Satellite Uplink Power Control

Field of the invention

The present invention pertains to the field of satellite communication and in particular to scintillation resistant power control techniques for geostationary satellite communication systems in accordance with claim 1,8,15 and 16 respectively.

Background of the Invention

A satellite communication system generally comprises one or more gateway stations, a satellite and a number of user stations. The gateway stations provides an interface to the terrestrial networks and are transmitting and receiving communication carriers at high frequencies to and from the satellite. The satellite is functioning as an amplifier and/or frequency converter for the communication carriers. The user stations may be fixed or mobile. In systems comprising a small number of large gateway stations serving a large population of small user stations (fixed or mobile), satellite cost is normally governed by the characteristics of the forward transmission link, i.e. from the gateways to the user stations. This stems from the requirement to use small antennas on the user stations for cost reasons, which in turn requires more satellite power to achieve a particular transmission quality. This requires high power efficiency in the forward link to achieve good system economy.

The communication carriers are exposed to a number of effects that influence the signal quality or the signal level along the path from a gateway to the user station.

The most important elements are:

- Variations in transmitter gain leading to variations in output power towards the satellite.
- Uplink atmospheric effects such as rain fading and scintillation leading to large signal variations.
- Variations in the satellite transponder signal gain.
- Downlink atmospheric effects such as rain fading and scintillation.

The severity of these effects varies with the climatic conditions at the ground stations and their operating carrier frequency. The atmospheric effects are increased for ground earth stations (gateways or user stations) located such that the satellite is seen at a shallow angle above the horizon since the length of the atmospheric path increases with lower elevation angles.

All these contributions adds to a significant variation in the received signal level on the ground which in turn leads to the need of transmitting signals with an excessive margin to ensure a minimum guaranteed quality level. This margin detracts power from the satellite reducing the system capacity and thus the economics of the system as a whole.

Prior art

Uplink power control systems has been described in several patents proposing various mechanisms to maintain constant transmit power from the satellite in satellite communications systems irrespective of atmospheric and other disturbances at the uplink station. Most applications are concerned with and designed to compensate relatively slow variations in the transmission path such as rain fading which have time constants of the order of minutes.

US patent 4,567,485 describes a system where one of the stations in a satellite network is stabilized by using a satellite generated beacon signal as level reference in a power control loop. This station is then used as a level reference for the other stations in the network that are slaved to the first station. The system relies on a satellite beacon for its mode of operation, which may not be available at a frequency sufficiently close to the frequency band of the signals to be stabilized. For example, a normal satellite beacon around 3.9 GHz will not be effective in a mobile satellite communication system with its communication carriers around 1.5 GHz.

US patent 4,752,967 describes various methods to compensate variations in the uplink transmission path of a satellite earth station utilizing signals from one or two other stations in the network as beacon stations in the process. In this proposal, rather than stabilizing one particular master station as described US 4,567,485, one or two stations in locations with favorable atmospheric conditions are chosen as references for the

power control system. Although the proposed methods will compensate slow varying atmospheric variations quite efficiently, they all have some shortcomings:

the beacon station(s) must exist with substantially less atmospheric variations than the station to be stabilized;

in any of the methods described either satellite variations, local station transmitter variations or both remain un-compensated;

atmospheric uplink variations at the beacon stations are transferred either 100% or 50/50 from each beacon station to the local station;

short term transmitter variations and/or long term variations of the beacon stations are transferred either 100% or 50/50 from each beacon station to the local station;

Summary of the invention

The objective of this invention is to combat not only the slow varying rain fading but also to be able to compensate rapid scintillation effects which occur especially to Satellite Earth Stations that see the satellite at a low elevation angle. These variations are caused by fluctuations in the ionosphere and can cause significant signal fluctuations over a period of a few seconds so schemes relying on heavy low-pass filtering to remove induced errors from external reference carriers (typically 10 seconds or more) will not be able to compensate such variations.

