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(54) **TRANSPARENT MESH OVERLAY IN HUB-SPOKE SATELLITE NETWORKS**

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H04B 7/185 (2006.01)

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CPC ***H04W 24/08*** (2013.01); ***H04B 7/18584*** (2013.01); ***H04N 21/242*** (2013.01);

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(58) **Field of Classification Search**

CPC H04W 24/08; H04W 56/00; H04W 52/04–52/60; H04W 84/06;

(Continued)

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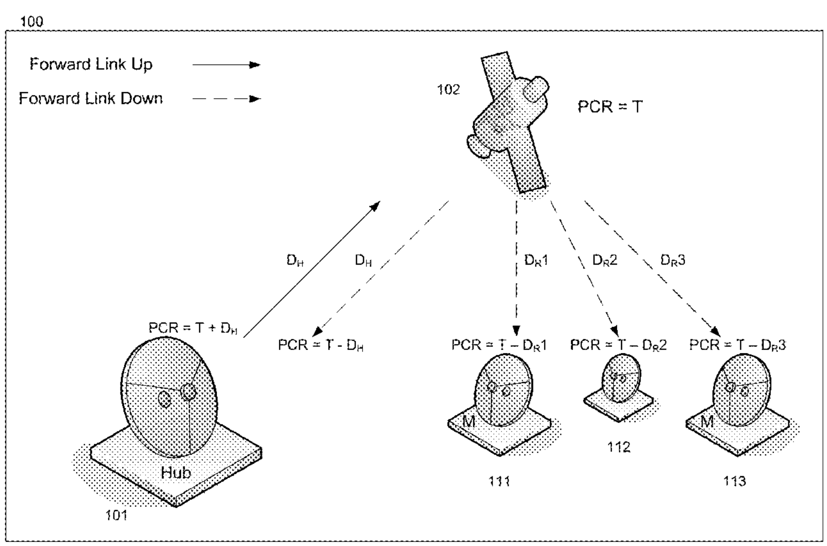
(57) **ABSTRACT**

In a satellite-based communication network comprised of a central hub and plurality of remote terminals configured to transmit data to and receive data from the central hub in accordance with EN 301 790 (DVB-RCS), and where one or more of these remote terminals may be configured to include an additional receiver module configured to receive MF-TDMA transmission of other remote terminals, a mesh receiver and methods for coupling the mesh receiver with the host remote terminal. In addition, described herein are methods for synchronizing the mesh receiver on the network's timing and frequency and for utilizing the available link power for achieving efficient connectivity.

18 Claims, 8 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/087,827, filed on Aug. 11, 2008.

(51) **Int. Cl.**
H04W 56/00 (2009.01)
H04N 21/242 (2011.01)
H04J 3/06 (2006.01)
H04L 7/00 (2006.01)
H04N 21/43 (2011.01)

(52) **U.S. Cl.**
CPC ***H04W 56/00*** (2013.01); *H04J 3/0644* (2013.01); *H04L 7/0008* (2013.01); *H04N 21/4305* (2013.01)

(58) **Field of Classification Search**
CPC H04B 7/18584; H04B 7/18523; H04J 3/0644; H04N 21/242; H04N 21/4305; H04L 7/0008; Y02B 60/50
See application file for complete search history.

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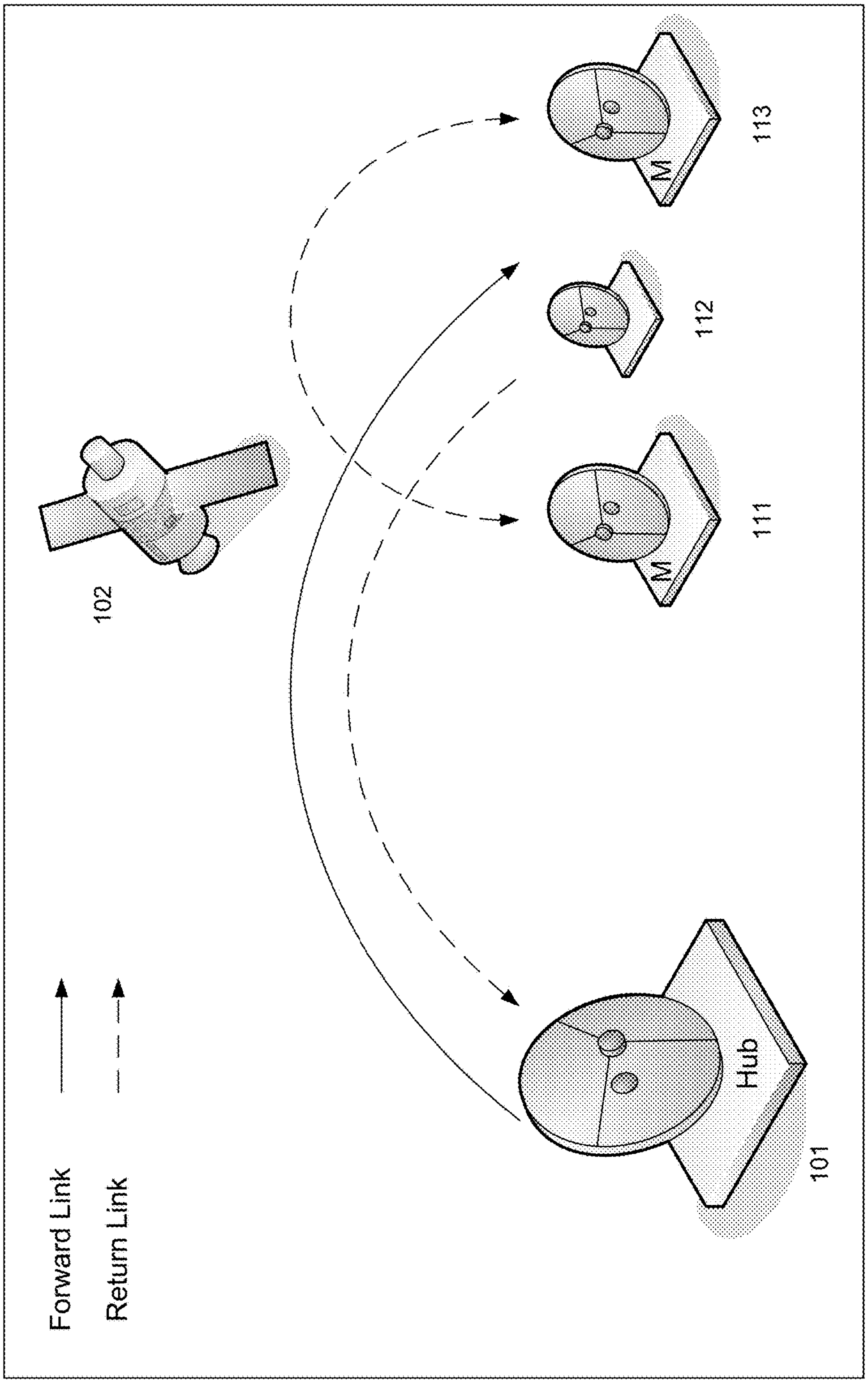

Fig. 1

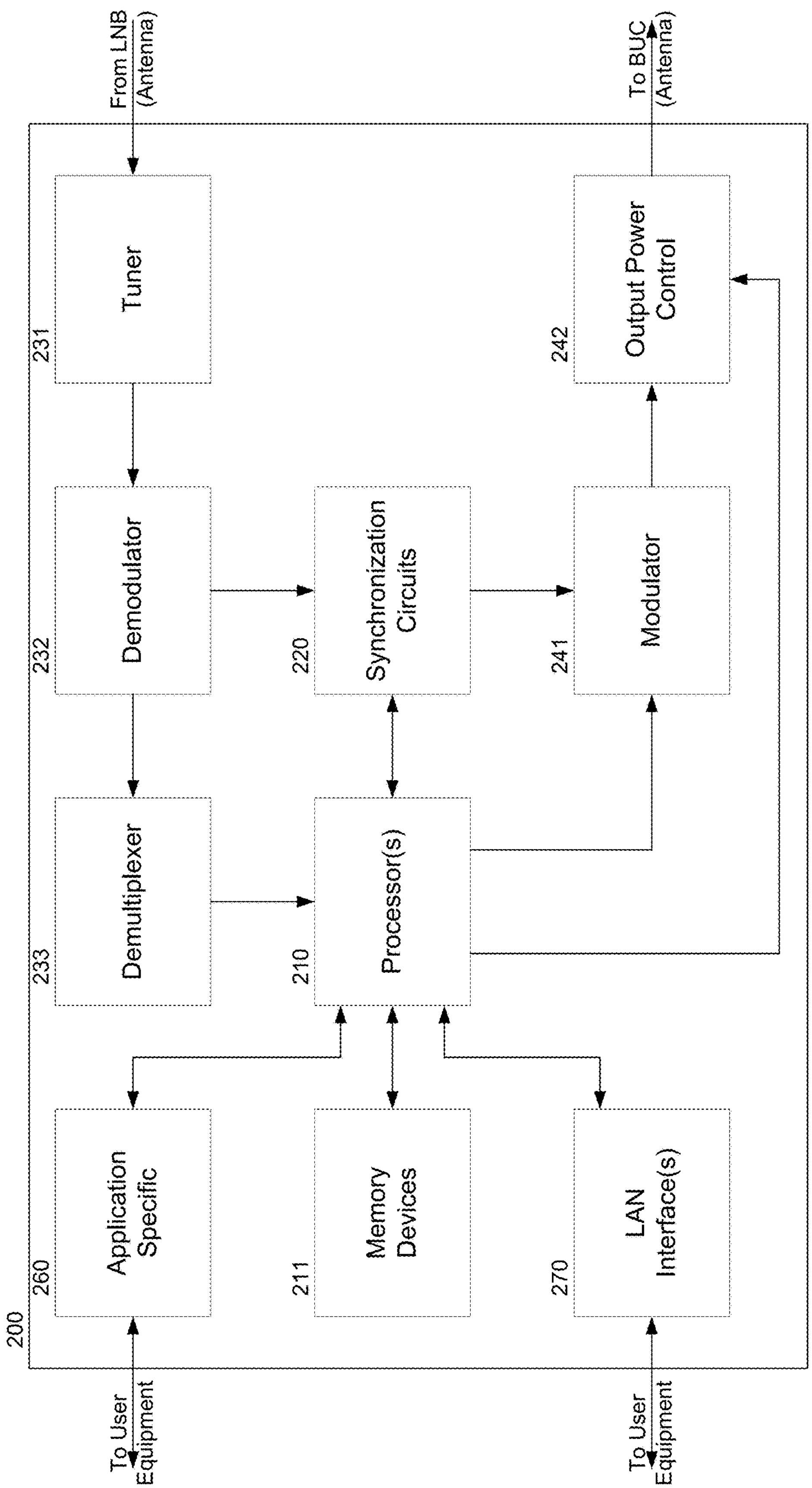
From LNB (Antenna)
To BUC (Antenna)
231
Tuner
242
Output Power Control
232
Demodulator
220
Synchronization Circuits
241
Modulator
233
Demultiplexer
210
Processor(s)
260
Application Specific
211
Memory Devices
270
LAN Interface(s)
200
To User Equipment
To User Equipment

Fig. 2

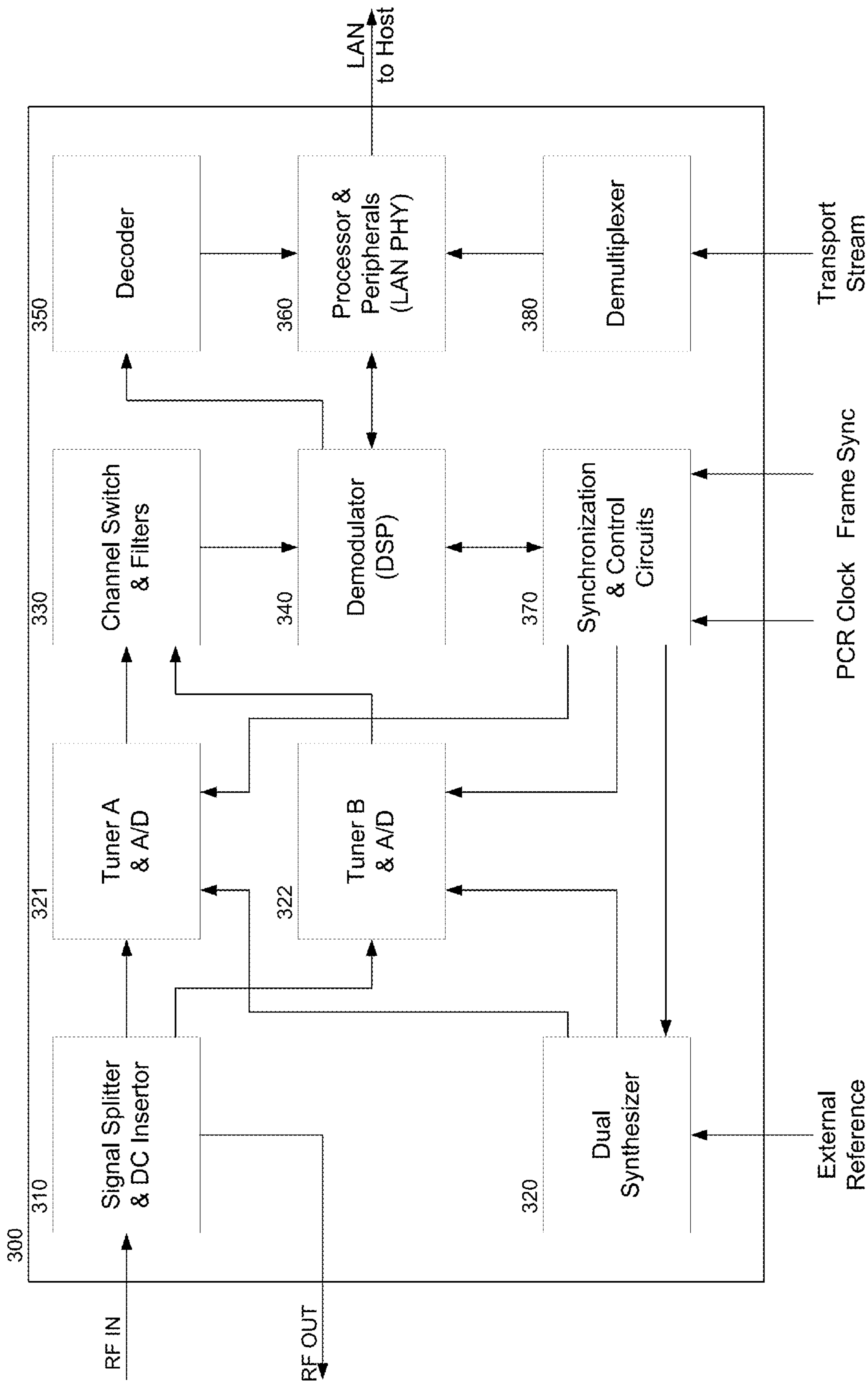
LAN
to Host
300
350
Decoder
360
Processor &
Peripherals
(LAN PHY)
380
Demultiplexer
Transport
Stream
330
Channel Switch
& Filters
340
Demodulator
(DSP)
370
Synchronization
& Control
Circuits
Frame Sync
PCR Clock
321
Tuner A
& A/D
322
Tuner B
& A/D
310
Signal Splitter
& DC Insertor
320
Dual
Synthesizer
External
Reference
RF IN
RF OUT

