schematically illustrating operation of the APR **2** in accordance with the present invention.

[0025] As shown in **FIG. 1, a** conventional wireless communications network **4** comprises a plurality of base stations **8**, each of which provides wireless communications services within a respective coverage area or cell **10**. Mobile communications devices (not shown) within a cell **10** access wireless communications services of the network **4** by negotiating a wireless connection with the respective base station **8** of the cell **10**, in a manner known in the art. The size and shape of each cell **10** may be irregular, and will depend on many factors, including, for example, distance from the respective base station **8**, and the presence of obstacles (e.g. buildings and geographical features such as hills, valleys etc.) which tend to attenuate radio signals. Within a multi-cell network **4** such as shown in **FIG. 1**, inter-cell boundaries **12** are determined as the point at which a mobile communications device is switched or "handed-off" from one base station **8** to a base station **8** of an adjacent cell **10**. Typically, this is determined on the basis of signal power. At the edge of the wireless communications network **4**, the cell boundary corresponds with the network coverage area boundary **14**, which may nominally be determined as the point at which the signal-to-noise (S/N) ratio becomes too low to permit negotiation of a satisfactory connection between the nearest base station **8** and a mobile communications device.

[0026] Within each cell **10**, the quality of wireless service access may vary widely. For example, within a built-up area, multiple reflections from the surfaces of buildings can create a high-noise or attenuation environment which degrades reliability of access to the wireless communications network. Within buildings, both signal scattering and attenuation can prevent reliable access to the wireless communications network.

[0027] The Adaptive Personal Repeater (APR) **2** of the present invention operates to define a personal wireless space **6** for the subscriber(s), and reaches back to a base station **8*a*** to enable the subscriber(s) to reliably access the wireless communications services of the network **4**. The personal wireless space **6** may be defined within a poorly served area of the wireless network **4** (e.g. within a building or other high noise/attenuation area) or, as shown in **FIG. 1**, in an area beyond the network coverage area boundary **14**. In either case, the APR **2** is functionally positioned between the base station **8*a*** and the subscriber's Wireless Communications Device(s) (WCD) **16**. The subscriber's WCD(s) **16** may take the form of any conventional wireless communications device, such as, for example, Personal Digital Assistants (PDA's), wireless telephone handsets, pagers, and one and two-way messaging devices.

[0028] Between the APR **2** and the base station **8*a***, a network link is established, in which respective uplink and downlink channel power levels are detected and adjusted in order to optimize performance of the link. Similarly, between the APR **2** and the subscriber's mobile communications device **16**, a local wireless link **20** is established, in which respective uplink and downlink channel power levels are detected and adjusted as will be described in greater detail below. However, the APR **2** does not terminate any connections intermediate the base station **8***a* and the subscriber's mobile communications device **16**, and does not perform any signal format or communications protocol conversions. Accordingly, the APR **2** is functionally transparent to both the network and conventional mobile communications devices, and thereby enables protocol- and signal format-independent interaction between the base station **8***a* and the subscriber's mobile communications device **16**. Once the respective links **18**, **20** between the APR **2** and the base station **8***a*, and between the APR **2** and the WCD **16** have been set up, and respective up-link and down-link channel powers negotiated, the APR **2** operates to transparently facilitate signaling between the WCD **16** and the base station **8***a*. Thus the WCD **16** interacts with the base station **8***a* to negotiate communications links (e.g. protocols, signal formats, time slots etc.) in a conventional manner, so that wireless communications services of the network **4** can be seamlessly accessed by the subscriber using the WCD **16**. However, as described in greater detail below, the transmit and receive performance of the APR **2** exceeds that of a conventional mobile communications device, thereby enabling a connection between the WCD **16** and the base station **8***a* to be established over a greater distance and/or in a higher noise/attenuation environment than would be possible if the WCD **16** were communicating with the base station **8***a* directly. Moreover, the APR adaptively maintains a reliable link between the WCD and the base station.

[**0029**] The APR **2** of the present invention is an "on-frequency" repeater, in that uplink and downlink RF signals are conveyed through the APR **2** without altering the respective channel frequencies. In operation, transmissions from the subscriber's WCD(s) **16** are detected by the APR **2**, which then adapts to the RF characteristics of the subscriber's WCD(s) **16** by acquiring appropriate uplink and downlink channel frequencies. Thereafter, the APR **2** operates to selectively receive, amplify, and retransmit RF signals within these uplink and downlink channel frequencies.

[**0030**] FIGS. 2-6 schematically illustrate principal elements of an APR **2** in accordance with an embodiment of the present invention. As shown in **FIG. 2**, the APR **2** generally comprises a Directional Donor Unit (DDU) **22** and a Subscriber Coverage Unit (SCU) **24**. The DDU **22** and SCU **24** may be integrated into a single device, or may be provided as separate components suitably coupled to each other (e.g. via a coaxial cable or the like). For ease of description, each of the DDU **22** and SCU **24** are described below as separate devices coupled together by a suitable connection path **26** (e.g. a coaxial cable connection).

[**0031**] In the illustrated embodiment, each of the DDU **22** and SCU **24** are provided as highly integrated units, which co-operate to implement the entire functionality of the APR **2**. As described below, this arrangement improves performance, lowers cost and eliminates the need for an electronic unit separate from the antennas to house the repeater's functional building blocks.

[**0032**] Conventional On-Frequency Repeaters (OFRs) generally comprise one or more power amplification and control units connected to two passive antennas via respective lengths of coaxial cable. These electronic units are usually located at some distance from the passive antennas, requiring the need for expensive coaxial cable to minimize losses and maintain isolation between each unit and the antennas. Also, because even expensive coaxial cables have some amount of loss, expensive high performance building blocks, such as highly linear power amplifiers are required to overcome the loss and meet the system performance specifications. High performance functional blocks and high grade cables are necessary to meet not only the transmit power requirements, but to preserve the receive signal quality as well. Since OFRs are non-frequency translating and the system gain within the unit can approach **100** dB, the possibility of internal system instabilities are high. Thus, it is frequently necessary to implement separate shielding for all internal building blocks, typically by using expensive multiple aluminum enclosures within each electronic unit.

[**0033**] In the illustrated embodiment, the functionality of the APR **2** is provided by two highly integrated units, each of which provides a portion of the system gain necessary to meet the repeater's overall performance requirements. As will be described in further detail below, this division of system gain substantially reduces the need for high performance (and thus expensive) components and high shielding requirements within each unit.