Scintillation also exhibits strong frequency dependency rendering compensation schemes utilizing beacon signals in a different frequency band to the carriers to be stabilized inefficient.

The present invention, in its preferred embodiments, addresses all the shortcomings in the prior art described above. This is accomplished by:

using a larger number of beacon stations, typically 3-5, to estimate local downlink conditions reducing the reliance on the individual beacon station characteristic;

superior method to estimate local down-link variations using adaptive weights to the beacon signals determined by their current individual behavior.

Implementing specific mechanisms for instantaneous detection and subsequent suppression of erroneous or abnormal beacon signals.

Inclusion of a local RF reference in the control loop to enable simultaneous suppression of all unwanted effects in the transmission path without introducing sensitivity to other unwanted detrimental effects.

The variations imposed on the received signal power level along the signal path is given by the equation:

$$\Delta Prx_{US} = \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{US} \quad \text{where}$$

ΔTX_{Gw} is the variations in transmitter gain leading to variations in output power towards the satellite. Δup_{GW} is the uplink atmospheric effects such as rain fading and scintillations leading to large signal variations. ΔSat is the variations in the satellite transponder signal gain. ΔDwn_{US} is the downlink atmospheric effects such as rain fading and scintillation.

The variations of these signal levels can be observed and measured by observing deviations from nominal level values of the different parameters. Parameters associated with equipment will have their nominal level values determined by the nominal settings of the controlling parameters of the equipment as known to a person skilled in the art. Settings may be validated on a day with a clear sky.

The objective of the present invention is to minimize these effects on the signal quality of the communication system and give the communication system the same quality as observed on a day with a clear sky.

A common method used in many systems is the use of Uplink Power Control (UPC) to maintain constant signal power out of the satellite in order to maximize system efficiency. The basic principle is to equip the gateway with a measurement receiver capable of measuring the received level of its own carrier (or a pilot carrier) looped back from the satellite. This information is used to adjust the transmitted level in the opposite sense to eliminate variations in the signal level when it is received on the ground.

In order to minimize satellite power and intersystem interference, it is desirable to maintain the communication carriers at a predefined constant level at the satellite output independent of the variations in the transmission path. This is accomplished by

compensating for transmitter, uplink and satellite effects. The signal level information derived from the receiver at the gateway also includes downlink effects and signal detector (receiver) variations. Simple systems use empirical information to apportion a fixed amount of the total measured variations to uplink and satellite effects. In practice the following effects restricts the usefulness of this scheme and makes it unsuitable for many systems:

- The ratio between uplink effects and downlink effects is not constant, but may vary considerably.
- Receiver gain variations can introduce significant errors in the power regulation accuracy.
- Uplink and downlink scintillations are not coherent if the uplink and downlink frequencies are significantly different leading to little or no improvement during scintillation events.

Substantial improvements can be achieved if the satellite has a beacon transmitter operating in the same frequency band as the communication carrier's downlink from the satellite. The beacon signal is transmitted with a stable signal level from the satellite itself and is only subject to downlink effects and gateway receiver errors. By comparing the looped back communication signal level with the beacon signal level, downlink effects is canceled and the control signal comprises only the desired components.

The beacon signal is received at the gateway with the following variations in signal level:

$$\Delta Beac_{Gw} = \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

where ΔRx_{Gw} is the gateway receiver chain variations.

The looped back pilot signal is received at the gateway with the following variations in signal level:

$$\Delta Pil_{Gw} = \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The difference used to control the transmitter gain becomes:

$$\Delta Gain_{Gw} = \Delta Dwn_{Gw} + \Delta Rx_{Gw} - (\Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw})$$

This reduces to:

$$\Delta Gain_{Gw} = -(\Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat)$$

The communication carriers at the output of the satellite are:

$$\Delta P_{Sat} = \Delta Gain_{Gw} + \Delta Tx_{Gw} + \Delta Up_{Gw} + \Delta Sat$$

Which becomes:

$$\Delta P_{Sat} = -(\Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat) + \Delta Tx_{Gw} + \Delta Up_{Gw} + \Delta Sat = 0$$

This works well if the frequency difference between the beacon transmitter and the compensated communication carriers are not too large so that the atmospheric disturbances of the beacon signal are identical to the disturbances of the communication carriers.