Fig. 3

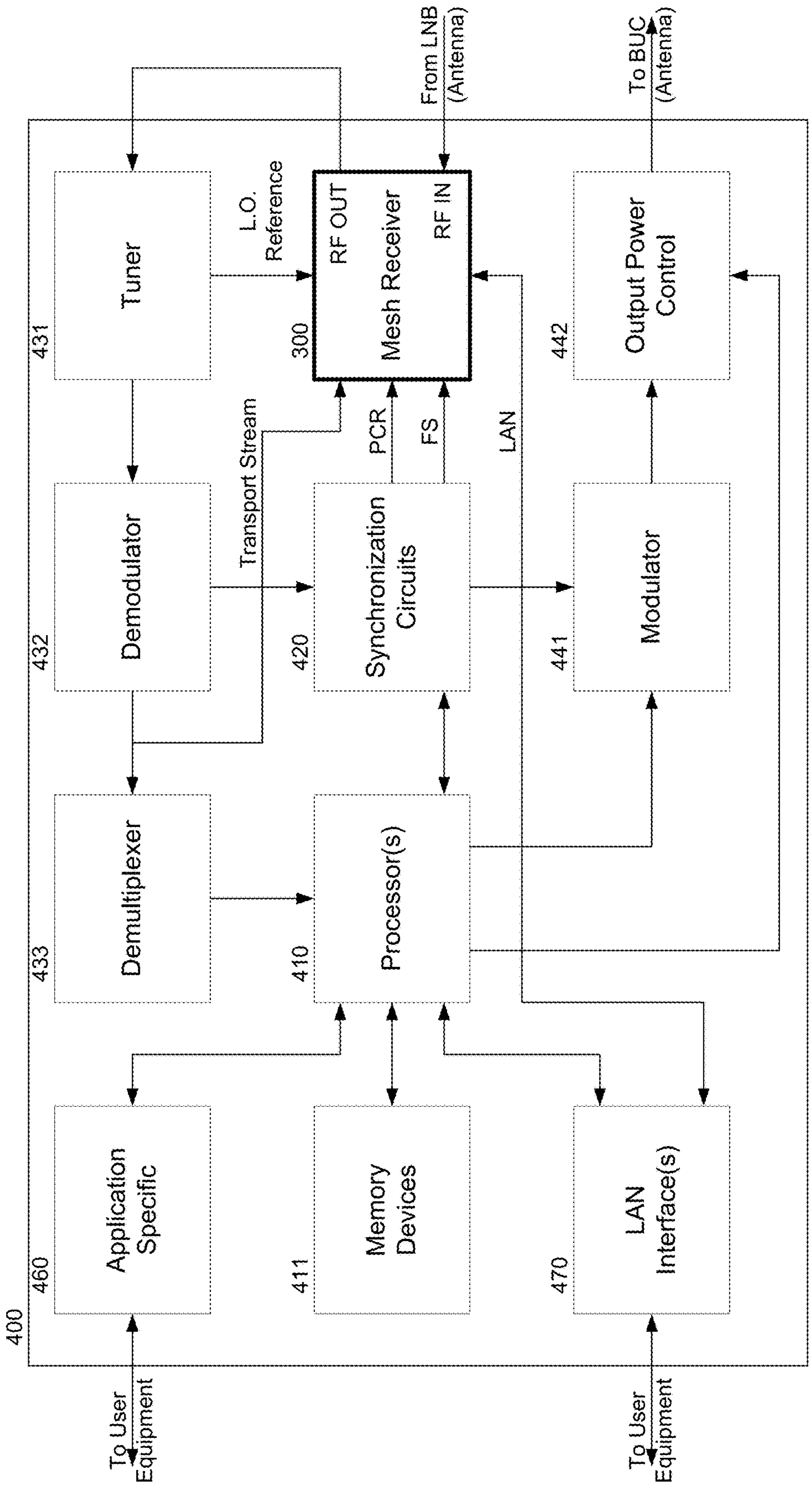
400
From LNB (Antenna)
To BUC (Antenna)
431
Tuner
L.O. Reference
300
RF OUT
Mesh Receiver
RF IN
442
Output Power Control
432
Demodulator
Transport Stream
PCR
FS
LAN
420
Synchronization Circuits
441
Modulator
433
Demultiplexer
410
Processor(s)
460
Application Specific
411
Memory Devices
470
LAN Interface(s)
To User Equipment
To User Equipment

Fig. 4

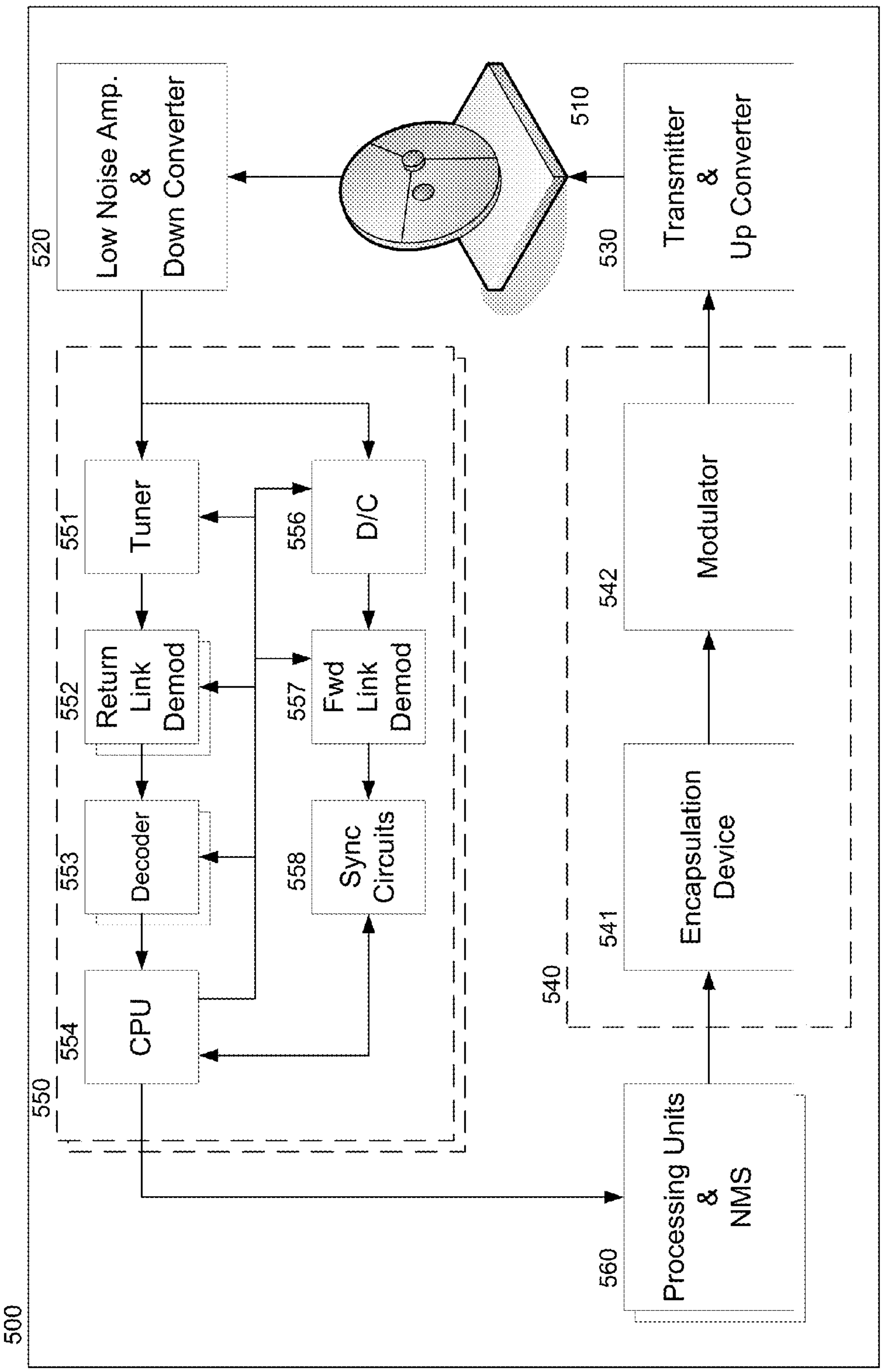
500
520
Low Noise Amp. & Down Converter
510
530
Transmitter & Up Converter
550
551
Tuner
552
Return Link Demod
553
Decoder
554
CPU
556
D/C
557
Fwd Link Demod
558
Sync Circuits
540
541
Encapsulation Device
542
Modulator
560
Processing Units & NMS

Fig. 5

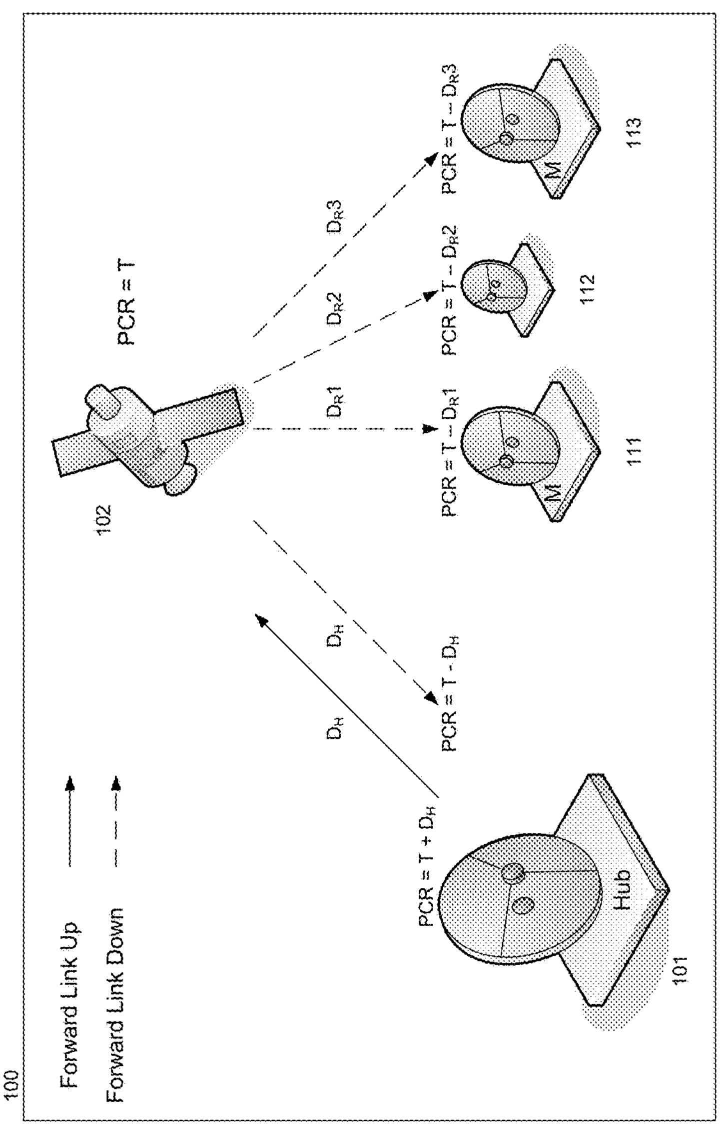
100
Forward Link Up
Forward Link Down
101
Hub
PCR = T + D_H
D_H
D_H
PCR = T - D_H
102
PCR = T
D_R1
D_R2
D_R3
PCR = T – D_R1
PCR = T – D_R2
PCR = T – D_R3
M
M
111
112
113