[**0034**] In accordance with the present invention, the DDU **22** and SCU **24** implement a technique of Adaptive Interference Mitigation, in which RF interference in the subscriber's personal wireless space **6** is mitigated by a combination of one or more of: physical antenna separation; cross polarization; RF power management; and the use of a narrow beam network link **18** between the APR **2** and the base station **8***a*. Interference has become a problem in most wireless service networks. The type and degree of interference varies from one network to the other. So-called "Smart" antenna technology has been used in a wide variety of applications to combat interference in these networks. This smart antenna technology can be effectively applied at a base station to reduce the interference problem for both the downlink (interference to the handset from other base stations) and the uplink (interference to the base station from other handsets) communication paths. However, smart antenna technology has not been used to mitigate interference occurring at the handset end of the link. This is largely due to the size and power constraints of the handset, and the requirement that the handset antenna must be omni-directional to successfully connect to, and communicate with the base station in a wide area network.

[**0035**] The APR **2** of the present invention provides a means to mitigate interference at the handset end of the network for both the downlink and the uplink propagation paths. The APR **2** operates to transform the handset's omni-directional antenna pattern of the WCD **16**(for the local wireless link **20**, which is confined to a small area of reliable coverage) into a directional antenna pattern (of the network link **18**) by masking over the weak handset signal with a strong conditioned signal in a specific direction. Additionally, the APR **2** adaptively provides continuous interference mitigation within the subscriber's personal wireless space **6**, and minimizes any possible interference that may be generated, by confining the size of the personal wireless space **6** to only the subscriber's position.

[0036] Directional antennas radiate RF energy in one direction more than in other directions. The APR **2** uses an external directional antenna to reach back into the network and radiate RF power to the base station **8***a* from the subscriber's personal wireless space **6**. By virtue of the directionality of the antenna, the subscriber's personal wireless space **6** not only can discriminate against interference coming from outside the antenna's beam-width, but also can prevent generating possible interference to other base stations **8** in other directions. This in itself passively mitigates the interference in both the downlink and uplink paths. The antenna's discrimination provides the means to spatially separate the desired signal from possible sources of interference from other base stations. With this discrimination in hand, the APR **2** then amplifies and conditions the desired signal and adaptively transmits it to ensure that at the WCD **16**, the desired signal remains relatively constant in level regardless of the subscriber's position or movement within the personal wireless space **6**. Unlike conventional mitigation schemes, where the interference is reduced relative to the desired signal or itself, the APR **2** operates to increase the desired signal level relative to the interference within the subscriber's personal wireless space **6**.

[0037] The DDU **22** operates to establish and maintain the network link **18** between the APR **2** and the base station **8***a* of the wireless communications network **4**. As is known in the art, signal attenuation within such a wireless link **18** is generally a function of distance between the base station **8***a* and the DDU **22**. Accordingly, the DDU **22** preferably enables the APR **2** to maintain a connection with the base station **8***a* over a wide range of receive and transmit power levels. The DDU **22** may, for example, be advantageously designed to receive downlink signal power levels to as low as −120 dBm. Additionally, the DDU **22** may be designed to transmit uplink signals to the base station to as high as +37 dBm, which will typically be on the order of 10 dB greater than that of conventional cellular handsets. This transmit and receive performance of the DDU **22** enables maintenance of the network link **18** with the base station **8***a*, even when the DDU **22** is located well beyond the conventional cell (and network coverage area) boundary **14**.

[0038] In the embodiment illustrated in **FIG. 2**, the Directional Donor Unit (DDU) **22** is provided as a single port active antenna comprising a Directional Donor Antenna (DDA) **28** integrated with a Transceiver Diplexor (TRD) **30**. A bi-directional port **32** couples the DDU **22** to the SCU **24** through the coaxial cable connection **26**.

[0039] In the illustrated embodiment, the DDA **28** is provided as a high performance, vertically polarized, directional antenna. The DDU **22** is positionable (i.e. rotatable in a horizontal plane) to allow for alignment of the DDA **28** to the base station **8***a* during installation. Directionality of the DDA **28** helps to fine tune positioning. Vertical polarization maximizes coupling to the typically vertical electromagnetic (EM) field of the (conventional) base station **8***a*.

[0040] The DDU **22** can beneficially be designed for outdoor use. In such cases, fewer components with better temperature ratings can be used in this unit to implement the functional performance requirements of the DDU **22** while keeping costs down. The DDU **22** components may, for example, represent less than 20% of the APR's total component count, all of which are designed to operate in an outdoor environment. The DDU **22** may also include a low-cost plastic enclosure that protects the functional components from the outdoor elements. This enclosure houses an integrated high gain antenna and Transceiver Diplexer (TRD) on a common Printed Wiring Board (PWB). As part of the TRD, a low noise amplifier is used to preserve the downlink receive signal quality, while a power amplifier delivers the necessary power in the uplink path. Since both devices are connected directly to the integrated antenna via a diplexer, the system performance is maximized while keeping component costs comparatively low. This means that the low noise amplifier and power amplifier requirements can be relaxed by 3 to 5 dB in comparison to conventional OFRs so that costs are significantly lower. Performance is enhanced by virtue of little or no loss between the antenna and the diplexer. Also, the system reliability can be improved by using lower power devices. The DDU gain for both the uplink and the downlink paths can be less than 40 dB, keeping isolation requirements within the unit moderately low. Consequently, individual components or building blocks do not require separate aluminum enclosures for shielding, but rather the uplink and downlink paths can be separated and the building blocks shielded together as functional sections, using simple board-level shields to increase isolation and prevent circuit coupling of unwanted high-level signals. Since the DDU **22** sets the system Noise Figure (NF) of the APR **2** in the downlink path, and provides the necessary gain for a given input to produce a +37 dBm EIRP output in the uplink path, the loss of the coaxial cable **26** can be relatively high, without adversely affecting the system performance. For this reason, in comparison with conventional OFR systems, a much lower grade cable (e.g. RG58 verses ½ inch heliax) can be used, hence the cost of the cable can be very low by comparison (e.g. by a factor of 10 or more for a given length). Lower cost cable usually means a much smaller cable diameter, which greatly improves ease of installation by allowing for a tighter bend radius. Also, because the isolation requirements are lower, the shielding of the cable is not as critical.