Disclosure of the Invention

Some systems do not have a satellite beacon transmitter with frequency sufficiently close to that of the communication carriers to be of any use for scintillation compensation. As an example, geostationary mobile satellite systems typically use L-band signals (1.5/1.6 GHz). Between the satellite and the mobile terminals while the feeder link between the satellites and the gateways are at C-band (6/4 GHz). The satellite beacon transmitter is around 4 GHz, which is not sufficiently close to the downlink L-band signals to be used directly for scintillation cancellation as shown above.

Therefore there is a need for another solution to this problem. The present invention takes advantage of the fact that in networks comprising several gateways with each gateway transmitting carriers to the satellite, simultaneous reception of these carriers by any of the gateways can be exploited to derive the local downlink atmospheric conditions at the gateway. This information can then in turn be used in an uplink power

control system to make it immune to the downlink effects prevailing at the gateway similar to the use of a beacon transmitter as in the case above.

Brief description of the Drawings

Fig. 1 shows a typical scenario comprising a geostationary satellite 2, a gateway 3 employing the invention , other gateways 4 operating on the same satellite 2, and a number of user stations 5 communicating with the gateway 3. The user stations 5 may be mobile or in a fixed location. The gateways 3 and 4 communicate with the user stations 5 via outbound signals through the satellite 2 and the user stations 5 communicate with the gateways 3 and 4 via inbound signals through the satellite 2.

Fig. 2A illustrates the outbound signals 10 transmitted by one of the gateways 3 to the satellite, which in turn retransmits the signals 11 down link to the user stations 5. The gateway also normally monitors its outbound signals 10 (signal 11).

Fig. 2B illustrates the inbound signals 20 transmitted by the user stations to the satellite, which in turn retransmits the signals 21 down link to the gateway 3.

Fig. 2C illustrates the gateway 3 monitoring via signal 31 the outbound signals 30 transmitted by other gateways 4 operating over the satellite.

Fig. 3 illustrates the main components of the gateway station 3 employing power control 400 to its transmitted carriers 10. It comprises an antenna 100 receiving and emitting signals 10,11,31 to the satellite 2, a receiver chain 200, a transmitter chain 500, signal detectors 300, a power control function 400 and an optional reference signal generator 600.

Fig. 4 illustrates a first exemplary embodiment of the invention. The TDM signals 30 are retransmitted by the satellite 2 and are monitored as the signals 31 by the gateway 3 that employs the invention. The pilot detector 310 detects the received pilot signal 11s power level and the scanner detector 320 finds the selected TDM signals 31s power levels the invention uses to determine the scintillation and to determine the necessary amount of adjustment of the power control 400 in the transmitting chain 500.

Fig. 5 illustrates a second embodiment of the invention, in addition to the functions depicted in Fig. 4, which also includes a reference signal 600 in the receiving chain 200

to characterize gain variations in the receive system allowing elemination of variations in the satellite 2 gain in the final regulation loop.

Fig. 6 illustrates a best mode implementation of the invention. The receiving means 310,320 containing the necessary electronics for signal conditioning and tuning of the signal can be adjusted by control sequences from the micro controller 52 to receive the different TDM signals 31 or pilot signal 11or the reference signal 600. The Analog to Digital Converter 53 converts the received signals 11,31 to digital form for processing by control sequences in the micro controller 52 performing the steps of the invention. The Digital to Analog Converter 54 converts the digital UPC control signal to analog form suitable for connecting to a standard AGC input control signal of the power amplifier via the output means 55 containing the necessary electronics for interfacing the signal to the AGC input of the power control 400 of the transmitter chain 500.

Fig. 7 illustrates the typical components of power control system.

Fig. 8 illustrates the basic steps in the algorithm for an adaptive downlink estimator according to the invention.