Fig. 6

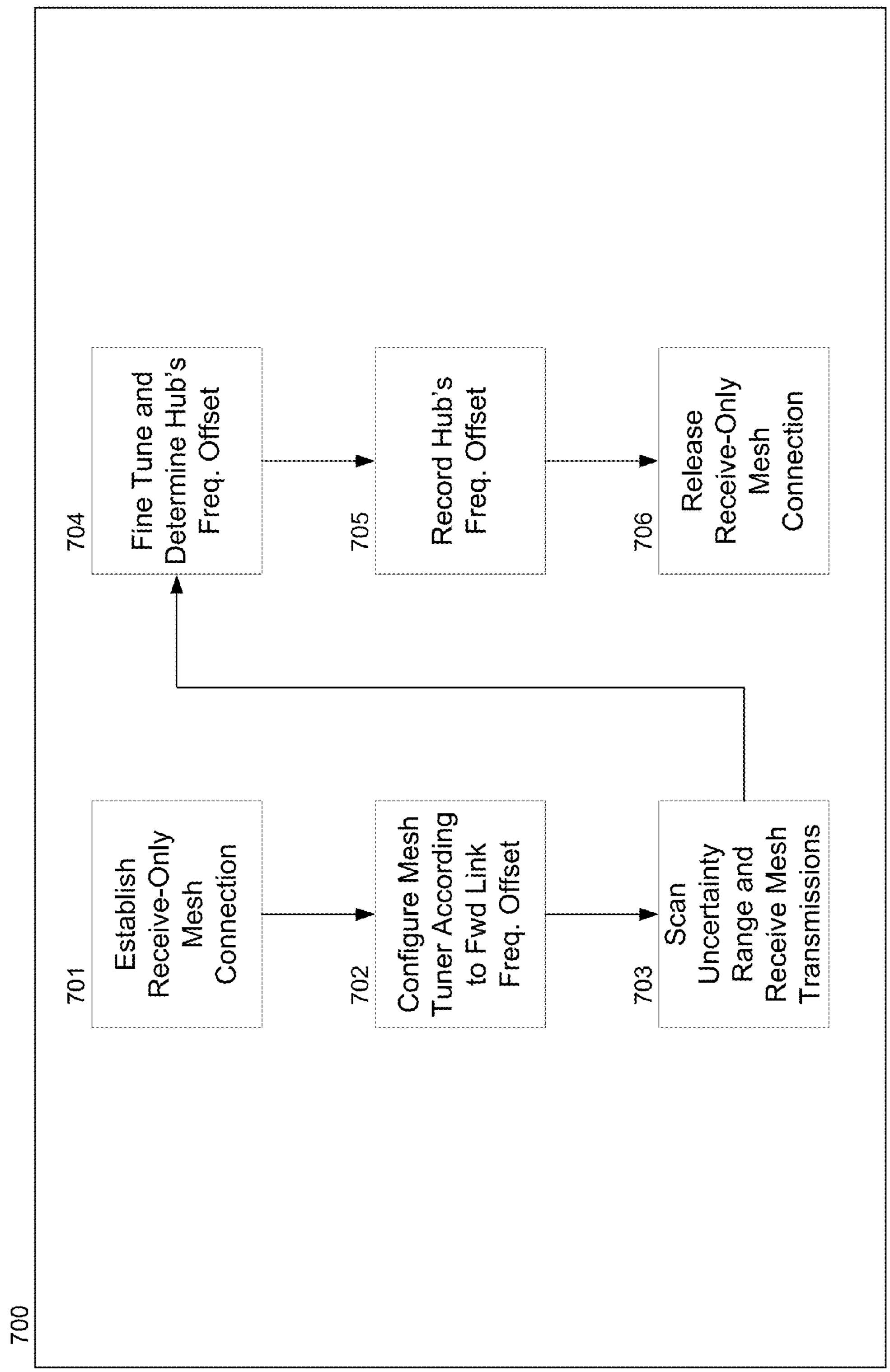
700
701
Establish Receive-Only Mesh Connection
702
Configure Mesh Tuner According to Fwd Link Freq. Offset
703
Scan Uncertainty Range and Receive Mesh Transmissions
704
Fine Tune and Determine Hub's Freq. Offset
705
Record Hub's Freq. Offset
706
Release Receive-Only Mesh Connection

Fig. 7

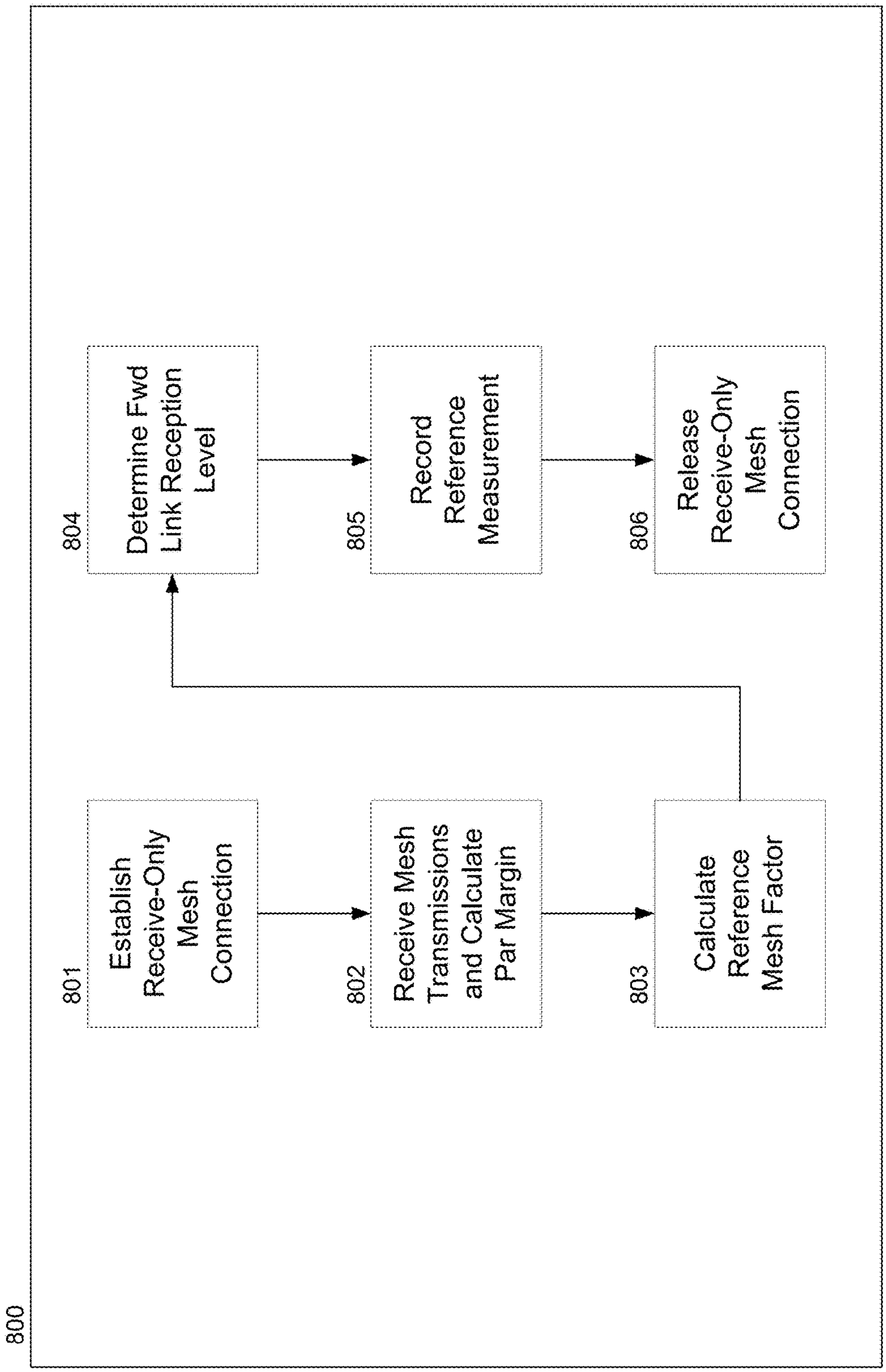
800
801
Establish Receive-Only Mesh Connection
802
Receive Mesh Transmissions and Calculate Par Margin
803
Calculate Reference Mesh Factor
804
Determine Fwd Link Reception Level
805
Record Reference Measurement
806
Release Receive-Only Mesh Connection

Fig. 8

TRANSPARENT MESH OVERLAY IN HUB-SPOKE SATELLITE NETWORKS

RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 12/538,242, filed Aug. 10, 2009, entitled "Transparent Mesh Overlay In Hub-Spoke Satellite Networks," which is a non-provisional of U.S. Provisional Application Ser. No. 61/087,827, filed Aug. 11, 2008, entitled "Transparent Mesh Overlay In Hub-Spoke Satellite Networks." The contents of each of these related applications are incorporated herein by reference in their entirety for all purposes.

TECHNICAL FIELD

This invention relates to the filed of satellite communication networks. More specifically, this invention relates to methods for realizing mesh connectivity overlay in a hub-spoke satellite communication network. In addition, this invention also relates to the Digital Video Broadcast Return Channel via Satellite standard (EN 301 790, also known as DVB-RCS).

BACKGROUND

The DVB-RCS standard (EN 301 790) defines a hub-spoke communication architecture for satellite communication systems. Under these definitions, any given remote terminal may communicate with an external network or with any other remote terminal via a central hub.

However, hub-spoke architecture is non-optimal for communication between remote terminals, especially if such communication makes up a substantial portion of the total traffic in the network. Mesh connectivity is much more suitable for communication between remote terminals. Mesh connectivity offers lower latency while being more efficient in terms of bandwidth usage.

The latest version of the DVB-RCS standard (EN 301 790 v1.5.1) includes references to mesh connectivity. The DVB-RCS standard recognizes two possible implementations, one based on regenerative satellites (i.e. with on-board processing for extracting the information from the MF-TDMA bursts and encapsulating it into a DVB-S or DVB-S2 TDM downlink signal) and one based on transparent satellites and on MF-TDMA receivers incorporated into the remote terminals.

In reference to the implementation over transparent satellites, while the DVB-RCS standard includes some provisioning for supporting mesh-capable terminals, it does not include any recommendations as to methods for realizing mesh connectivity.

The following applications may be considered as prior art in the field of which this invention relates to:

US2006/0126576 A1, Dale et al, Partial Mesh Communication in Hub Based System

This application describes in very general terms a method using which transparent mesh overlay can be implemented in a hub-spoke satellite network employing forward and return links according to EN 301 790 (DVB-RCS).

It is suggested that the system and the methods described herein are materially different than those described in the above-mentioned application. The differences can be found in many aspects, such as the architecture of the mesh receiver, the way it is interconnected with the host terminal, the way frequency offsets are compensated, the way power control is applied and more. Furthermore, the above-mentioned application does not teach any concrete method or embodiment for achieving the claimed functionality (except suggesting that such is possible), while the description included here-in teaches such methods.

U.S. Pat. No. 6,212,360, Fleming, III et al, Methods and Apparatus for Controlling Earth-Station Transmitted Power in a VSAT Network.

This application describes methods for controlling transmission power both over a forward link and over return channels.

It is suggested that the system and the methods described herein are materially different than those described in the above-mentioned application. The differences can be found in many aspects, the most important of them are the network topology and the algorithms used.

U.S. patent application Ser. No. 12/337,330 (based on provisional application 61014478), Ben Laish et al, Multi-Dimensional Adaptive Transmission Technique

This application, also assigned to the applicant of this application, describes methods for providing transmission adaptability in satellite-based communication networks. This application further suggests that transmission power control may be applicable to satellite communication networks where mesh connectivity is possible between remote terminals.

It is suggested that the above-described application merely cites that it is possible to have transmission power control methods existing in a satellite communication network with mesh connectivity facilities, but it does not teach any such methods in specifics. Therefore some aspects of this current invention may be viewed as a related to the above-mentioned application, the contents of which are incorporated herein by reference in their entirety for all purposes.

BRIEF SUMMARY

The following presents a simplified summary in order to provide a basic understanding of some aspects of the invention. The summary is not an extensive overview of the invention. It is neither intended to identify key or critical elements of the invention nor to delineate the scope of the invention. The following summary merely presents some concepts of the invention in a simplified form as a prelude to the description below.

In aspects of the present invention, a satellite-based communication network may include a central hub and plurality of remote terminals (VSATs), all configured to transmit data to and receive data from the central hub in accordance with EN 301 790 (DVB-RCS). Furthermore, in addition to a TDM receiver as per EN 301 790, some of these remote terminals may be equipped also with an additional receiver module, also referred to herein as a mesh receiver. Such mesh receiver may be configured to receive MF-TDMA transmission of other remote terminals.

Aspects of this invention include the mesh receiver, comprising at least two reception channels for at least the purpose of supporting fast frequency hopping. Each of these reception channels may be further comprised of a configurable tuner. The mesh receiver may further include a transport stream demultiplexer for at least the purpose of enabling autonomous extraction of relevant allocations, a dedicated processor for at least the purpose of combining received ATM cells or MPEG frames into messages and an

Ethernet interface for at least the purpose of transmitting received messages to a host terminal. Further embodiments of this invention may also include coupling of the mesh receiver with the antenna in parallel with the TDM receiver of the host terminal.

In additional aspects of the invention, methods may be used by a host remote terminal and a mesh receiver for synchronizing the mesh receiver to the network timing. These methods include at least a method for timing synchronization acquisition and a method for detecting loss of timing synchronization.

In further aspects of this invention, the satellite-based communication system may use methods for synchronizing the tuners of a mesh receiver to the transmission frequencies of other remote terminals. These methods include at least an initial frequency synchronization method, a frequency tracking method and a frequency resynchronization method.

In still further aspects of the invention, the satellite-based communication system may use methods for dynamically determining the difference in link conditions between the hub down-link and the down-link of each remote terminal equipped with a mesh receiver. These methods include at least an initial link difference measurement method, and a recalibration method. By determining this deference in real time, the system may be configured to support multi-dimensional adaptive transmissions over mesh connectivity as well as towards the hub.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** shows a satellite communication network in accordance with aspects of this invention.

FIG. **2** shows a block diagram of a remote terminal in accordance with aspects of this invention.

FIG. **3** shows a block diagram of a mesh receiver in accordance with aspects of this invention.

FIG. **4** shows a block diagram of a remote terminal containing a mesh receiver in accordance with aspects of this invention. In addition, this figure also shows coupling of the mesh receiver to an antenna in parallel to the TDM receiver of the host terminal according to aspects of this invention.

FIG. **5** shows a block diagram of a hub in accordance with the aspects of this invention.

FIG. **6** shows an embodiment of the timing scheme of a satellite communication system in accordance with aspects of this invention.

FIG. **7** shows a flow chart describing an initial frequency synchronization algorithm in accordance with aspects of this invention.

FIG. **8** shows a flow chart describing a mesh factor calibration algorithm in accordance with aspects of this invention.

DETAILED DESCRIPTION

FIG. **1** shows a satellite-based communication network **100** comprised of a central hub **101** and plurality of remote terminals (VSATs) **111** to **113**. Hub **101** and remote terminals **111** to **113** may be configured to transmit data and receive data via satellite **102** in accordance with EN 301 790 (DVB-RCS). In some preferred embodiments of this invention, the forward link may be configured in accordance with EN 300 421 (DVB-S) or in accordance with EN 302 307 (DVB-S2) and the return link may be configured in accordance with EN 301 790.