[0041] In operation, the DDA **28** simultaneously transmits uplink RF signals and receives downlink RF signals through the network link **18**. For example, the DDA **28** may be designed to transmit uplink RF signals within a frequency band from 824 to 849 MHz and receive downlink RF signals within a frequency band from 869 to 894 MHz. A 12 dBi antenna gain is required to transmit a maximum EIRP of +37 dBm in the uplink path for a +25 dBm TRD output.

[0042] The bi-directional port **32** simultaneously receives and transmits both uplink and downlink frequency bands through the coaxial connection **26**. For example, the port **32** may be designed to receive uplink RF signals from the SCU **24** within the uplink frequency band of 824 to 849 MHz and transmit downlink RF signals to the SCU **24** within the downlink frequency band of 869 to 894 MHz.

[0043] As shown in **FIG. 3**, the TRD **30** comprises respective uplink and downlink signal paths **34**, **36** connected between a DDA diplexer **38** coupled to the DDA **28**, and a TRD port diplexer **40** coupled to the port **32**. The DDA diplexer **38** operates to separate the signal paths **34**, **36** at the DDA **28**. Similarly, the TRD port diplexer **40** operates to separate the signal paths at the port **32**. The respective TRD port and DDA diplexers **38**, **40** also operate to define and limit the frequency band(s) over which the system must maintain stability.

[**0044**] In the illustrated embodiment, the uplink path **34** comprises: a two-stage driver **42** including a pair of series connected driver amplifiers **44***a* and **44***a*; and a power amplifier (PA) **46** connected in series with the two-stage driver **42**. This arrangement of cascaded driver and power amplifier circuits connected directly to the DDA via the DDA diplexer **38** reduces output power requirements of the PA **46**. For example, the output power of the PA **46** at the DDA **28**, which may be automatically controlled (i.e. enabled or disabled) by a simple detection circuit **48**, can be approximately 3 dB lower than the equivalent output power of a conventional cellular handset. This arrangement minimizes losses between the PA **46** and the DDA **28**; improves performance, power consumption and reliability; while at the same time lowering cost.

[**0045**] The two-stage driver **42** and the power amplifier **46** within the uplink path **34** facilitate automatic RF power management, and so allows the DDU **22** to reliably maintain the network link **18** with the base station **8***a*. This operation is simplified by the fact that the propagation environment of the network link **18** is comparatively static due to the fixed locations of the base station **8***a* and the DDU **22**. Reliable maintenance of the network link **18** can thus be achieved by measuring the power of downlink RF signals received from the base station **8***a*, and using the measured power to control the signal power of uplink RF signals transmitted to the base station **8***a*. For example, if the measured power of the received downlink RF signals is greater than a predetermined minimum threshold, then the uplink RF signal transmit power can be reduced to improve spectrum efficiency, conserve energy, increase reliability and reduce system gain. Conversely, if the measured power of the received downlink RF signals drops below the predetermined minimum threshold, then the uplink RF signal transmit power can be increased to improve the signal-to-noise ratio. In the illustrated embodiment, control of the uplink RF signal transmit power in this manner is accomplished within the SCU **24**, as will be described in greater detail below. It will be appreciated, however, that uplink RF signal transmit power control may be effected within the TRD **30** using a suitable cross-over circuit (not shown) in which, for example, the PA **46** is provided as a variable gain amplifier controlled by a controller unit coupled to the downlink path **36** to detect the received downlink RF signal power.

[**0046**] To further improve the reliability of the PA **46**, an isolator **50** may be placed in series between the PA **46** and the DDA diplexer **38** to prevent reflected power from appearing at the output of the PA **46** (due, for example, to any mismatch between the DDA **28** and the DDA diplexer **38**). Additionally, the isolator **50** can provide constant impedance matching for the DDA diplexer **38** when the PA **46** is enabled and disabled. As may be appreciated, frequency crossover noise may contaminate the uplink RF signal in the uplink path **34**. Such frequency cross-over noise is attenuated by the DDA and port diplexers **36, 38**. Further attenuation of frequency crossover noise within the uplink path **34** may be accomplished using an uplink Band Pass Filter (BPF) **52**, connected in series between the two driver stages **44***a* and **44***a*. Isolation of the DDA diplexer **38** prevents the PA **46** from saturating the downlink path amplifiers (described below). This isolation is critical because the transmit power from the PA **46** into the DDA diplexer **38** can be as high as +28 dBm.

[**0047**] The downlink path **36** generally comprises a Low Noise Amplifier (LNA) **54**, a downlink band pass filter (BPF) **56**, and a downlink signal driver **58** connected in series between the DDA diplexer **38** and port diplexer **40**. The LNA **54** is preferably a high performance amplifier providing, for example, 15 dB of gain with a noise figure of about 1.5 dB. The LNA gain and noise figure, in combination with the DDA **28** gain and losses in the DDA diplexer **38**, determine the minimum signal strength and quality (i.e. signal-to-noise [S/N] ratio) of received downlink RF signals. For example, in the illustrated embodiment, a received downlink RF signal of −120 dBm in a 25 kHz noise bandwidth yields a S/N ratio of +17 dB at the output of the bi-directional port **32**, excluding any environmental noise.

[**0048**] The downlink BPF **56** (which may, for example, be a SAW BPF) operates to reject both image and frequency crossover noise, and further attenuates any uplink RF signal in the downlink path **36**. The downlink signal driver **58** is conveniently provided as an amplifier which operates as a buffer and gain stage to compensate for losses in the (coaxial cable) connection **26** between the DDU **22** and SCU **24**. Because cable losses in low-cost coaxial cable tend to be relatively high, it is preferable to amplify the received downlink RF signal upstream of the connection **26**, and thus before the loss is incurred, to preserve the S/N ratio established by the DDA **28**, LNA **54**, and DDA diplexer **38**.

[**0049**] Total APR gain is the summation of both the DDU **22** and SCU **24** gains minus the losses in the coaxial cable connection **26**, and may be limited by the isolation between the units achieved during installation. The DDA **28** preferably has a front to back ratio of greater than 25 dB to help maximize the isolation between the two units, and therefore achieve sufficient APR gain to maintain a reliable network link **18**.