Fig. 9 illustrates the basic steps in the algorithm for an enhanced adaptive downlink estimator.

Preferred embodiment of the Invention

In a preferred embodiment of the invention (fig. 4) the system comprises a number of gateways (N1 to Nn) 4 each transmitting a communication carrier or a signaling carrier that is always on (e.g. a Time Division Multiplex carrier, TDM) 30.

The TDM 31 from Gateway N1 4 is received at the gateway 3 at the input of the receiver chain 200 employing the invention with the following variations in signal level:

$$\Delta TDM_{GwN1} = \Delta TX_{GwN1} + \Delta Up_{GwN1} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

Similarly, the TDM from gateway Nn 4 is received with the following variations in signal level:

$$\Delta TDM_{GwNn} = \Delta TX_{GwNn} + \Delta Up_{GwNn} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The gateways 4 are located remote to each other such that the atmospheric conditions can be assumed to be independent of each other. Likewise, the transmitter variations are also independent. By averaging over a number signal levels of carriers 31 and applying suitable signal processing as known to a person skilled in the art, the independent terms can be significantly reduced to an insignificant noise term. The resultant mean value after this process can be expressed as:

$$\Delta TDM_{Mean} = N + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

where N denotes the residual noise after the averaging process. The measurement of each signal level of carrier 31 can be effected by either a set of receivers, one for each TDM 31 signal, a scanning receiver capable of measuring each signal level of carrier 31 in rapid succession or a combination of the two. The scanning receiver and the averaging process must be rapid to accurately track the atmospheric variations during scintillation events, the actual rate depending on the carrier frequencies involved.

The looped back pilot signal 11 is received at the gateway 3 with the following variations in signal level:

$$\Delta Pil_{Gw} = \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The difference, used to control the transmitter 500 gain, becomes:

$$\Delta Gain_{Gw} = N + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw} - (\Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw})$$

This reduces to:

$$\Delta Gain_{Gw} = N - (\Delta TX_{Gw} + \Delta Up_{Gw})$$

The signal level variations of the communication carriers at the output of the satellite 2 are:

$$\Delta P_{Sat} = \Delta Gain_{Gw} + \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat$$

Which becomes:

$$\Delta P_{Sat} = N - (\Delta TX_{Gw} + \Delta Up_{Gw}) + \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat$$

Which reduces to:

$$\Delta P_{Sat} = N - \Delta Sat$$

The atmospheric variations and the gateway 3 signal level variations have been eliminated and the residual error is only the satellite signal level variations and a small noise term.

An other embodiment of the invention illustrated in figure 6, a reference generator 600 is added to the receiving subsystem 200 of the gateway 3 to enable real time measurement of gain changes in the receiver chain 200.

As in the first exemplary embodiment of the invention the averaging process and measurements of the signal levels of the TDM signals 31 from the different gateways 4 will produce an average variation level signal:

$$\Delta TDM_{Mean} = N + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The average value is subjected to a high-pass filter with a cut-off that removes the slow satellite 2 variations from the estimate, but to pass the rapid scintillations. This also removes the slow gain variations of the gateway receiver system 200 resulting in the following variations of the level signal:

$$\Delta TDM`_{Mean} = N + \Delta Dwn_{Gw}$$

The high-pass filter is applied on each received signal level of the TDM 31 signal before averaging the signal levels.

The filter can be implemented in the form:

$$TMP_t = K_1 * P + (1 - K_1) * TMP_{t-1}$$

$$P'_t = P - TM\ P_t$$

where TMP_t is a temporary variable at a current time t, K_1 is a coefficient set to be between 0 and 1, P is the current measured power of TDM 31 which the scanning detector 320 is tuned to at time t, TMP_{t-1} is the previous sample value of the temporary variable TMP and P'_t is the desired high-pass filter value of TDM 31 signal power level.