Furthermore, in addition to a TDM receiver configured to receive the forward link, remote terminals **111** and **113** may be configured to include an additional MF-TDMA receiver module, also referred to herein as a mesh receiver. A mesh receiver may be configured to receive transmissions of other remote terminals where such transmission are in accordance with EN 301 790. If so configured, remote terminals **111** and **113** may exchange information via satellite **102** without routing that information via the hub. Consequently, remote terminals **111** and **113** may achieve connectivity with shorter latency while utilizing minimal capacity, as the forward link capacity, that would have been required should the information been routed via the hub, is saved.

Furthermore, while remote terminals **111** and **113** may be configured to include a mesh receiver, other remote terminals, such as remote terminal **112**, may remain in a traditional configuration, i.e. not including a mesh receiver, and continue to provide service as part of satellite-based communication network **100**. Like in a regular star-topology network, any traffic to remote terminal **112** is routed via the hub including any such traffic originated from remotes **111** and **113**. In some embodiments of this invention, information originated from remote terminal **112** and destined to remote terminals such as **111** and **113** may be routed directly over the satellite to the receiving remote terminal, while any returning information is routed via the hub. Such embodiments allow reducing latency and bandwidth utilization for inter-terminal communication even if only some of the terminals are configured to include a mesh receiver while other terminals are not so configured.

FIG. **2** shows an exemplary block diagram of a remote terminal such as remote terminal **112** of FIG. **1**. A remote terminal may be configured to include an antenna (not shown), a low-noise block amplifier (LNB) that may be mounted on the antenna (not shown), a satellite transmitter (also sometimes referred to as block up converter (BUC)) that may be mounted on the antenna (not shown), and an indoor unit **200**, which may be coupled to the antenna, and/or to the other components that may be mounted on the antenna, via appropriate cables.

Indoor unit **200** may further include a TDM receiver comprised of tuner **231**, demodulator **232** and demultiplexer **233**, a transmission channel comprised of modulator **241** and output power control hardware **242** (e.g. attenuators), synchronization circuits **220**, one or more processors **210** coupled with volatile and/or non-volatile memory devices **211** and one or more LAN interfaces **270**. It should be appreciated by anyone skilled in the art that various signals exchanged between the various blocks described in FIG. **2** cannot be shown in details at such an abstraction level.

Tuner **231** may be configured to tune on the forward-link signal. Tuner **231** may also include a frequency down converter, which may be configured to provide the forward channel signal to demodulator **232** at either IF, near base-band or base-band frequencies rather than at higher frequency bands often used at outputs of LNB units.

Demodulator **232** may be configured to demodulate and decode the forward link signal as per the applicable modulation technique (e.g. DVB-S or DVB-S2). Demodulator **232** may also be configured to measure certain parameters of the received forward link signal, such as the frequency offset at which the forward link signal is received and the signal to noise ratio of the received signal, either in terms of C/N (carrier to noise) or E_S/N_0 (normalized symbol energy).

Furthermore, demodulator **232** may also be configured to output the demodulated transport stream, which may be comprised of a plurality of frames, such as but not limited to MPEG frames (as per DVB-S and DVB-S2), immediately following one another,. This transport stream may then be fed into demultiplexer **233**.

Demultiplexer **233** may be configured to receive a transport stream comprised of a plurality of frames, such as but not limited to MPEG frames, immediately following one another and to inspect a header in each frame in order to determine whether a received frame is relevant for this remote terminal, i.e. destined at least to this remote terminal. Demultiplexer **233** may further be configured to discard non-relevant frames and forward relevant frames to processor **210**.

Demodulator **232** may further be configured to extract frames containing clock timestamps, such as PCR timestamps defined by DVB-RCS, out of the transport stream and provide them on a separate interface. Such interface may be coupled to synchronization circuits **220** for at least the purposes of obtaining synchronization on the network's time base and reconstructing an accurate local clock at the rate of the original clock used for generating said timestamps. Where derived from PCR timestamps, said accurate clock is referred to as PCR clock.

Furthermore, based on the obtained synchronization on the network's time base and in some embodiments also on knowledge of the distance between the remote terminal and the satellite, synchronization circuits **220** may be configured to generate the necessary signals for timing the remote terminal's transmissions, so that such transmissions may arrive at the satellite (e.g. satellite **102** of FIG. **1**) and then at the hub (e.g. hub **101** of FIG. **1**) at their designated times as per the timeslots that the hub may allocate to the remote terminal.

Modulator **241** may be configured to receive information formatted for transmission according to the DVB-RCS standard and modulate it into transmission bursts according to the applicable frequency, symbol rate, modulation type and coding rate. Modulator **241** may further be configured to receive symbol rate, modulation type and coding rate information from processor **210** on a per burst basis and modulate each burst as per the requested frequency, symbol rate, modulation type and coding rate.

In order to facilitate transmission over a different channel at a time, modulator **241** may also be configured to include at least one configurable frequency synthesizer and at least one up converter. In some embodiments of this remote terminal, modulator **241** may include at least two configurable synthesizers in order to facilitate fast frequency hopping, i.e. allow the remote terminal to change transmission channels on every timeslot without requiring any gap between such timeslots except for guard intervals which may already exist between timeslots.

Before being transmitted toward the antenna, the modulated signal may be configured to pass via output power control circuits **242**. These circuits may be configured to have different gain (attenuation) for each transmitted burst. Therefore, each burst may be transmitted at the lowest power level sufficient for achieving proper reception at the hub (e.g. hub **101** of FIG. **1**). In some embodiments of satellite-based communication network **100** (of FIG. **1**), the remote terminal may be configured to transmit at some margin above the lowest power level sufficient for achieving proper reception at the hub, for at least the purpose of (rain) fade mitigation.

Processor **210** may be configured to receive relevant frames from demultiplexer **233**, process them according to applicable protocols, and send packets resulting from such processing to any user equipment, which may be connected to the remote terminal via any of the LAN interfaces **270** or via another interface, which may be available through application specific hardware (and software) **260** that may be integrated into indoor unit **200** as shown in FIG. **2**. In some embodiments, application specific hardware (and software) **260** may be externally coupled with indoor unit **200** via any of the LAN interfaces **270**. Furthermore, processor **210** may be also configured to receive packets from user equipment connected to the remote terminal as described above, process these packets according to applicable protocols, format packets resulting from such processing into transmission bursts and send said transmission bursts to modulator **241** for the purpose of transmitting them over the satellite (e.g. satellite **102** of FIG. **1**) toward the hub (e.g. hub **101** of FIG. **1**).

Application specific hardware (and software) **260** may be configured not only to provide a different interface to user equipment other than LAN but also to perform further processing of information received from and transmitted to processor **210**, including converting it into a different format, such as but not limited to voice signals and/or video signals.

FIG. **3** shows a block diagram of a mesh receiver **300**, which remote terminals **111** and **113** of FIG. **1** may be configured to include. Mesh receiver **300** may be comprised of signal splitter **310**, dual synthesizer module **320**, at least two configurable tuners **321** and **322**, channel switch **330**, demodulator **340**, decoder **350**, processor **360**, synchronization and control circuits **370** and demultiplexer **380**. It should be appreciated by anyone skilled in the art that various signals exchanged between the various blocks described in FIG. **3** cannot be shown in details at such an abstraction level.

Signal splitter **310** may be configured to receive a signal from an antenna or from an LNB mounted on an antenna via a first port, and to generate first and second copies of the input signal. Signal splitter **310** may further be configured to output said first copy of the input signal via a second port. Signal splitter **310** may yet further be configured to split said second copy of the input signal into a third and fourth copies of the input signal for the purpose of providing similar or identical input signals to tuners **321** and **322**. Furthermore, signal splitter **310** may be configured to pass through DC current and DC voltage at minimal loss from said second port to said first port for at least the purpose of powering an LNB, to which mesh receiver **300** may be coupled. In yet additional embodiments, signal splitter **310** may be configured to provide high isolation between said second port and tuners **321** and **322**, which may be configured to receive said third and fourth copies of the input signal.

Dual synthesizer **320** may be configured to use two independent synthesizer circuits for at least the purpose of synthesizing two independent local oscillator signals, and to provide each such local oscillator signal to one of the tuners **321** and **322**. Dual synthesizer **320** may further be configured to receive an external reference signal, e.g. at a frequency of 27 MHz, and to use said external reference signal as reference for both synthesizers at least for the purpose of having identical frequency offset ratios (or relative frequency errors, e.g. in PPM) for both local oscillator signals, which may be generated by said synthesizers. Furthermore, said local oscillator signals may be configured to have different frequencies or same frequency. In preferred embodiments, while one synthesizer is active and its output signal is used by one of the tuners **321** or **322**, the other synthesizer may be configured to change its output signal's frequency in preparation for receiving a next burst.

Tuner **321** may be configured to receive a copy of the input signal from signal splitter **310**, to receive a local oscillator signal from dual synthesizer **320**, to extract (filter) a signal of interest from the input signal and to convert it to a digitally sampled signal. For the purpose of the analog to digital conversion, tuner **321** may be configured to receive a sample clock from synchronization and control circuits **370**. Said sample clock may be configured to be of different rate on a per burst basis at least for the purpose of allowing mesh receiver **300** to dynamically receive signals of different symbol rates. As tuner **322** is identical to tuner **321**, the above description is applicable to tuner **322** as well.

Channel switch **330** may be configured to receive the digital outputs of tuners **321** and **322**, to select one of these outputs on a per burst basis and to pass the selected signal to demodulator **340**. Channel switch **330** may further be configured to include decimation filters and/or FIR filters at least for the purpose of providing the output signal with a constant number of samples per symbol.

Demodulator **340** may be configured to receive information of expected bursts and their expected modulation types (such as QPSK, 8PSK or any other method which may be applicable), demodulate each received burst according to the expected modulation type, and forward the demodulated coded bits to decoder **350**. In some embodiments, demodulator **340** may be implemented as software code running over a digital signal processor (DSP). In such embodiments, demodulator **340** may also be configured to control tuners **321** and **322**, and dual synthesizer **320** via synchronization & control circuits **370**. In further embodiments, demodulator **340** may be configured to provide certain measurements of received bursts, such as but not limited to frequency offset at which bursts are received and the signal to noise ratio of received signals, either in terms of C/N (carrier to noise) or E_S/N_0 (normalized symbol energy).

Decoder **350** may be configured to receive blocks of coded bits, to receive information of coding rate on a per block basis, to decode each block according to the applicable coding rate and to provide blocks of user bits to processor **360**. These blocks may follow the formats of return channel bursts (as defined in EN 301 790) in general and the format of traffic (TRF) bursts in particular. In some embodiments, decoder **350** may be implemented in a programmable gate-array device (e.g. FPGA) together with other modules, such as synchronization circuits **370** and channels switch **330**. In such embodiments, only demodulator **340** (implemented as software over DSP) may be configured to interface with the programmable device. In such embodiments, decoder **350** may be configured to output the blocks of user bits to demodulator **340**, which may further be configured to pass these blocks to processor **360**.

Demultiplexer **380** may be configured to receive a transport stream, which may be comprised of a plurality of frames immediately following one another, such as but not limited to MPEG frames (as per DVB-S and DVB-S2). This transport stream may include frames containing forward link signaling as defined in EN 301 790. Said forward link signaling may be further comprised of tables containing definitions of the return channel composition (e.g. a timeslot composition table (TCT), a frame composition table (FCT) and a super-frame composition table (SCT)) and of a terminal burst time plan table (TBTP), which may contain information regarding which timeslot is allocated to which terminal. Demultiplexer **380** may be configured to extract from the received transport stream at least the terminal burst time plan table (TBTP) and forward it to processor **360**.

Processor **360** may be coupled with external peripherals for at least the purposes of storing software, storing parameters, storing received user information blocks and communicating with a host terminal. Said peripherals may include volatile memory, non-volatile memory and an Ethernet transceiver (PHY). In some embodiments, some or all of said peripherals may be embedded into processor **360**. Regardless, for the purpose of this discussion processor **360** is considered to include said peripherals whether embedded into the processor chip itself or externally coupled with the processor chip.

Processor **360** may be configured to receive blocks of user bits, which may be formatted as return channel bursts according to EN 301 790 definitions, extract relevant ATM cells or MPEG frames out of said bursts, combine said ATM cells or MPEG frames into messages and send said messages via an Ethernet LAN interface to a host terminal. In some embodiments, the interest in an extracted frame may be determined based on a stream identifier, such as the VCI and VPI fields included in the ATM cell header or the PID field included in the MPEG frame header. Processor **360** may be configured to discard an extracted frame if it does not include an expected stream identifier. Furthermore, where a burst includes more than one frame, it is possible that any number of frames included within a burst will be either of interest or of non-interest.

Processor **360** may further be configured to receive from a host terminal via the LAN interface run-time software, parameters, information regarding the composition of the return channel (processor **360** may obtain this information also via demultiplexer **380**), and other information items necessary for proper operation of mesh receiver **360**. In addition, processor **360** may be configured to receive requests for telemetry, to reply these requests with the requested information, and to send events upon detecting a malfunction in any one or more components of mesh receiver **300**.

Finally, synchronization & control circuits **370** may be configured to receive a reference PCR clock, e.g. at 27 MHz, and a frame synchronization signal, to drive a counter using said reference PCR clock and to load a predetermined value into said counter upon a transition of the frame synchronization signal. Furthermore, synchronization & control circuits **370** may be configured, including in run-time (e.g. by demodulator **340** where implemented as software running over DSP), to provide interrupts, symbol rate clocks and other control signals on a burst-by-burst basis to one or more other modules according to the values of said counter.

Furthermore, synchronization & control circuits **370** may also be configured to receive the external reference signal, which drives dual synthesizer **320** and measure its frequency using the received PCR clock signal, which may be much more accurate. Processor **360** may then be configured to read this measurement at least for the purpose of determining the frequency offset introduced by tuners **321** and **322**.

In preferred embodiments, synchronization & control circuits **370** may be implemented using a programmable gate-array device (e.g. FPGA). Said programmable device may also include implementations of other modules, such as demultiplexer **380** and channels switch **330** together with its associated filters. In such embodiments, said programmable device may be coupled with a memory device for at least the purpose of facilitating the implementation of said modules.