[**0050**] Referring back to **FIG. 2**, the Subscriber Coverage Unit (SCU) **24** operates to create the subscriber's personal wireless space **6** by maintaining the local wireless link **20** between the APR **2** and the subscriber's WCD(s) **16**. As with a conventional cell **10** of the wireless communications network **4**, the subscriber's personal wireless space **6** may be irregular in shape. However, the coverage area will not only be determined as a function of RF signal power and/or signal-to-noise ratio of uplink RF signals received by the SCU **24**, but also as a function of the position of the subscriber's WCD **16** relative to the SCU **24**. In all cases, it is anticipated that the coverage area of the subscriber's personal wireless space **6** will be very much smaller than a conventional cell **10** of the wireless communications network **4**. For example, in some embodiments, it is expected that the subscriber's personal wireless space **6** will extend 25 m (or less) from the SCU **24**. Such embodiments are particularly suited for enabling the subscriber to access wireless communications services of the network **4** from, for example, any location in and about their residence or place of business. Other embodiments may provide a larger or smaller personal wireless space **6**, if desired.

[**0051**] In any event, it is preferable for the subscriber's WCD **16** to operate at a minimum signal transmission power. Thus the SCU **24** implements a technique of Adaptive Coverage Breathing (ACB), such that the coverage area of the subscriber's personal wireless space **6** is automatically adjusted in order to ensure acceptable signal-to-noise ratio in both the uplink and downlink paths of the local link **20**, while at the same time minimizing transmission (i.e. uplink RF signal) power in the WCD **16**.

[**0052**] In general, Adaptive Coverage Breathing (ACB) comprises a technique of RF power management that allows the coverage area of the subscriber's personal wireless space **6** to "breathe" by adaptively expanding and contracting to the position of the subscriber's WCD **16** relative to the SCU **24**. This allows both the subscriber's WCD **16** and the SCU **24** to radiate only the necessary powers needed to maintain reliable signaling over the local link **20**. As the subscriber's WCD **16** moves relative to the SCU **24**, the coverage area of the personal wireless space **6** changes continuously to adapt to the movement. As the WCD **16** moves towards the APR **2**, the coverage area automatically contracts, so that the personal wireless space **6** is limited to just encompass the WCD **16**. This can be accomplished by measuring the signal power of uplink RF signals received from the WCD **16**, and then adjusting the transmission power of downlink RF signals accordingly. If two or more wireless communications devices **16** are being used simultaneously, then the SCU **24** can operate to expand the coverage area to accommodate the WCD **16** located furthest from the SCU **24** (or transmitting the weakest uplink RF signals). This is achieved by measuring the power of uplink RF signals received from each of the wireless communications devices **16**, and adjusting the downlink transmit power to account for the difference between the measured signal power levels.

[**0053**] Two major benefits for the subscriber resulting from the ACB concept include reduced RF radiation, and increased battery life within the subscriber's WCD **16**. Reduced RF radiation for the subscriber is a major benefit, particularly in view of growing concerns that high level RF radiation in close proximity to the subscriber's body (typically the head) may be hazardous to human health. The ACB concept implemented by the present invention permits the RF power radiation of the subscriber's WCD **16** to be significantly reduced (in comparison to that required for communications within the conventional wireless communication network **4**), by maintaining reliable balanced power levels in the uplink and downlink paths. Typically, the single most power-consuming section in a wireless communications device is the uplink channel RF amplifier. This amplifier is normally a class AB or C amplifier, which consumes battery power proportional to the RF input signal level. That is, a large RF input signal will cause the uplink channel RF amplifier to consume a large amount of battery power to produce the necessary uplink RF signal power through the antenna. Lowering the uplink RF signal power requirement of the WCD **16**, as enabled by the present invention, significantly extends the battery life, and thus the "talk time" of the WCD **16**.

[**0054**] In the illustrated embodiment, a minimum acceptable uplink channel RF signal power of the WCD **16** is negotiated at a start of a communications session. This uplink channel RF signal power is then maintained constant (during the communications session), and the SCU **24** adapts to changes in the position of the WCD **16** by accepting widely varying uplink channel RF signal powers from the WCD **16**. With this arrangement, the variation in received uplink channel RF signal power may be as high as 50 to 60 dB, depending largely on the proximity of the WCD **16** to the SCU **24**. Accordingly, the SCU **24** is preferably designed to receive uplink channel RF signal power levels varying between, for example, 0 dBm to −60 dBm.

[**0055**] The received uplink channel RF signal power level can be measured by the SCU **24**, and used to control the downlink channel RF signal power. For example, if the received power of the uplink RF signals is greater than a predetermined minimum threshold, then the downlink RF signal transmit power can be reduced (i.e. the coverage area of the subscriber's personal wireless space **6** reduced) to improve spectrum efficiency, conserve energy, increase reliability and reduce system gain. Conversely, if the measured power of the received uplink RF signals drops below the predetermined minimum threshold, then the downlink RF signal transmit power can be increased (i.e. the coverage area of the subscriber's personal wireless space **6** expanded)to improve the signal-to-noise ratio.

[**0056**] In the illustrated embodiment, the Subscriber Coverage Unit (SCU) **24** is provided as a single port active antenna comprising a Subscriber Coverage Antenna (SCA) **60** integrated with a dual-directional processor (DDP) **62**. A single bi-directional port **64** couples the DDP **62** to the TRD **30** via the coaxial cable **26**. As shown in **FIG. 4**, the DDP **62** comprises respective uplink and downlink signal paths **66** and **68** connected between an SCA diplexer **70** coupled to the SCA **60**, and a port diplexer **72** coupled to the bi-directional port **64**. The SCA diplexer **70** operates to separate the signal paths **66, 68** at the SCA **60**. Similarly, the port diplexer **72** operates to separate the signal paths **66** and **68** at the bi-directional port, **P264**. The respective SCA and port diplexers **70** and **72** also operate to define and limit the frequency band(s) over which the system must maintain stability.

[**0057**] In the illustrated embodiment, the SCA **60** is provided as a wide beam-width, horizontally polarized, directional antenna. Vertical positioning of the SCU **24** (and thus the SCA **60**) provides a mechanism to improve isolation between the DDA **28** and SCA **60**, as well as to optimize total APR gain. A wide beam-width of the SCA **60** ensures adequate forward coverage to create a "bubble-effect" for the personal wireless space **6**. Horizontal polarization creates an orthogonal relationship to the polarization of the DDA **28**, further improving isolation between the SCA **60** and the DDA **28**, while increasing the field coupling between the SCA **60** and the WCD **16**. System isolation is further improved by the front to back ratio of the SCA **60**, which may, for example, be >10 dB.