The measured variation of the level of the reference signal injected at the input of the receiving system 200 is:

$$\Delta Re_{Gw} = \Delta Rx_{Gw}$$

This value is added to the TDM estimate to give the following value:

$$\Delta TDM`_{Mean} = N + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The looped back pilot signal 11 is received at the gateway 3 with the following variations in signal level:

$$\Delta Pil_{Gw} = \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw}$$

The difference, used to control the transmitter 500 gain, becomes:

$$\Delta Gain_{Gw} = N + \Delta Dwn_{Gw} + \Delta Rx_{Gw} - (\Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat + \Delta Dwn_{Gw} + \Delta Rx_{Gw})$$

This reduces to:

$$\Delta Gain_{Gw} = N - (\Delta TX_{Gw} + \Delta Sat + \Delta Up_{Gw})$$

The level of the variations of the communication carrier signals at the output of the satellite 2 is:

$$\Delta P_{Sat} = \Delta Gain_{Gw} + \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat$$

Which becomes:

$$\Delta P_{Sat} = N - (\Delta TX_{Gw} + \Delta Sat + \Delta Up_{Gw}) + \Delta TX_{Gw} + \Delta Up_{Gw} + \Delta Sat$$

Which reduces to:

$$\Delta P_{Sat} = N$$

Which is only a small noise term.

In the disclosure of the two exemplary embodiments of the invention the noise term is small. But in order to reduce the noise term further the following steps can be applied to the multi TDM estimate calculations:

1. If the power level of the TDM 31 from a gateway 4 falls below a predefined threshold (Thrl), its measured value of power level is replaced by a constant value in the averaging process to limit the effect of a faulty gateway 4 on the performance.
2. If the instantaneous value of any particular power level of a TDM 31 signal deviates from the instantaneous average value of all the power levels of the TDMs (31) by more than a second predefined value (Thr2), it will be replaced by a constant value in the averaging process. This reduces substantially the effects that a local uplink scintillation event at a gateway 4 can have on the power regulation.
3. If the absolute value of the level difference between the current average value of all TDMs (31) and the average one processing sample earlier is below a third threshold (Thr3), the average is filtered by a low-pass filter with a suitable bandwidth. If Thr3 is exceeded, i.e. a scintillation event is detected at the gateway 3, the bandwidth of the filter is increased to enable a fast tracking mode to accurately track and suppress the scintillation as long as the condition is satisfied.

The low-pass filter in step 3 above can be of the form:

$$D'_t = K_2 * D + (1 - K_2) * D'_{t-1}$$

where D'_t is the filter output at the current sample time t, K_2 is a parameter that can be set to one of two different values between 0 and 1 depending on the absolute rate of change of the third difference being above or below the predefined threshold Thr3, and thereby enable fast tracking mode, D is the prevailing third difference and D'_{t-1} is the previous sample filter output.

There are several possible implementation of the invention in an existing gateway 3 earth station. The invention requires the gateway transmitter to be capable of electronic gain control. If this is not already part of the existing installation, such functionality can be achieved through the inclusion of a standard off the shelf UPC controller as known to a person skilled in the art. The UPC controller, which is usually controlled by the pilot signal 11 only, is controlled by the output signal $\Delta Gain_{Gw}$. The power control can be selected to be in a closed loop or open loop configuration, usually by a command setting in the UPC controller.

Yet an other embodiment is shown in fig.7, the overall control system is as before but the downlink estimation is made adaptive. The steps of an algorithm (fig. 8) of a basic estimator of downlink variations using adaptive weights to the TDM 31 signals determined by their current individual behavior are shown as functional blocks:

Block 101: High-pass filter signal levels.
The inputs are the levels of the TDM 31 signals as detected by the scanning detector 320.

Each detected TDM 31 signal level is passed through an individual high-pass filter. It takes the form of subtracting a low-pass filtered version of the signal from the signal itself. The output represents the instantaneous change in level with respect to a longer-term mean value.

Block 102: Compute instantaneous variance.
This block takes as input the signals output from block 101.
It computes the difference between the change in each of the signals and the mean of the changes of the other signals. It then computes the absolute value of said difference.