FIG. **4** shows a block diagram of a remote terminal, such as remote terminal **111** or remote terminal **113** of FIG. **1**. A remote terminal may be configured to include an antenna (not shown), a low-noise block amplifier (LNB) that may be mounted on the antenna (not shown), a satellite transmitter (also sometimes referred to as block up converter (BUC)) that may be mounted on the antenna (not shown), and an indoor unit **400**, which may be coupled to the antenna, and/or to the other components that may be mounted on the antenna, via appropriate cables.

Indoor unit **400** may further include a TDM receiver comprised of tuner **431**, demodulator **432** and demultiplexer **433**, a transmission channel comprised of modulator **441** and output power control hardware **442** (e.g. attenuators), synchronization circuits **420**, one or more processors **410** coupled with volatile and/or non-volatile memory devices **411**, one or more LAN interfaces **470** and a mesh receiver **300**.

Indoor unit **400** is very similar to indoor unit **200** of FIG. **2** and differs from it by being configured to include mesh receiver **300** and the applicable interfaces of said mesh receiver with the other modules. Therefore, except for mesh receiver **300**, the description of all other modules is similar to that given in reference to FIG. **2** as per the respective modules.

Again, in reference to FIG. **4**, mesh receiver **300** may be integrated with indoor unit **400**. Given the interfaces of mesh receiver **300** with indoor unit **400** and though several embodiments may be possible, in a preferred embodiment mesh receiver **300** may be implemented as a plug-in module, which may be plugged into a dedicated interface of indoor unit **400** (e.g. a back panel equipped with an expansion slot connector) and fitted inside the indoor unit's casing (e.g. within an expansion bay).

Furthermore, when configured to include mesh receiver **300**, indoor unit **400** may be coupled with an antenna or with an LNB mounted on an antenna in a different way than in a regular remote terminal, which is not configured to include a mesh receiver. Instead of configuring tuner **431** to receive a signal from an antenna (like in the case of tuner **231** in FIG. **2**), the antenna may be coupled with the first port of mesh receiver **300** (as described above in reference to FIG. **3**). Signal splitter **310** of mesh receiver **300** (FIG. **3**) may then be configured to output a copy of the input signal via a second port, which may then be (externally) coupled using a short cable to the input of tuner **431**.

Furthermore, as signal splitter **310** of mesh receiver **300** may be configured to pass DC current and voltage from the mesh receiver's second port to its first port, any DC current and voltage provided by tuner **431** for at least the purpose of powering an LNB may be passed via mesh receiver **300** to such LNB. Furthermore, as DC power supply to an LNB arrives from tuner **431** and not from mesh receiver **300**, reception of the forward link signal (via tuner **431**) may be independent of the condition of mesh receiver **300**, which at times may be powered off or otherwise non-functional. Therefore the remote terminal's primary function of communicating with the hub (such as hub **101** of FIG. **1**) is unaffected by the condition of mesh receiver **300** and connectivity with and via the hub remains possible at all times (i.e. as long as the host terminal is logged on to the hub, e.g. as defined in EN 301 790).

Another aspect of this embodiment of the invention regards the ability of signal splitter **310** of mesh receiver **300** to provide high isolation between the mesh receiver's second port, now coupled with tuner **431**, and the mesh receiver's tuners **321** and **322**. The high isolation prevents signals, which may be leaking from tuner **431** (e.g. local oscillator of tuner **431**), from becoming interfering signals at the input of tuners **321** and **322**, and visa versa (i.e. preventing signals leaking from tuners **321** and **322** from interfering tuner **431** as well as interfering one another). As the required isolation is taken care of by mesh receiver **300**, no additional considerations are required, either in tuner **431** or externally to the indoor unit's casing.

Additional aspects of this invention shown in FIG. **4** relate to coupling of interfaces of mesh receiver **300** to various signals within indoor unit **400**. In a similar manner to the description of FIG. **2**, demodulator **432** may be configured to extract PCR timestamps from the forward link transport stream and provide them to synchronization circuits **420** for at least the purposes of obtaining synchronization on the network's time base and reconstructing a PCR clock. Synchronization circuits **420** may be further configured to generate a Frame Sync signal at constant intervals. Said intervals may be configured as equal to one or more return channel super frame intervals. Indoor unit **400** may yet further be configured to couple the PCR clock and the Frame Sync inputs of mesh receiver **300** to the extracted PCR clock and the Frame Sync signal generated by synchronization circuits **420**. Such coupling may then be used at least for the purpose of synchronizing mesh receiver **300** to the network's time base. With such synchronization established, mesh receiver **300**, having knowledge of the return channel composition and the PCR clock value at the start of any super frame, may be configured to receive a burst at a given timeslot number within a given super frame.

Furthermore, indoor unit **400** may be configured to couple the transport stream input of mesh receiver **300** with the transport stream output of demodulator **432**. Said coupling may then be used for at least the purpose of having mesh receiver **300** (specifically demultiplexer **380**) independently extracting the terminal burst time plan table (TBTP) from the transport stream. Such independency may insure that information on expected bursts is not delayed in the host terminal for any reason (e.g. high throughput or load) and reaches mesh receiver **300** as soon as possible at all times. Thus processor **360** of mesh receive module **300** (FIG. **3**) may have sufficient time for extracting the necessary information from said table and for configuring all other relevant components of mesh receiver **300** for receiving those bursts of interest. On the other hand, the host terminal may also be free of the need to process the terminal burst time plan table (TBTP) several tens of times per second, in real time, for the purpose of seeking assignments of interest for mesh reception. Thus the performance of the host terminal in all other aspects may be unaffected by the fact that it may be configured to include a mesh receiver.

In some embodiments, the transport stream coupling described above may also be used for the purpose of having mesh receiver **300** (specifically demultiplexer **380**) independently extracting other forward link signaling tables from the transport stream, such as a timeslot composition table (TCT), a frame composition table (FCT) and a super frame composition table (SCT). Mesh receiver **300** may then use the extracted tables to obtain the necessary knowledge of the return link composition, without requiring such information to be provided by the host.

Furthermore (as described in reference to FIG. **2**), tuner **431** may be configured to include a frequency down converter, e.g. for the purpose of converting the frequency of the forward channel signal from higher bands often used at outputs of LNB units (e.g. L-band) to either IF, near base-band or base-band frequencies often expected and used by demodulators. Down conversion often requires use of a local oscillator signal, which may be configurable in run-time for at least the purpose of allowing a remote terminal to tune on a forward link signal at any frequency within a predefined range, as per the implementation of the satellite communication network (e.g. network **100** of FIG. **1**). Said local oscillator may be generated by a synthesizer, which may be configured to include a reference signal, e.g. at 27 MHz.

Indoor unit **400** may be configured to couple the reference input of mesh receiver **300** with a reference signal of a synthesizer, which may be part of tuner **431**. Said coupling may then be used at least for the purpose of having identical frequency offset ratios (or relative frequency errors, e.g. in PPM) for both the synthesizer of tuner **431** and the synthesizers of dual synthesizer **320**, which may drive tuners **321** and **322** of mesh receiver **300**. Therefore, the frequency error of a signal received via an LNB and then tuner **431** would be identical to that of the same signal received via the same LNB and either tuner **321** or tuner **322** of mesh receiver **300**. As demodulator **432** may be configured to measure the frequency at which the forward link signal is received, processor **360** of mesh receiver **300** may be configured to use such measurement in order to calculate the required configuration of dual synthesizer **320** for receiving return link signals at demodulator **340** (almost) without any frequency offset.

Finally, indoor unit **400** may be configured to couple the LAN interface of mesh receiver **300** with one of the LAN interfaces **470**. Said coupling may then be used by both indoor unit **400** (specifically processor **410**) and mesh receiver **300** (specifically processor **360**) for exchanging various information, such as but not limited to run-time software, parameters, return channel composition information, synchronization information, frequency offset measurements, telemetry requests and responses, events and so on. In addition, said coupling may also be used for transferring the received messages or packets from mesh receiver **300** to processor **410** at least for the purpose of further processing and routing as necessary.

FIG. **5** shows a block diagram of a hub **500**, which may be similar to hub **101** of FIG. **1**. Hub **500** may be comprised of a hub antenna **510**, a low noise amplifier and down converter **520**, a high power transmitter and up converter **530**, a forward link generation module **540**, one or more return channel receivers **550** and one or more processing units **560** (e.g. computers, personal computers, work stations or any one or more other processing devices, which may be configured to include the hardware and software necessary for performing at least the required tasks), where at least one of these processing units functions (either solely or also) as a network management system (NMS).

Low noise amplifier and down converter **520** may be configured to amplify signals received from the satellite via antenna **510** and change their frequencies from satellite frequencies (e.g. in Ku-band, C-band, Ka-band, etc) to lower frequencies (e.g. in L-band or IF), which may be better suited for further processing by return channel receivers **550**. High power transmitter and up converter **530** may be configured to receive a modulated signal from forward link generation module **540** in relatively low frequency (e.g. in L-band or IF), change its frequency to a satellite frequency (e.g. in Ku-band, C-band, Ka-band, etc) and to significantly amplify it for the purpose of transmitting it towards a satellite via antenna **510**.

Forward link generation module **540** may be further comprised of an encapsulation device **541** coupled with a modulator **542**. Encapsulation device **541** may be configured to receive packets, such as IP packets, to encapsulate them, e.g. into MPEG frames and/or DVB-S2 baseband frames, and to output the resulting transport stream toward modulator **542**. Modulator **542** may be configured to receive a transport stream, e.g. as MPEG frames or as DVB-S2 baseband frames, to receive modulation and coding information coupled with said baseband frames, and to generate a forward link signal compatible with EN 301 790 (e.g. DVB-S or DVB-S2). In addition, modulator **542** may be further configured to insert PCR timestamp frames into the transport stream and/or to re-stamp already existing PCR timestamp frames, which encapsulation device **541** may be configured to insert into the transport stream. For that purpose, i.e. PCR time-stamping, modulator **542** may be configured to include a highly accurate frequency source or to receive a highly accurate reference clock signal from an external source, such as a highly stabilized oscillator, an atomic clock, a GPS receiver or other. In some embodiments, encapsulation device **541** and modulator **542** may be integrated into a single device, which may be configured to perform the above described functions.

A return channel receiver **550** may be further comprised of tuner **551**, one or more return link demodulators **552**, one or more decoders **553**, and a processor **554**. Tuner **551** may be configured to tune on one or more channels within a predetermined bandwidth and to provide the received channels to demodulators **552** at either IF, near base-band or base-band frequencies. Return link demodulator **552** may be configured to receive a return link channel at either IF, near base-band or base-band frequency, to demodulate the signal as per the applicable modulation technique (e.g. QPSK, 8PSK, etc) and to forward blocks of coded bits to decoder **553**. Decoders **553** may be configured to receive a block of coded bits, to decode said block of coded bits according to the applicable coding rate, and forward blocks of user bits to processor **554**. Processor **554** may be configured to at least receive return channels assignment (frames), to receive frame composition and timeslot composition information for the assigned channels (frames), to control all other components for at least the purpose of facilitating the reception of return link bursts, and to send the received information, e.g. over a LAN interface, to one or more of the hub processing units **560**.

In addition, a return channel receiver **550** may further be configured to include a down converter circuit **556**, a forward link demodulator **557** (e.g. similar to demodulator **232** of indoor unit **200** of FIG. **2**) coupled with down converter circuit **556**, and synchronization circuits **558** coupled with forward link demodulator **557**. The additional components (**556** to **558**) and processor **560** may be configured for at least extracting PCR timestamps from the forward link transport stream, obtaining synchronization on the network's time base and reconstructing an accurate local clock at the rate of the original clock used for generating the PCR timestamps.

FIG. **6** shows the same satellite-based communication network **100** of FIG. **1**, including central hub **101**, which may be similar to hub **500** of FIG. **5**, satellite **102** and plurality of remote terminals **111** to **113**. Hub **101** and remote terminals **111** to **113** may be configured to transmit data to and receive data via satellite **102** in accordance with EN 301 790 (DVB-RCS). Hub **101** may be further configured to transmit (over the forward link) frames containing timestamps, which are also referred to as PCR timestamps. Said timestamps may be of a network clock reference (NCR), where said clock reference is driven by a highly accurate clock source (as described in reference to modulator **542** of FIG. **5**). As described above, these timestamps may be used both by remote terminals **111** to **113** and by the receivers of hub **101** (return channel receivers **550** of FIG. **5**) in order to obtain synchronization on the network's time base and for generating an accurate local clock running at the rate of the original reference clock. As all network components lock their locally generated PCR clocks on a single reference (i.e. that which hub **101** transmits as timestamps), all PCR clocks run at exactly the same rate, though not necessarily showing the same value at the same time, as shown herein.

FIG. **6** further shows the PCR clock value at each of the system's components at a given point in time. Though satellite **102** may not have a PCR counter element in a physical manner, it should be appreciated that a reference to such counter is still valid, whereby if satellite **102** were to have such a counter, it would have shown the same value included in a PCR timestamp frame as that particular frame is received at satellite **102**.

Again in reference to FIG. **6**, all PCR clock values are referenced to T, which is the PCR clock value at satellite **102** at the moment of reference. As each earth station may be located at a different distance from satellite **102**, the propagation interval for each station may be different. The propagation delay (in PCR clock units) for hub **101** is marked as D_H and for remote terminals **111**, **112** and **113** as D_R1, D_R2 and D_R3 respectively.

As PCR timestamp T reaches satellite **102**, the PCR clock value of satellite **102** becomes T. As it would take an additional interval of DH for the same timestamp to reach return channel receivers **550** of hub **101** (FIG. **5**), the local PCR clock of return channel receivers **550** is running late in reference to the PCR clock of satellite **102** by exactly DH.

Therefore the local PCR clock of return channel receivers **550** shows the value of T−DH as the PCR clock value of satellite **102** becomes T. In a similar way, the local PCR clocks of remote terminals **111** to **113** at the same moment show the values T−DR**1**, T−DR**2** and T−DR**3** respectively. Furthermore, by the time PCR timestamp T reaches satellite **102** (i.e. the PCR clock value of satellite **102** is T), the PCR clock value at forward link generation module **540** of hub **101** (of FIG. **5**) progresses by additional DH units and therefore shows the value of T+DH.