[**0058**] The SCU **24** can beneficially be designed as an indoor unit that incorporates the SCA **60** integrated with the dual directional processor (DDP) **62**. In some embodiments, the radiating element of the antenna can be physically attached to the printed wiring board (PWB) shields, which can then serve as the reflector portion of the antenna. The DDP **62** includes two intelligent gain controllers (IGCs) **92** and **94**, each sharing a common IF down-converter and narrowband detector, and being controlled by a single digital controller in accordance with an adaptive control algorithm. The number of components in the SCU **24** may, in some embodiments, account for over 80% of the APR's total component count, all of which can be low power devices with a commercial temperature rating to satisfy the indoor environment, which in turn helps to keep costs down.

[0059] The gain in the SCU **24** can be less than 60 dB for both the uplink and downlink paths. This gain is manageable in a single PWB, without the need to separately enclose the individual building blocks. As with the DDU **22**, the uplink and downlink paths are separated, and the building blocks can be shielded together as functional sections using simple, conventional, board-level shields to increase isolation and prevent circuit coupling of unwanted high-level signals. The digital controller can be shielded from the RF and analog sections (also be means on conventional board-level shields), to prevent digital noise from radiating to the RF and analog sections. This simple shielding requirement helps to lower the product cost while improving the reliability by maintaining unit stability.

[0060] The SCA **60** operates to transmit downlink RF signals to the subscriber's WCD **16**, and receives uplink RF signals from the subscriber's WCD **16**. An antenna gain of 6 dBi is required, but not limited to radiate a maximum −20 dBm EIRP in the downlink channel. Maximum EIRP, minus the antenna gain, determines the output of the DDP **62**, which may, for example, be about −26 dBm.

[0061] The bi-directional port **64** simultaneously receives and transmits both uplink and downlink frequency bands. For example, the bi-directional port **64** may accept downlink RF signals from the DDU **22** within a frequency band from 869 to 894 MHz, and transmit uplink RF signals to the DDU **22** within a frequency band from 824 to 869 MHz.

[0062] In the illustrated embodiment, the dual-directional processor (DDP) **62** is provided as a combined RF and digital processing module. RF signals within the uplink and downlink paths **66** and **68** are separately amplified, conditioned and processed (over their entire 25 MHz bands). This processing scheme improves performance while reducing complexity, thus lowering product cost. The DDP **62** comprises: the uplink path **66** including a wideband uplink Automatic Gain Controller (AGC) **74** series connected with a slaved variable gain amplifier (VGA) **76** and an output amplifier **78**; the downlink path **68** including a preamplifier **80**, wideband downlink automatic gain controller (AGC) **82**, a slaved variable gain amplifier (VGA) **84**, and an output amplifier **86**; a switched common down-converter **88**; and a digital controller **90** operating under software control.

[0063] The uplink path **66** interfaces with the down-converter **88** and digital controller **90** to define an uplink intelligent gain control (IGC) **92**. Similarly, the downlink path **68** interfaces with the down-converter **88** and digital controller **90** to define a downlink IGC **94**.

[0064] As is known in the art, on-frequency repeaters can oscillate if the system gain exceeds the antenna isolation. For this reason, and depending on the required link performance, installation of on-frequency repeaters can be very difficult. In accordance with the present invention, the IGCs incorporate the concepts of Adaptive Coverage Breathing (ACB) and Coverage Area Signature (CAS) to prevent and eliminate the possibility of oscillations occurring due to system instability during installation and subsequent operation of the APR **2**. The ACB concept ensures only the necessary power is transmitted in both the uplink and downlink paths to maintain a reliable local link **20**, hence the system gain is only as high as it needs to be in both paths, which ultimately increases system stability. The CAS concept provides a means to de-correlate the leakage signals that appear at the APR inputs (DDA **28** and SCA **60**) from the incoming received signals. This de-correlation allows the APR **2** to separate the leakage signal from the incoming signals in order to adaptively adjust the APR gain to maintain a defined level of stability.

[0065] An unconditionally stable system requires that total system isolation (comprising the front to back ratios of the DDA **28** and SCA **60**; polarization loss; propagation path loss; and cable losses) must be greater than the maximum combined gain of the DDP **62** and the TRD **30**. System stability within a defined band can be maintained by operation of the uplink and downlink IGCs **92** and **94** which adaptively adjust the hardware gain in the uplink and downlink paths **66** and **68** independently, so as to minimize the transmit power in both directions, via a hardware and software control algorithm. Gain reduction as a result of insufficient isolation only reduces the coverage area of the personal wireless space **6**. It does not limit the ability of the APR **2** to maintain reliable links **18, 20** in both directions for the reduced coverage area of the personal wireless space **6**.

[0066] As part of the IGC, the down-converter **88** and digital controller **90** operate to implement a digital offset correction method which enables the output of a wideband AGC to be set for RF signals that have not captured the AGCs **74** and **82**. As in known in the art, a wideband AGC will level to the highest signal that captures the AGC within a defined bandwidth. If no signals are present, the AGC may level to the thermal and system noise of a given bandwidth. If weak desired (i.e. uplink or downlink RF) signals are present, and the AGC bandwidth is much larger than the signal bandwidth (such that noise masks the weak signals) the AGC will be captured by the noise rather than the weak desired signal. In the present invention, narrowband detection is used as a means to detect the (weak) desired signals embedded in the noise. Detection of the desired uplink and downlink signals is then used by the digital controller **90** to offset the output to which the appropriate AGCs **74** and **82** level. This same technique can also be used to detect weak desired signals in the presence of high-level unwanted signals that would otherwise capture an AGC and limit the system gain for the desired signals.

[0067] As shown in **FIG. 4**, the down-converter **88** comprises a switching input **96**, an active mixer **98**, a Xtal band pass filter **100**, a log amp detector **102**, and a tunable synthesizer **104**, which is tuned by the digital controller 90 to 45 MHz above the uplink channel frequency and 45 MHz below the downlink channel frequency. The switching input **96** is controlled by the digital controller **90** to supply an RF signal from a selected one of the uplink and downlink AGCs **74** and **82** to the active mixer **98**. Similarly, the synthesizer **104** is controlled by the digital controller **90** to supply an RF synthesized signal to the mixer **98**. The output of the mixer **98** is channeled by the Xtal BPF **100** and supplied to the detection log amplifier **102**, which operates to detect the uplink and downlink signals within their respective channels. The output of the detection log amplifier **102** is supplied to the digital controller **90**, and is used for decision making in accordance with the adaptive control algorithm. Thus when the switching input **96** supplies an RF signal from the uplink path **66** to the mixer **98**, the Xtal BPF **100** and detection log amplifier **102** operate to detect the level and number of desired signals within the uplink channel, and this information can be used by the digital controller **90** to set the appropriate power in the uplink path **66** and to tune the synthesizer **104** to the corresponding downlink channel frequency. Conversely, when the switching input **96** supplies an RF signal from the downlink path **68** to the mixer **98**, the Xtal BPF **100** and detection log amplifier **102** operate to detect weak desired signals within the downlink channel, and this information can be used by the digital controller **90** to set the appropriate power in the downlink path **94**. This arrangement enables the digital controller **90** to detect any number of weak desired uplink and downlink signals that are below either high-level wanted signals and/or adjacent carrier signals, or the −95 dBm system noise floor within a respective 25 MHz bandwidth. The digital controller **90** provides a digital correction to each of the AGCs **74** and **82**, thereby offsetting the respective leveled outputs to the weak desired signals.