Furthermore, hub **101** and remote terminals **111** to **113** may be configured to regard any timestamps included in forward link signaling, such as but not limited to super-frame start time (which may be included in a super-frame composition table (SCT) such as defined by EN 301 790), as referring to the local PCR counter of satellite **102**. Therefore, a remote terminal assigned a timeslot, the start time of which is PCR clock value T, may be configured to transmit a burst over said assigned timeslot when the local PCR counter of said remote terminal shows the value of T−**2**DR, where DR is the propagation delay of said remote terminal. Since the remote terminal's local PCR clock runs behind the satellite's PCR clock by a D_R interval, the burst may be transmitted when the satellite's PCR clock shows the value of T−D_R, and since it takes the burst an additional D_R interval to reach the satellite, the burst may be received at the satellite when the satellite's local PCR clock shows the value T, as intended.

Furthermore, the forward link signal (and therefore the PCR timestamps) and return link signals (and therefore transmitted bursts) are subjected to the same propagation delay for any given earth station. Therefore a burst transmitted at a timeslot of timestamp T, as described above, arrives at any receiver, be it a return channel receiver **550** (FIG. **5**) at hub **101** or a mesh receiver **300** (FIG. **3**) at a remote terminal such as **111** or **113**, exactly when the local PCR clock at that receiver shows the value T.

As described above, return channel receivers **550** (FIG. **5**) may be configured to reconstruct a local PCR clock from a received forward link signal, and mesh receive module **300** (FIG. **3** and FIG. **4**) may be configured to receive a PCR clock from a host terminal, which may be configured to reconstruct it in a similar manner as return channel receivers **550**. Therefore, in order to independently follow the return channel composition, synchronize on transmitted bursts and process them as described above, each receiver requires knowledge of the PCR clock value at a given moment in time (i.e. the network's time base). While a return channel receiver **550** may extract such information directly from the transport stream using demodulator **557** (in the same way described in reference to demodulator **232** of indoor unit **200** of FIG. **2**), mesh receiver **300** may not be configurable of using the same mechanism, as said PCR timestamp frames may not exist in the transport stream provided by demodulator **432** (FIG. **4**) or suffer (inconsistent) delay if such frames do exist

A remote terminal, such as **111** or **113**, which may be configured to include a mesh receiver **300**, may also be configured to generate a Frame Sync signal (via synchronization circuits **420**) towards mesh receiver **300**, as described above and shown in FIG. **4**. Said Frame Sync signal may be generated at constant intervals, which may be configured as equal to one or more return channel super frame intervals. Furthermore, based on the timestamps extracted from the forward link and the value of the local PCR clock at any given time, the host terminal may be configured to calculate (either in software or hardware) the expected local PCR clock value at the next significant edge of said Frame Sync signal, and to send said expected PCR clock value to mesh receiver **300** via LAN connectivity as shown in FIG. **4**. Mesh receiver **300** may be configured to receive such PCR clock information over its LAN interface, load the received expected PCR clock value into synchronization & control circuits **370** (FIG. **3**) and then load said value into its local PCR counter using the significant edge of the Frame Sync signal. Once so configured, mesh receiver **300** acquires the network's time base and may follow the return channel composition, synchronize on transmitted bursts and process them as described above.

In some embodiments, mesh receiver **300** and a host terminal may further be configured to repeat the above described mechanism either for every significant edge of the Frame Sync signal or for one in every predetermined number of such edges. Furthermore, upon loading a new value into the counter, mesh receiver **300** may compare said new value with the current value of its local PCR counter. If the difference between the two values is larger than a predefined threshold (e.g. 1) mesh receiver **300** may alert the host terminal (e.g. by sending an event packet over the LAN interface) that a synchronization problem may exist. In some embodiments, mesh receiver **300** may be configured to perform said comparison on every significant edge of the Frame Sync signal, where the value for comparison is either received from the host terminal or computed by mesh receiver **300** based on knowledge of the previous comparison value, the Frame Sync signal interval and the PCR clock rate.

Another aspect of this invention relates to frequency synchronization of mesh receiver **300** to a satellite-based communication network, such as network **100** of FIG. **1**. In order to receive a return channel signal, a mesh receiver **300** has to be synchronized with transmitting remote terminals not only in time but also in frequency. Such synchronization may be initially acquired and then maintained over time. Some embodiments may also include a method for detecting loss of frequency synchronization and repeating the initial acquisition method thereafter.

Mesh implementation in said satellite-based communication system, such as network **100** of FIG. **1**, may be intended as an overlay. Therefore it is only logical and even advantageous in some aspects (e.g. mesh multicasting) that mesh receiver **300** adjusts its reception frequency to match the transmission frequency of any other remote terminal rather than the other way around (i.e. for each remote terminal to adjust its transmission frequency according to a frequency offset of a possible receiver).

The above approach is further justified when considering that each remote terminal, as part of its regular operation according to EN 301 790, may already have its transmission frequency aligned with remote channel receivers **550** at the hub. Return channel receivers **550** of hub **101** may be configured to measure the frequency offset of received return channel signals. Hub **101** may be further configured to calculate frequency correction information on the basis of said measurements and to send said frequency corrections to remote terminals, such as remote terminals **111** to **113** (e.g. using a correction message table (CMT) as defined in EN 301 790). Return channel receivers **550** may be configured to perform said measurements using a reference signal, which may be derived from the reference signal driving the PCR counter, or another independent, yet sufficiently accurate (e.g. 0.1 PPM or better) reference signal.

Therefore, as all remote terminals may already be aligned to a certain reference (e.g. the one that may be used by return channel receivers **550**), a mesh receiver **300** may be configured to align with any one of these remote terminals in order to acquire frequency synchronization with all remote terminals of said satellite-based communication network.

As described above in reference to FIG. **2** and FIG. **4**, demodulator **432** may be configured to measure the frequency of the received forward link signal, e.g. while using the accurate reconstructed PCR clock as reference. Any measured offset from the nominal frequency is the sum of all offsets introduced by any one or more components comprising the forward link path, including modulator **542** (ΔF_{MOD}), transmitter & up converter **530** (ΔF_{UC}), satellite **102** (ΔF_{SAT}), an LNB device coupled to the remote terminal's antenna (ΔF_{LNB}) and tuner **431** (ΔF_{T431}). Therefore, the measured frequency offset of the forward signal (ΔF_{FS}) is:

$$\Delta F_{FS}=\Delta F_{MOD}+\Delta F_{UC}+\Delta F_{SAT}+\Delta F_{LNB}+\Delta F_{T431} \qquad \text{(Eq. 1)}$$

Considering a signal transmitted by a remote terminal already frequency aligned with return channel receivers **550**. The signal may then travel via several components affecting the signal's total frequency offset, as such may be measured by demodulator **340** of mesh receiver **300**. Included in these components are satellite **102** (ΔF_{SAT}), an LNB device coupled to the remote terminal's antenna (ΔF_{LNB}) and tuners **321** and **322** (ΔF_{T32x}), which have the same frequency offset at any given frequency (as described in reference to FIG. **3**). In addition, if return channel receivers **550** measure the frequency of received return channel signals using an independent reference signal (as described above), an additional small offset (ΔF_{REF}) may also exist. Therefore, the frequency offset of a return link signal (ΔF_{RCS}), as measured by demodulator **340** of mesh receiver **300**, is:

$$\Delta F_{RCS}=\Delta F_{SAT}+\Delta F_{LNB}+\Delta F_{T32x}+\Delta F_{REF} \qquad \text{(Eq. 2)}$$

However, both the forward link signal and the return channel signals travel via satellite **102** and the LNB device coupled with the remote terminal's antenna. Therefore satellite **102** and the LNB device apply the same offsets both to the forward signal and to return channel signals. In addition, as described above, tuner **431** of the indoor unit and tuners **321** and **322** of mesh receiver **300** may be configured to share the same reference signal and therefore have the same frequency offset ratio. Thus, for any given frequency, ΔF_{T431} is equal to ΔF_{T32x}. Therefore (integrating Eq. 2 into Eq. 1), the frequency offset of the forward signal may be expressed as follows:

$$\Delta F_{FS}=\Delta F_{RCS}-\Delta F_{REF}+\Delta F_{MOD}+\Delta F_{UC} \qquad \text{(Eq. 3)}$$

Except for the ΔF_{RCS} factor, the frequency offset introduced by up converter **530** (ΔF_{UC}) is the most dominant of all the remaining factors, primarily because the affected signals are at high frequency (such as in Ku-band or Ka-band). This frequency offset may be significantly greater than the frequency offset, which may be allowed by demodulator **340** of mesh receiver **300**. However, like modulator **542** and return channel receivers **550**, up converter **530** may also be configured to use an accurate reference signal, which may also exhibit slow aging. Therefore the combined frequency offset (ΔF_{HUB}) that may be introduced by up converter **530** (ΔF_{UC}), modulator **542** (ΔF_{MOD}) and return channel receivers **550** (indirectly) may be almost constant and with a very slow change rate (i.e. it may be weeks or months until a significant change is accumulated).

Therefore, the frequency offset of a return channel signal can be determined from the measured frequency offset of the forward signal if the almost constant offset introduced by several hub components is known (integrating the following Eq. 4 into Eq. 3):

$$\Delta F_{HUB}=\Delta F_{MOD}+\Delta F_{UC}-\Delta F_{REF} \qquad \text{(Eq. 4)}$$

$$\Delta F_{RCS}=\Delta F_{FS}-\Delta F_{HUB} \qquad \text{(Eq. 5)}$$

FIG. **7** shows a flow chart describing a frequency synchronization acquisition algorithm for mesh receiver **300**. This algorithm may be executed upon a host terminal and/or its included mesh receiver **300** determining that no information regarding ΔF_{HUB} is available. Such condition may exist upon installation of mesh receiver **300**, either as part of a newly installed remote terminal or in an already installed remote terminal. Furthermore, this algorithm may also be executed upon a host terminal and/or its included mesh receiver **300** determining that any available information regarding ΔF_{HUB} is outdated and/or significantly inaccurate and therefore irrelevant and/or unusable. Such condition may exit if mesh connectivity is not or could not be attempted for weeks or months.

In step **701**, a first host terminal, configured to include a mesh receiver **300**, may send a message to hub **101** (e.g. using the Connection Control Protocol (C2P) or an extension of it) and request to set up unidirectional mesh connectivity with a second remote terminal (which may or may not be configured to include a mesh receiver), where the first remote terminal is the receiving party of said mesh connectivity. Said request may not specify which remote terminal is the second remote terminal, hence the second remote terminal may be any remote terminal currently logged on into the satellite network (including said first terminal), which may be configured to transmit a strong enough signal that may be received by mesh receiver **300** of the first remote terminal. In addition, said message may also include a capacity request (e.g. a rate-based capacity request). In some embodiments, one or more remote terminals may be designated to be used in synchronization sequences of mesh receivers. In such embodiments, the connection setup request may specify one of those one or more designated remote terminals as a second remote terminal to be used as the transmitting party of said mesh connectivity.

Hub **101** may be configured to select a second remote terminal in various ways upon receiving a request as described above, i.e. where a second remote terminal is not specified. In some embodiments, the selected second remote terminal may be the one capable of transmitting the strongest signal at the time the request is processed by hub **101**. Once a second remote terminal is selected, hub **101** may set up the connection by sending one or more appropriate messages (e.g. using C2P or an extension of it) to both first and second remote terminals. Furthermore, hub **101** may also start allocating timeslots for this connection, as per the capacity request that may be included in the initial request message sent by the first remote terminal. These timeslots may be allocated on one or more return channels, as per the hub's discretion. Hub **101** may then use forward channel signaling (i.e. a terminal burst time plan table) in order to inform the second remote terminal of the timeslots allocated to it for transmission on said unidirectional mesh connection. In order to achieve that, hub **101** may be configured to use one or more information elements and/or descriptors of any forward channel signaling table in a manner which extends the definitions of EN 301 790.

In step **702**, first remote terminal may be configured to obtain a measurement or a reading of the forward link signal's frequency offset (ΔF_{FS}) from demodulator **432** and to pass it on to its included mesh receiver **300** (via their coupled LAN interfaces). As described in reference to FIG. **3** and FIG. **4**, mesh receiver **300** may be configured to measure the frequency of the reference signal driving tuners **321** and **322**, which may also be the reference signal which drives the down converter of tuner **431**. Knowing the current frequency of the local oscillator within tuner **431** (in some embodiments, this information may be passed on to mesh receiver **300** together with the frequency offset measurement) and using the measurement of the reference signal driving said local oscillator, as described above, processor **360** of mesh receiver **300** may calculate the frequency offset of tuner **431** (ΔF_{T431}).

On the other hand (integrating Eq. 6, which is based on Eq. 1, into Eq. 2):

$$\Delta F_{LNB}=\Delta F_{FS}-\Delta F_{T431}-(\Delta F_{HUB}+\Delta F_{REF}+\Delta F_{SAT}) \quad \text{(Eq. 6)}$$

$$\Delta F_{RCS}=\Delta F_{FS}-\Delta F_{T431}+\Delta F_{T32x}-\Delta F_{HUB} \quad \text{(Eq. 7)}$$

Mesh receiver **300** may be configured to initially assume a predefined value for the frequency offset introduced into the forward link signal by the various hub components (ΔF_{HUB}). In some embodiments, this initial value may be 0. Mesh receiver **300** may then be configured to set tuners **321** and **322** at an offset of ΔF_{RCS} from the nominal frequency of each return channel, where ΔF_{RCS} may be calculated using Eq. 7 above, as all the factors on the right side of Eq. 7 may be known to mesh receiver **300** or may be calculated as described above.

Again in reference to FIG. **7**, in step **703**, the second remote terminal, i.e. the one that may be selected by hub **101** as the transmitting side for said unidirectional mesh connectivity, may be configured to transmit information bursts on all timeslots allocated for the said unidirectional mesh connection. In some embodiments, all said information bursts may contain predetermined and constant content. Furthermore, mesh receiver **300** of the first remote terminal associated with said unidirectional mesh connection, may be configured to receive a terminal burst time plan table (TBTP) that may be transmitted by hub **101** (as described in reference to FIG. **3** and FIG. **4**), to further identify allocations made for said unidirectional mesh connection (e.g. using one or more identifiers, which may be included in the signaling messages sent by hub **101** to the first remote terminal in step **701**), and to configure tuners **321** and **322** as described above (in reference to step **702**) to the appropriate frequencies at the appropriate times (as per the timing synchronization mechanism already described in reference to FIG. **6**), at least for the purpose of receiving said bursts transmitted by the second remote terminal on said allocated timeslots.

Initially, the bursts transmitted by the second remote terminal may not be received by mesh receiver **300** of the first remote terminal. ΔF_{HUB} may not be equal to the initially assumed predetermined value and may be greater than the offset tolerable by demodulator **340** of mesh receiver **300**. Since the second remote terminal may transmit on every allocated timeslot, mesh receiver **300** of the first remote terminal may be configured to deduce that the chosen ΔF_{HUB} is wrong after failing to receive any of the transmitted bursts over a predefined number of allocated timeslots. Mesh receiver **300** may further be configured to assume a different value for ΔF_{HUB} within a predefined range (i.e. the ΔF_{HUB} uncertainty range) and repeat the above described procedure using the newly assumed value of ΔF_{HUB}. It should be appreciated by anyone skilled in the art that there could be several algorithms for determining new values for ΔF_{HUB} and that each and every one of them is consistent with the aspects of this invention.

Step **703** may be concluded once mesh receiver **300** of the first remote terminal succeeds in receiving one or more bursts transmitted by the second remote terminal. In some embodiments, if such reception does not occur within a predetermined interval or within a predetermined and sufficient number of iterations using different values for ΔF_{HUB}, mesh receiver **300** may terminate the algorithm while sending an event to the host terminal that frequency acquisition has failed. Such event may then be further delivered to the network management system at hub **101** for at least the purpose of notifying a network operator of said malfunction.

In step **704**, mesh receiver **300** of first remote terminal, after succeeding in receiving bursts transmitted by the second remote terminal, may be configured to fine tune (i.e. slightly modify) the value of ΔF_{HUB}, so that return channel signals are received at the center of a frequency window supported by demodulator **340** of mesh receiver **300**, or at any other desired position within said frequency window. Once reception at the desired position within said frequency window is achieved, mesh receiver **300** may determine the exact value of ΔF_{HUB} (using Eq. 7 where all other factors are known from the measurements described above).

In step **705**, mesh receiver **300** of first remote terminal, and/or the host terminal, may be configured to record the value of ΔF_{HUB} found in step **704**. Said recording may involve the writing of this value into one or more non-volatile memory devices coupled either with processor **360** of mesh receiver **300** or with processor **410** of the host terminal (indoor unit **400** of FIG. **4**). Along with the value of ΔF_{HUB}, mesh receiver **300** and/or the host terminal may be configured to record date information or any other real-time-clock information that may be later used to determine how old (and therefore how accurate) the recorded ΔF_{HUB} information is.

In step **706**, the first remote terminal may be configured to send a message to hub **101** (e.g. using C2P or an extension of it) and request to release the said unidirectional mesh connection. Upon receiving this request, hub **101** may send one or more appropriate messages (e.g. using C2P or an extension of it) to both first and second remote terminals and close the said connection. Furthermore, hub **101** may stop allocating timeslots for this connection.

During normal operation, the first remote terminal and its included mesh receiver **300** may be configured to perform the procedures described herein, at least for the purpose of maintaining frequency synchronization on return channels. These procedures may achieve such maintenance without repeating the algorithm described in FIG. **7** and without using any bandwidth specifically for this purpose. Any bandwidth used by these procedures may be initially used for at least the purpose of exchanging user information between remote terminals using mesh connectivity.

The first remote terminal may repeatedly inform its included mesh receiver **300** of frequency offset readings taken from demodulator **432** (ΔF_{FS}), as described above in reference to step **702**. The periodicity at which such readings may be reported to mesh receiver **300** may depend on the frequency stability of the least stable component in the reception chain, which in many embodiments may be the LNB. Such readings may be reported to mesh receiver **300** at all times, regardless of whether mesh connectivity reception is in progress or not.

In addition, during normal operation, mesh receiver **300** may be configured to repeatedly measure the reference signal driving tuners **321** and **322**, as described above in reference to step **702**. Such measurement and the resulting calculation of ΔF_{T431} may be done at all times, regardless of whether mesh connectivity reception is in progress or not.

Furthermore, during normal operation, the first remote terminal may be required to receive bursts transmitted by other remote terminals, for at least the purpose of receiving user information. Mesh receiver **300** of said first remote terminal may be configured to use Eq. **7** for calculating the necessary configuration of tuners **321** and **322** using the latest reading of ΔF_{FS}, the latest frequency measurement of the tuners' reference signal, the latest calculation of ΔF_{T431} and the last known value of ΔF_{HUB}, as described above. Mesh receiver **300** (specifically demodulator **340**) may further be configured to measure the actual frequency offset of each received burst (regardless of a connection or a session this burst may be associated with and/or of symbol rate, modulation and coding of each such burst) and to further process these measurements (e.g. using a moving average function over a predetermined number of samples, an exponential averaging function or any other suitable method), at least for the purposes of minimizing measurement errors and/or preventing any single relatively large measured offset to significantly influence the measured frequency offset.

Over time, mesh receiver **300** may determine that the measured frequency offset of received bursts, relative to the center of the frequency window supported by demodulator **340** or relative to any other desired position within said frequency window, is no longer 0 as it was immediately upon completion of step **704**. Mesh receiver **300**, upon determining that said frequency offset exceeds a predefined threshold (which may exceed any expected measurement error), may be configured to repeat steps **704** and **705** described above, i.e. to recalculate the value of ΔF_{HUB} and to record the newly calculated value over the previous value, hence deleting the previous value of AF_{HUB}.

Furthermore, mesh receiver **300** may use the procedure described herein at least for the purpose of preventing the acquisition algorithm described in FIG. **7** from being unnecessarily activated. During normal operation, upon obtaining frequency offset measurements from sufficient number of bursts received over an interval not exceeding a predefined length, and processing them as described above, mesh receiver **300** may be configured to examine the date attached to the recorded value of ΔF_{HUB}, as described in reference to step **705**. If the recorded value of ΔF_{HUB} is older than a predefined threshold, mesh receiver **300** may use the current frequency offset measurement in order to update the recorded value of ΔF_{HUB} (as described in steps **704** and **705**) and attach a current date to the newly recorded value. Mesh receiver **300** may be configured to follow the above-described procedure even if the difference between the current measurement of ΔF_{HUB} and the recorded value of ΔF_{HUB} does not exceed the threshold, which requires updating the recorded value of ΔF_{HUB}.

Again, in reference to FIG. **7**, the above described frequency synchronization methods (both the acquisition part and the maintenance part) are based on measuring the frequency offset of the forward link signal (ΔF_{FS}) and on the assumption that any significant change in that measurement is likely to result from changes in the offsets of components, which also affect the frequency offset of return channels, e.g. the LNB device and/or the reference signal that drives tuners **431**, **321** and **322**. However, as shown in Eq. 1 above, a change in ΔF_{FS} may also result from a change in the frequency offsets introduced by some hub components, such as up converter **530** (ΔF_{UC}) and/or modulator **542** (ΔF_{MOD}), where such change does not affect the frequency offset of return channel signals (ΔF_{RCS}). When such a change occurs (e.g. when redundant up converter and/or modulator units, which are not synchronized in frequency with the main units, take over the main units) and the change is greater than the frequency window supported by demodulator **340** of mesh receiver **300**, mesh receiver **300** may lose frequency synchronization on the return channels.

A remote terminal and/or its included mesh receiver **300** may be configured to monitor established mesh connectivity sessions, where the remote terminal is expected to receive bursts transmitted by one or more other remote terminals. If one or more such sessions were allocated timeslots for transmission by any of the other remote terminals and afterwards terminated without any burst received, the remote terminal and/or its included mesh receiver **300** may be configured to interpret such event as an indication for a synchronization loss (either frequency synchronization or synchronization on any other parameter) and thereafter repeat the frequency synchronization acquisition algorithm described in FIG. **7**. In some embodiments, other criteria for determining synchronization loss may be used, including but not limited to receiving bursts with uncorrectable errors at a number or at a ratio exceeding a predefined threshold.

Another aspect of this invention relates to dynamically determining the difference in link conditions between the hub down-link and the down-link of each remote terminal equipped with a mesh receiver. By determining this deference in real time, a satellite-based communication network, such as network **100** of FIG. **1**, may be configured to support adaptability over mesh connectivity as well as towards the hub. In other words, any remote terminal transmitting over a mesh connection towards another remote terminal may be configured to adjust its transmission power to fit the other transmission parameters (i.e. symbol rate, modulation and coding) and the link condition of the receiving remote terminal. Furthermore, hub **101** may be configured to use such measurements during any bandwidth allocation process, at least for the purposes of selecting the most efficient symbol rate, modulation and coding option supportable by each mesh connection and for insuring that the allocated bandwidth can be successfully utilized (i.e. that the receiver will indeed be capable of receiving any transmission made over these allocations).

In a satellite-based communication network, such as network **100** of FIG. **1**, remote terminals **111** to **113** and hub **101** may be configured to use one or more methods for transmission power regulating, regardless of mesh connectivity.

Hub **101** may be configured to include an up-link power control (ULPC) mechanism for at least the purpose of compensating for changes in link conditions between hub **101** and satellite **102**. Up-link power control may be based on receiving at the hub's site either a satellite beacon signal or the transmitted forward link signal (where satellite **102** does not transmit a beacon signal), detecting changes in reception level of the received signal, and adjusting the transmission level of the forward link signal for at least the purpose of having the forward link signal received at constant power level at satellite **102** (and consequently at remote terminals **111** to **113** assuming constant link conditions at their respective down links). In addition, remote terminals **111** to **113** may be configured to measure the reception level of the forward signal and to periodically report these measurements to the hub. In some embodiments, forward link reception level information may be included in link maintenance bursts (such as SYNC bursts as defined in EN 301 790), and used by hub **101** for at least the purpose of supporting adaptive coding and modulation over the forward link.

Furthermore, hub **101** may be configured to measure the reception level of received return link signals and to provide these measurements over the forward link, e.g. using a correction message table (CMT) as defined in EN 301 790. Remote terminals may be configured to receive such measurements and to use output power control **242** of FIG. **2** to adjust their transmission power according to the received measurements and according to all other transmission parameters (i.e. symbol rate, modulation and coding).

Furthermore, a remote terminal, such as remote terminals **111** to **113**, may be configured to determine its maximal transmission power. In preferred embodiments, the remote terminal may be configured to use a linear satellite transmitter (BUC) therefore the maximal transmission power level may correspond to the 1 dB compression point of such satellite transmitter. In some embodiments, maximal transmission power (and the corresponding settings of output power control **242**) may be determined as part of the remote terminal's installation procedure. In other embodiments, the remote terminal may be configured to occasionally measure the maximal transmission power. In some of these embodiments the remote terminal may by configured to gradually increase the transmission power level of certain maintenance bursts (e.g. SYNC bursts as defined by EN 301 790) and to use the reception level measurements provided by the hub for at least the purpose of calculating the point where the transmission gain decreases by 1 dB.

Regardless of the method selected for determining the remote terminal's maximal transmission power, once determined the remote terminal may use that information at least for the purpose of informing the hub of its maximal transmission capability, i.e. of the additional gain (e.g. in dB) it may apply to a signal transmitted at a minimal reference power level. In some embodiments, the minimal reference power level may be the transmission level required for transmitting the most robust signal (i.e. the signal requiring the minimal transmission power) in order for that signal to be received at hub **101** at a minimal reception level. Once informed of transmission capability of a given remote terminal, the hub may use this information during bandwidth allocation at least for the purpose of selecting efficient symbol rate, modulation and coding rate options that may be supported by the remote terminal and for insuring that any allocated bandwidth can be successfully utilized.

Furthermore, a satellite-based communication network, such as network **100** of FIG. **1**, may be configured to dynamically determine a mesh factor for each remote terminal containing a mesh receiver **300**, such as remote terminals **111** and **113**. The mesh factor may represent the difference in link conditions and properties between the hub downlink and the receiving remote terminal's downlink. Considering that a signal has to be transmitted from a first remote terminal via the satellite towards the hub and received at par level, where par level may be defined as quasi-error-free level plus any predefined fade margin. Therefore, for at least the purpose of achieving reception at the same par level at a mesh receiver of a second remote terminal, at any given time the mesh factor for the second remote terminal may represent the additional gain needed when transmitting a signal of the same other properties (i.e. symbol rate, modulation and coding rate) from a first remote terminal via the satellite towards the second remote terminal.

In order to determine a mesh factor for each remote terminal equipped with a mesh receiver, a satellite-based communication network, such as network **100** of FIG. **1**, may be configured to use a calibration method and a tracking method.

FIG. **8** shows a flow chart describing mesh factor calibration algorithm **800** for mesh receiver **300**. This algorithm may be executed upon a host terminal and/or its included mesh receiver **300** determining that a mesh factor has not yet been calculated. Such condition may exist upon installation of mesh receiver **300**, either as part of a newly installed remote terminal or in an already installed remote terminal.

In step **801**, a first host terminal, configured to include a mesh receiver **300**, may send a message to hub **101** (e.g. using the Connection Control Protocol (C2P) or an extension of it) and request to set up unidirectional mesh connectivity with a second remote terminal (which may or may not be configured to include a mesh receiver), where the first remote terminal is the receiving party of said mesh connectivity. Said request may not specify which remote terminal is the second remote terminal, hence the second remote terminal may be any remote terminal currently logged on into the satellite network (including said first terminal), which may be configured to transmit a strong enough signal that may be received by mesh receiver **300** of the first remote terminal. In addition, said message may also include a capacity request (e.g. a rate-based capacity request).

Hub **101** may be configured to select a second remote terminal in various ways upon receiving a request as described above, i.e. where a second remote terminal is not specified. In some embodiments, hub **101** may be configured to select a remote terminal with transmission capabilities either equal or exceeding a predetermined mesh factor figure. The predetermined mesh factor figure may exceed the expected clear sky mesh factor (which may be predetermined using link budget calculations) by a predetermined margin at least for the purpose of increasing the probability of success should the calibration attempt occur while link conditions are not optimal. Once a second remote terminal is selected, hub **101** may establish the connection by sending one or more appropriate messages (e.g. using C2P or an extension of it) to both first and second remote terminals. The message to the first remote terminal may further contain the predetermined mesh factor figure, at least for the purpose of calculating a reference mesh factor measurement, as further described herein. The message to the second remote terminal may further contain the predetermined mesh factor figure, at least for the purpose of having the second remote terminal transmitting at that predefined gain over that mesh connection.