[**0068**] The digital controller **90** comprises a micro-processor **106** operating under software control, a configuration switch **108** enabling a user to control an operating configuration of the micro-processor **106**, and one or more Digital-to-Analog converters (DACs) **110** and Analog-to-Digital Converters (ADCs) **112** for enabling interaction between the micro-processor **106** and other elements of the DDP **62**. The digital controller **90** operates in accordance with an adaptive control algorithm (described in greater detail below), which provides the necessary processing control for APR operation as a stand-alone unit without intervention after the installation. It may also control APR operations during system set-up, in order to simplify installation of the APR **2**.

[**0069**] The DACs **110** accept respective digital output signals generated by the micro-processor **106**, and convert these digital output signals into analog control signals which are used, for example, for setting AGC gain in both the uplink and downlink paths **66** and **68**. The ADCs **112** convert analog RF signals into digital input signals, which are supplied to the micro-processor **106**. During operation, the micro-processor **106** processes these input signals, under software control, to determine system parameter levels (e.g. AGC gain levels) and generate appropriate digital output signals. This processing may include comparing digital input signals to one or more predetermined threshold values, and determining the system parameter levels in accordance with the comparison result.

[**0070**] The configuration switch **108**, which may be provided as a conventional DIP switch having one or more settings, allows the subscriber to select an operating configuration of the micro-processor **106**. Exemplary settings of the configuration switch includes: a "set-up" setting which may be used during installation of the APR **2**; a "run" setting which may be used during normal operation of the APR **2**; a carrier A/B band select setting which may be used by the subscriber to select the desired carrier. Carrier A/B bands may be selected together or individually. For example, when the configuration switch **108** is placed in the "set-up" setting, the micro-processor **106** may operate under software control to reduce AGC gain and transmission power levels to enable the subscriber to adjust the placement and positioning of the DDU **22** and SCU **24**. Additionally, the configuration switch **108** may have one or more settings by which the subscriber can choose to limit the coverage area of the subscriber's personal wireless space **6**, e.g. by causing the micro-processor **106** to limit gain within the downlink path **68**.

[**0071**] The DDP downlink path **68** is preferably designed to receive, process and transmit the entire 869 to 894 MHz cellular frequency band. As mentioned above and shown in **FIG. 4**, the DDP downlink path **68** comprises a preamplifier **80**, AGC **82**, slaved VGA **84** and an output amplifier stage **86**. These elements can be cascaded with a band-pass filter (BPF) **114** and inter-stage filters **116***a,* **116***b*.

[**0072**] The preamplifier **80** operates to preserve the S/N ratio established by the TRD LNA **54**, and buffers the port diplexer **72** from the first BPF **114** in the downlink path **68**. This BPF **114**, together with the port diplexer **72** limits the downlink bandwidth to 25 MHz, rejecting both image and frequency crossover noise and any out-of-band signals, including RF signals in the uplink path **66**.

[**0073**] The downlink AGC **82** is designed to provide substantially constant output leveling over a wide input range. As shown in **FIG. 5**, the downlink AGC **82** is preferably provided as an extremely fast, wide dynamic range, highly linear block comprising a single VGA stage **118**, a fixed-gain amplifier **120** cascaded with a pair of band-pass filters **122***a* and **122***b,* and a directional coupler **124**. Inter-stage filters **126***a*-**126***c* may also be included to reduce cascaded noise.

[**0074**] The downlink AGC VGA **118** preferably has approximately 60 dB of gain variation, and is cascaded with the fixed gain amplifier **120** to enhance system linearity while minimizing the cascaded noise figure. The BPFs **122***a*-**122***b* operate to limit VGA noise to the 25 MHz downlink bandwidth, thereby preventing out-of-band signals from capturing the downlink AGC **82** and saturating the downlink path **68** output amplifier **86**.

[**0075**] The directional coupler **124**, which may be a 17 dB directional coupler, samples the downlink RF signal downstream of the VGA **118**. The sample signal is supplied to a feedback path **127** which includes a cascaded RF amplifier **128** and log amplifier **130**, and a feedback directional coupler **132** which samples the RF signal within the feedback path **127** and supplies the sample signal to the switching input **96** of the downconverter **88**. The RF log amplifier **130** is preferably a variable detection log amplifier controlled by the digital controller **90**. The RF log amplifier **130** output supplies a gain control signal to the downlink AGC VGA **118** and the uplink path VGA **76**, and may also be supplied to the digital controller **90** to facilitate monitoring and decision functions of the adaptive control algorithm. The feedback path **127** preferably provides a 25 MHz bandwidth path which operates to ensure system stability by providing substantially instantaneous RF AGC feedback. The feedback path **127** closes the AGC loop, which in turn limits system oscillation by automatically adjusting gain of the VGA **118** in the event of inadequate isolation between the antennas **28** and **60**. The feedback path **127** also provides a means by which the gain of the downlink AGC **82** can be forced to a low level by the digital controller **90** to maintain stability during system setup, thereby ensuring the detection of weak desired signals without the need for initial system isolation maximization.

[**0076**] The downlink slaved VGA **84** accepts a gain control input from the uplink path AGC **74** to provide a hardware means to adaptively minimize the downlink output power, and thereby implement, in part, the ACB and CAS concepts. The output amplifier **86** increases the downlink RF signal power at the output of the slaved VGA **84** to −26 dBm at the output of the DCA diplexer **70**, when the received uplink RF signal power is at a minimum.