Furthermore, hub **101** may also start allocating timeslots for this connection, as per the capacity request that may be included in the initial request message sent by the first remote terminal. These timeslots may be allocated on one or more return channels, as per the hub's discretion. Hub **101** may then use forward channel signaling (i.e. a terminal burst time plan table) in order to inform the second remote terminal of the timeslots allocated to it for transmission on said unidirectional mesh connection. In order to achieve that, hub **101** may be configured to use one or more information elements and/or descriptors of any return channel signaling table in a manner which extends the definitions of EN 301 790.

The second remote terminal, i.e. the one that may be selected by hub **101** as the transmitting side for said unidirectional mesh connectivity, may be configured to transmit information bursts on timeslots allocated to the said unidirectional mesh connectivity. In some embodiments, all said information bursts may contain predetermined and constant content. Furthermore, mesh receiver **300** of the first remote terminal associated with said unidirectional mesh connectivity, may be configured to receive a terminal burst time plan table (TBTP) that may be transmitted by hub **101** (as described in reference to FIG. **3** and FIG. **4**) and to further identify allocations made to said unidirectional mesh connectivity (e.g. using one or more identifiers, which may be included in the signaling messages sent by hub **101** to the first remote terminal in step **801**). Mesh receiver **300** may be further configured to configure tuners **321** and **322** to tune on bursts transmitted by the second remote terminal at the appropriate frequencies and times (as per the timing and frequency synchronization mechanisms already described in reference to FIG. **6** and FIG. **7**), at least for the purpose of receiving said bursts transmitted by the second remote terminal on said allocated timeslots.

Again in reference to FIG. **8**, in step **802**, for each received burst, mesh receiver **300** of the first remote terminal may measure the burst's reception level (e.g. C/N or ES/N0) and calculate its par margin by subtracting the par level required for receiving that burst (as per the burst's other parameters, such as modulation and coding rate) from the measured reception level. Step **802** may be completed once a predefined number of bursts have been correctly received.

In step **803**, mesh receiver **300** of the first remote terminal may be configured to calculate a reference mesh factor figure. Mesh receiver **300** may apply a mathematical algorithm, such as but not limited to an averaging function, to the collection of par margin measurements obtained in step **802** and then subtract the result from the predetermined mesh factor figure, as provided to the first remote terminal in step **801**.

In parallel to steps **802** and **803**, the first remote terminal may be configured to obtain measurements or readings of the forward link signal's reception level from demodulator **432** and to pass them on to its included mesh receiver **300** (via their coupled LAN interfaces). In step **804**, mesh receiver **300** may be configured to determine the forward link's reception level by applying a mathematical algorithm, such as but not limited to an averaging function, to a collection of said forward link reception level measurements received from the host terminal.

In step **805**, mesh receiver **300** of first remote terminal, and/or the host terminal itself, may be configured to record a reference measurement. The reference measurement includes the reference mesh figure previously calculated in step **803** and the corresponding forward link reception level previously calculated in step **804**. Said recording may involve writing the reference measurement values into one or more non-volatile memory devices coupled either with processor **360** of mesh receiver **300** or with processor **410** of the host terminal (indoor unit **400**). Along with recording said reference measurement, mesh receiver **300** and/or the host terminal may be configured to record date information or any other real-time-clock information that may be later used to determine how old (and therefore how dependable) the recorded reference measurement is.

In step **806**, the first remote terminal may be configured to send a message to hub **101** (e.g. using C2P or an extension of it) and request to release the unidirectional mesh connectivity. The release message may further include the values of the recorded reference measurement. Upon receiving this request, hub **101** may send one or more appropriate messages (e.g. using C2P or an extension of it) to both first and second remote terminals in order to close the connection, and stop allocating timeslots for this connection. Furthermore, hub **101** may store the reference measurement in association with the first remote terminal, at least for the purpose of using it as further described herein.

In some embodiments, a remote terminal may further report a reference measurement whenever the remote terminal logs on to hub **101**. A remote terminal may skip algorithm **800** and report the already recorded reference measurement if the record is not too old as per the date recorded with the reference measurement in step **805**.

In some further embodiments, where the predetermined mesh factor figure is constant, the first remote terminal may include in the reference measurement the par margin measurements average and the corresponding forward link reception level. Hub **101** may be configured to receive the par margin measurements average and calculate the reference mesh factor of the reference measurement.

During normal operation, hub **101** may be further configured to calculate an actual mesh factor (MFACT) for a remote terminal containing a mesh receiver **300** using the stored reference measurement for that remote terminal (forward link reception level (FL_{REF}) and a reference mesh factor (MF_{REF})), and forward link reception level information (FL_{CUR}) that may be included in link maintenance bursts (such as SYNC bursts as defined in EN 301 790), which may be transmitted by that remote terminal, as previously described:

$$MF_{ACT}=MF_{REF}-(FL_{CUR}-FL_{REF}) \qquad \text{(Eq. 8)}$$

Hub **101** may be configured to include an up-link power control mechanism, as previously described. Therefore changes in forward link reception level may be attributed to changes in the satellite link between satellite **102** and the applicable remote terminal. As link condition deteriorate the forward link reception level decreases and the actual mesh factor has to be equally increased in order to maintain reception at par level. As link conditions improve, forward link reception level increases and the actual mesh factor may be equally decreased, at least for the purposes of allowing use of more efficient and higher throughput channels and regulating the transmission power of other remote terminals over mesh connectivity as well as towards the hub.

Furthermore, hub **101** may be configured to notify remote terminals of actual mesh factors upon establishment of a mesh connection. Considering a first remote terminal, configured to include a mesh receiver **300** and a second remote terminal where the second remote terminal requests to establish mesh connectivity towards the first remote terminal. Upon receiving a connection establishment request, hub **101** may be configured to respond with appropriate connection establishment messages to both remote terminals. Hub **101** may be further configured to include the actual mesh factor of the first remote terminal in the message sent towards the second remote terminal. Where the second remote terminal is also configured to include a mesh receiver **300**, hub **101** may further include the actual mesh factor of the second remote terminal in the message sent towards the first remote terminal.

Furthermore, as mesh factors of remote terminals may vary in time, including when mesh connections are already established, hub **101** may be further configured to transmit a table of mesh factors over the forward link for at least the purpose of allowing remote terminals transmitting over mesh connections to adjust their transmission gain to match the changes in mesh link conditions. Each record in the table may include at least a mesh factor figure and one or more identifiers, which may be sufficient to enable remote terminals to correctly identify the remote terminal to which the reported mesh factor relates to. In order to enable quick response, the table may be transmitted several times every second. In some embodiments, each transmitted instance of the table may include the mesh factor of each remote terminal configured to include a mesh receiver and listening on at least one active mesh connection. In other embodiments, a mesh factor of a remote terminal as described above may be included in one or more consecutive transmitted instances of the table only if the mesh factor of that terminal had changed by more than a predefined difference since the last time this mesh factor had been included in the table. Furthermore, a first remote terminal may be configured to receive a mesh factors table, determine whether any of the entries relates to a second remote terminal, with which the first remote terminal has an already open mesh connection where the first remote terminal is the transmitting party, and to adjust its transmission level over that connection according to the reported mesh factor.

As will be appreciated by one of skill in the art upon reading the following disclosure, various aspects described herein may be embodied as methods, systems, apparatus (e.g., components of a satellite communication network), and/or computer program product. Accordingly, those aspects may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects. Furthermore, such aspects may take the form of a computer program product stored by one or more computer-readable storage media having computer-readable program code, or instructions, embodied in or on the storage media. Any suitable computer readable storage media may be utilized, including hard disks, CD-ROMs, optical storage devices, magnetic storage devices, and/or any combination thereof. In addition, various signals representing data or events as described herein may be transferred between a source and a destination in the form of electromagnetic waves traveling through signal-conducting media such as metal wires, optical fibers, and/or wireless transmission media (e.g., air and/or space).

While illustrative systems and methods as described herein embodying various aspects of the present invention are shown, it will be understood by those skilled in the art, that the invention is not limited to these embodiments. Modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. For example, each of the elements of the aforementioned embodiments may be utilized alone or in combination or sub-combination with elements of the other embodiments. It will also be appreciated and understood that modifications may be made without departing from the true spirit and scope of the present invention. The description is thus to be regarded as illustrative instead of restrictive on the present invention.

The invention claimed is:

1. A method comprising:

receiving, by a computing device comprising at least one processor and memory device, a reference measurement corresponding to a first remote terminal in a satellite communication system, the reference measurement comprising a mesh factor figure (MF_{REF}) and a forward link reception level figure (FL_{REF}) associated with the first remote terminal;

receiving, by the computing device, a forward link reception level measurement (FL_{CUR}) associated with the first remote terminal in the satellite communication system;

determining, by the computing device, a first actual mesh factor (MF_{ACT}) for the first remote terminal, wherein the first actual mesh factor is determined based on the mesh factor figure, the forward link reception level figure, and the forward link reception level measurement associated with the first remote terminal;

generating, by the computing device, a table of actual mesh factors for a plurality of remote terminals in the satellite communication system, the actual mesh factors comprising the first actual mesh factor; and

transmitting, by the computing device and to at least one remote terminal in the satellite communication system, the table of actual mesh factors.

2. The method of claim **1**, wherein the computing device is a hub of the satellite communication system.

3. The method of claim **1**, wherein the first actual mesh factor (MF_{ACT}) for the first remote terminal is calculated using the formula $MF_{ACT}=MF_{REF}-(FL_{CUR}-FL_{REF})$.

4. The method of claim **1**, wherein receiving the forward link reception level measurement (FL_{CUR}) associated with the first remote terminal comprises:

receiving a link maintenance burst from the first remote terminal; and

extracting the forward link reception level measurement (FL_{CUR}) from the link maintenance burst.

5. The method of claim **4**, wherein the link maintenance burst comprises a synchronization burst type (SYNC) burst according to the Digital Video Broadcast Return Channel via Satellite standard (EN 301 790).

6. The method of claim **1**, further comprising:

receiving a request from one of the first remote terminal and a second remote terminal to establish mesh connectivity between the first remote terminal and the second remote terminal; and

in response to the request, transmitting one or more connection establishment messages to the second remote terminal, the one or more connection establishment messages including the first actual mesh factor (MF_{ACT}) for the first remote terminal.

7. The method of claim 1, further comprising:

transmitting the table of actual mesh factors to each remote terminal in the satellite communication system configured to include a mesh receiver.

8. The method of claim 7, wherein generating a table of actual mesh factors comprises:

identifying each remote terminal in the satellite communication system configured to include a mesh receiver and listening on at least one active mesh connection; and

creating a record in the table of actual mesh factors for each identified remote terminal.

9. The method of claim 1, wherein generating the table of actual mesh factors comprises:

identifying one or more remote terminals in the satellite communication system for which actual mesh factors corresponding to the one or more remote terminals have changed by more than a predefined amount from previous actual mesh factors corresponding to the one or more remote terminals that were included in a previous table of actual mesh factors; and

creating one or more records in the table of actual mesh factors corresponding to the one or more remote terminals.

10. A method comprising:

receiving, by a mesh receiver of a first remote terminal in a satellite communication system, one or more transmission bursts;

measuring, by the first remote terminal, reception levels for each of the one or more transmission bursts;

calculating, by the first remote terminal, a reference mesh factor (MF_{REF}) for the first remote terminal, based on the measured reception levels for each of the one or more transmission bursts;

determining, by the first remote terminal, a forward link reception level figure (FL_{REF}) for the first remote terminal;

transmitting, by the first remote terminal, a reference measurement to a hub of the satellite communication system, wherein the reference measurement comprises the reference mesh factor and the forward link reception level figure for the first remote terminal; and

receiving, by the first remote terminal and from the hub, a table of actual mesh factors for a plurality of remote terminals in the satellite communication system.

11. The method of claim 10, wherein calculating the reference mesh factor for the first remote terminal comprises:

calculating a par margin for each of the one or more transmission bursts; and

using the calculated par margins for the one or more transmission bursts to calculate the reference mesh factor for the first remote terminal.

12. The method of claim 11, wherein calculating the par margin comprises:

for each of the one or more transmission bursts, subtracting a par level required for receiving that transmission burst from the measured reception level of that transmission burst.

13. The method of claim 11, wherein calculating the reference mesh factor for the first remote terminal comprises:

receiving a predetermined mesh factor figure from the hub of the satellite communication system;

applying a mathematical algorithm to the calculated par margins for each of the transmission bursts to obtain a result; and

subtracting the result from the predetermined mesh factor figure received from the hub.

14. The method of claim 13, wherein applying the mathematical algorithm to the calculated par margins comprises averaging the calculated par margins.

15. The method of claim 10, wherein calculating the reference mesh factor for the first remote terminal comprises:

determining that a predefined minimum number of transmission bursts have been received by the first remote terminal; and

initiating the calculation of the reference mesh factor for the first remote terminal based on the determination that the predefined minimum number of transmission bursts have been received.

16. The method of claim 10, wherein determining, by the first remote terminal, a forward link reception level figure (FL_{REF}) for the first remote terminal comprises:

obtaining, at the first remote terminal, a plurality of forward link reception level measurements at the time of receiving said one or more transmission bursts; and

determining the forward link reception level figure based on the plurality of forward link reception level measurements.

17. The method of claim 10, comprising:

recording the reference measurement in a non-volatile memory of the first remote terminal; and

transmitting the recorded reference measurement to the hub responsive to the first remote terminal logging on to the hub.

18. The method of claim 10, comprising:

sending, by the first remote terminal, a request to the hub to establish unidirectional mesh connectivity with a second remote terminal, wherein the first remote terminal is a receiving party of the unidirectional mesh connectivity and wherein an identity of the second remote terminal is not specified; and

sending, by the first remote terminal, a request to conclude the unidirectional mesh connectivity upon transmitting the reference measurement to the hub.

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