[**0077**] Referring now to **FIG. 4**, the DDP uplink path **66** is designed to receive, process and transmit the entire 824 to 849 MHz uplink channel frequency band. This path **66** comprises the uplink AGC **74**, slaved VGA **76** and an output amplifier stage **78**, each of which may be cascaded with inter-stage filters **132***a,* **132***b*. The uplink AGC **74** functions similarly to the downlink AGC **82**. Referring to **FIG. 6**, the uplink AGC **74** is preferably provided as an extremely fast, wide dynamic range, highly linear block including a single VGA stage **134**, fixed-gain amplifiers **136***a* and **136***b* cascaded with band-pass filters **138**, and a directional coupler **140**. Inter-stage filters **142** may also be included to reduce cascaded noise.

[**0078**] The uplink AGC VGA **134** preferably has approximately 60 dB of gain variation, and is cascaded with the fixed gain amplifiers **136** to enhance system linearity. This is important, because the received uplink RF signals are much stronger than received downlink signals. The BPFs **138** following the VGA **134** limit the VGA noise to the uplink band, thereby preventing out-of-band signals from capturing the uplink AGC **74** and saturating the uplink output amplifier **78**.

[**0079**] The directional coupler **140**, which may be a 17 dB directional coupler, samples the uplink RF signal downstream of the VGA **134**. The sample signal is supplied to a feedback path **144** comprising an RF log amplifier **146** and a feedback directional coupler **148** which samples the RF signal within the feedback path **144** and supplies the sample signal to the switching input **96** of the downconvertor **88**. The RF log amplifier **146** is a variable detection amplifier controlled by the digital controller **90**. The RF log amplifier **146** output supplies a gain control signal to the uplink AGC VGA **134** and the downlink slaved VGA **84**, and may also be supplied to the digital controller **90** to facilitate monitoring and decision function of the adaptive control algorithm. The feedback path **144** provides a 25 MHz bandwidth path which operates to ensure system stability by providing substantially instantaneous RF AGC feedback. The feedback path **144** closes the uplink AGC loop, which in turn limits system oscillation by automatically adjusting gain of the VGA **134** in the event of inadequate isolation between the antennas **28** and **60**. The feedback path **144** also provides a means by which the gain of the uplink AGC **74** and the downlink slaved VGA **84** can be forced to a low level by the digital controller **90** to maintain stability during system setup, thereby ensuring the detection of weak desired signals in the downlink path **68** without the need for initial system isolation maximization.

[**0080**] The uplink slaved VGA **76** accepts a gain control input from the downlink AGC **82** to provide the hardware means to adaptively minimize the uplink channel output power, and thereby implements, in part, the ACB and CAS concepts. The uplink output amplifier **78** increases the uplink RF signal power to +2 dBm at the port diplexer **72** output. This output power level is necessary to overcome losses associated with the coaxial cable **26**.

[**0081**] **FIG. 7** is a state diagram illustrating exemplary states and state transitions traversed during operation of the APR **2**. Upon application of power to the APR **2**, the unit enters an Initialization state **150**. In the initialization state **150**, the digital controller **90** initializes the hardware (e.g. uplink and downlink IGCs, **92** and **94**) and performs a Power-up Built-In Test (PBIT). The results of the PBIT test may be stored in a memory (not shown). Upon successful completion of the PBIT, the APR **2** transitions to the Operational State **152**. If the PBIT fails, the APR **2** remains in the Initialize state **150**, and in a Standby mode. In addition, a fault message may be generated, for example for display on a suitable display device (not shown).

[**0082**] Upon entering the Operational state **152**, an Active mode is selected as an initial default. In the Active mode, the digital controller **90** operates under control of the Adaptive Control Algorithm (ACA) to dynamically adjust the network wireless link **18** for optimum performance. The link status can be displayed on a suitable display (not shown). While in the Operational state **152**, the digital controller **90** periodically performs a Continuous Built-In Test (CBIT), the results of which may be stored in memory. Upon detecting a CBIT failure **154**, the APR **2** enters the Standby mode of the Operational state **152**. A fault message may also be generated, for example for display to the Subscriber. A successful completion of the CBIT **156** maintains the APR **2** in (or returns the APR **2** to)the Active mode. Upon a reset event **158** (e.g. a watchdog reset or a power interruption) the Operational state **152** is exited and the Initialize state **150** is entered to reset (i.e. re-boot) the APR **2**. At any time, status request messages may be received by the APR **2**, for example, from an external maintenance system (not shown). Such status requests received while the APR **2** is in the Initialize state **150** may cause the APR **2** to enter the Test state **160**. While in the Test state **160**, the maintenance system may initiate a download (e.g. of updated software) to the APR **2**. The Test state **160** is exited upon a Quit request, for example, from the maintenance system. Status requests from the maintenance system while the APR **2** is in the Operational state **152** allows the maintenance system to extract status information from the APR **2**.

[**0083**] As described above, the Adaptive Control Algorithm (ACA) enables the APR **2** to control the subscriber's personal wireless space **6** and the network wireless link **18**. Both the subscriber's personal wireless space **6** and the network wireless link **18** are adjusted dynamically based on various parameters obtained through non-intrusive measurements of the wireless signals within the uplink and downlink paths. **FIG. 8** is a flow chart illustrating principle operations of an exemplary adaptive control algorithm during initialization and operation of the APR **2**.

[**0084**] As shown in **FIG. 8**, upon start-up, the adaptive control algorithm places the APR **2** into the initialize state **150**; sets the signal power levels in the network and local wireless links **18** and **20** to their default values (at step S2); and performs the power-up built-in test PBIT (at step S4). If the PBIT is completed successfully, the adaptive control algorithm transitions the APR **2** to its operational state **152**, and attempts to detect the presence of a base station **8***a* (at step S6). If a base station is not detected, the adaptive control algorithm sets default values of the signal power levels in the network and local wireless links **18** and **20** (at step S8), and then measures signal and noise levels in each of the uplink and downlink paths to test the quality of each of the network wireless link **18** and local link **20** (at step S**10**). These test results can be displayed on a suitable display device and may, for example, be used during installation of the APR **2** (e.g. to assist in obtaining proper positioning and alignment of the DDU **22**).

[**0085**] If the base station is detected (at step S6), the adaptive control algorithm attempts to detect a base station control channel within the network wireless link **18** (at step S**12**). If the base station control channel is detected at step S**12**, the adaptive control algorithm attempts to detect a subscriber control channel in the local wireless link **20** (at step S**14**). If the subscriber control channel is detected at step S**14**, the adaptive control algorithm uses measured signal power levels in the uplink and downlink paths to adjust transmit power levels in each of the network wireless link **18** and the local wireless link **20**, in order to optimize performance (at steps S**16** and S**18**).

[**0086**] If control channels are not detected in either of the network wireless link **18** or the local wireless link **20** (at Steps S**12** and S**14**), the adaptive control algorithm attempts to detect a voice channel in the local wireless link **20** (at step S**20**). If a subscriber voice channel is detected at step S**20**, the adaptive control algorithm then attempts to detect a voice channel in the network wireless link **18** (at step S**22**). If a base station voice channel is detected at step S**22**, the adaptive control algorithm returns to steps S**16** and S**18** to optimize the performance of the uplink and downlink paths. Otherwise, if voice channels are not detected in either the network wireless link **18** or the local wireless link **20** (at steps S**20** and S**22**), then the adaptive control algorithm returns to steps S**8** and S**10** to set the default power levels in the uplink and downlink paths, and measure signal and noise levels to test the quality of each of the network and local wireless links **18** and **20**.

[**0087**] As described above, transmit signal power in the network wireless link **18** is adjusted (at step S**16** of **FIG. 8**) based on the received signal power of downlink RF signals within either the base station control channel and/or voice channel. Similarly, the subscriber's personal wireless space **6** is adjusted by adjusting the transmit power of downlink RF signals within either the control channel and/or the voice channel, based on the received signal power of uplink RF signals transmitted by the subscriber's wireless communications device **16**. This process of continuous adjustment of the network and local wireless links **18** and **20** enables continuous optimization of the performance of each of these links, and, within the subscriber's personal wireless space **6**, implements the adaptive coverage breathing and coverage area signature functionality of the present invention. Periodic detection of base station and subscriber control and voice channels (at steps S**12**, S**14**, S**20** and S**22** of **FIG. 8**) enables the APR **2** to adaptively accommodate multiple subscriber wireless communications devices **16** within the subscriber's personal wireless space **6**.

[**0088**] Thus it will be seen that the present invention provides an apparatus that enables an individual subscriber to cost-effectively access and provide high quality wireless communications services, independently of a location of the subscriber.

[**0089**] The embodiment(s) of the invention described above is(are) intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

We claim:

1. A repeater adapted to transparently mediate signaling between a wireless communications device and a wireless communications network, the repeater comprising:

a Directional Donor Unit (DDU) adapted to maintain a network link with a transceiver of the wireless communications network;

a Subscriber Coverage Unit (SCU) adapted to maintain a local link with the wireless communications device within a personal wireless space of the repeater, the SCU comprising:

means for detecting respective uplink and downlink channel frequencies of the wireless communications device; and

control means adapted to control at least the SCU to selectively receive and transmit signals within the detected uplink and downlink channel frequencies.

2. A repeater as claimed in claim 1, wherein the DDU comprises:

a directional donor antenna (DDA) adapted to receive downlink channel signals from a base station of the wireless communications network, and to transmit uplink channel signals within a comparatively narrow beam to the base station; and

a transceiver diplexer (TRD) adapted to amplify received downlink channel signals and control a transmit power level of the uplink signals.

3. A repeater as claimed in claim 2, wherein the DDA is vertically polarized.

4. A repeater as claimed in claim 2, wherein the DDA and the TRD are integrated into a single unit.

5. A repeater as claimed in claim 1, wherein the SCU comprises:

a subscriber coverage antenna (SCA) adapted to receive uplink RF signals from the wireless communications device, and transmit downlink RF signals as a comparatively wide beam; and

a dual-directional processor (DDP) adapted to control respective power levels of the uplink and downlink RF signals.

6. A repeater as claimed in claim 5, wherein the SCA is horizontally polarized.

7. A repeater as claimed in claim 5, wherein the SCA and the DDP are integrated into a single unit.

8. A repeater as claimed in claim 5, wherein the DDP comprises means for controlling a transmit power level of the uplink RF signals based on a received power level of the downlink RF signals.

9. A repeater as claimed in claim 1, wherein the DDU and the SCU are integrated into a single unit.

10. A repeater as claimed in claim 1, wherein the DDU and the SCU are provided as separate units coupled together by a transmission path adapted to convey the uplink and downlink RF signals.

11. A repeater as claimed in claim 1, wherein the control means comprises:

means for detecting at least one of an uplink channel and a downlink channel of the wireless communications device; and

means for tuning respective uplink and downlink paths to selectively amplify RF signals within the detected uplink and downlink channels.

12. An adaptive repeater as claimed in claim 11, wherein the means for detecting at least one of an uplink channel and a downlink channel comprises means for acquiring weak desired RF signals embedded within respective broad-band channels.

13. An adaptive repeater as claimed in claim 12, wherein the means for acquiring a weak desired signal comprises:

a respective narrow band path adapted to sample RF signals within each of the uplink and a downlink paths; and

a detector coupled to each narrow band path and adapted to detect the weak RF signals within the sampled RF signals.

14. An adaptive repeater as claimed in claim 11, wherein the means for tuning respective uplink and downlink paths comprises:

respective uplink and downlink Intelligent Gain Controllers (IGCs) adapted to control a power level of corresponding uplink and downlink RF signals; and

a digital controller adapted to control a gain of each IGC based on detection at least one of an uplink channel and a downlink channel.

15. A repeater as claimed in claim 1, wherein the control means further comprises means for dynamically adjusting a coverage area of the personal wireless space in accordance with a location of the wireless communications device relative to the SCU.

16. A repeater as claimed in claim 15, wherein the means for dynamically adjusting a coverage area of the personal wireless space comprises means for controlling a transmit power level of downlink RF signals transmitted by the SCA based on detected signal power of uplink RF signals received by the SCA.

17. A repeater as claimed in claim 16, wherein the means for controlling the transmit power level of downlink RF signals comprises:

a broadband path adapted to sample the uplink RF signal received by the SCA; and

a variable gain amplifier coupled to the broadband path and adapted to adjust a power level of the downlink RF signal based on the sampled uplink RF signal.

18. A method of providing wireless communications services of a wireless communications network to a subscriber located in an area that is poorly serviced by the wireless communications network, the method comprising a step of providing the subscriber with a personal repeater adapted to transparently mediate signaling between at least one wireless communications device and a base station of the wireless communications network.

19. A method of enabling a subscriber located in an area that is poorly serviced by a wireless communications network to access wireless communications services of the wireless communications network, the method comprising a step of providing the subscriber with a personal repeater adapted to transparently mediate signaling between a wireless communications device and a base station of the wireless communications network.

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