Block 103: Low-pass filter variance.
This block takes as input the signals output from block 102.

It produces a low-pass filtered version of the variance. The output of the filters are estimates of the current variance of each carrier with respect to the average of all the TDM 31 carriers.

Block 104: Compute relative weights.
This block takes as input the signals output from block 103.
It computes a weight for each signal such that when multiplied by the weight, they each contribute the same variance. I.e. the relative weights are the inverse of the variance.

Block 105: Normalize weights.
This block takes as input the signals output from block 104.
It normalizes the weights such that the sum of the weights is 1 while maintaining the relative ratio. I.e. the normalized weight is equal to the relative weight divided by the sum of the relative weights.

Block 106: Compute downlink estimate
This block takes as input the signals output from block 101 and block 105.
It computes a downlink estimate by first multiplying the level changes output from block 101 with the associated normalized weights output from block 105. The resulting products are then summed to form the instantaneous downlink estimate.

Block 107: Low-pass filter Estimate
This block takes as input the signals output from block 106.
It produces a low-pass filtered version of the downlink estimate. The time constant is optimized (a few seconds or less) to the characteristics of the scintillation.

The best mode embodiment of the invention is shown in fig. 9. This is an enhanced version of the estimator shown in fig. 8 by adding a special event detector. The steps of the enhanced estimator are shown as blocks in fig. 9. The steps are the same as in fig. 8 except that the block 208, 209 and 210 has been augmented to the steps. These blocks detect anomalies in the TDM 31 signals and take immediate action to prevent errors to be induced in the control loop.

Block 201: High-pass filter signal levels.
The inputs are the level of the TDM 31 signals from the scanning detector 320.
Each detected TDM 31 signal level is passed through an individual high-pass filter. It takes the form of subtracting a low-pass filtered version of the signal from the signal

itself. The output represents the instantaneous change in level with respect to a longer-term mean value.

Block 208: Detect carrier presence.
The inputs are the signals from the scanning detector 320.
Each detected TDM31 signal level is compared to a pre-set threshold. If the level is above the threshold a qualifier associated with the signal is set to one, otherwise it is set to zero.

Block 202: Compute instantaneous variance.
This block takes as input the signals output from block 201 and the qualifiers from block 208. Only signals with qualifiers equal to one are processed.
It computes the difference between the change in each of the qualified signals and the mean of the changes of all the TDM 31 qualified signals. It then computes the absolute value of said difference. The said absolute value is then raised to a power of n where n typically is in the range 2 to 4 dependent on how many TDMs are available for the estimation process.

Block 203: Low-pass filter variance.
This block takes as input the signals output from block 202.
It produces a low-pass filtered version of the variance. The outputs of the filters are estimates of the current variance of each carrier with respect to the average of the TDM 31 carriers.

Block 204: Compute relative weights.
This block takes as input the signals output from block 203.
It computes a weight for each TDM 31 signal such that when multiplied by the weight, they each contribute the same variance. I.e. the relative computed weights are the inverse of the variancece computed in block 203.

Block 209: Detect abnormal carriers.
This block takes as input the signals output from block 202.
The instantaneous variance of each TDM 31 signal is compared to a pre-set threshold. If the variance of level is less than the threshold a second qualifier associated with the signal is set to one, if it is greater it is set to zero.

Block 210: Suppress abnormal carriers.
This block takes as input the signals output from block 204 and the second qualifiers from block 209. Signals with second qualifiers equal to one are passed to the output; signals with second qualifiers equal to zero are blocked from further processing.

Block 205: Normalize weights.
This block takes as input the signals output from block 210.
It normalizes the weights such that the sum of the weights is 1 while maintaining the relative ratio. I.e. the normalized weights are equal to the relative weights divided by the sum of the relative weights.

Block 206: Compute downlink estimate.
This block takes as input the signals output from block 201 and block 205.
It computes a downlink estimate by first multiplying the level changes output from block 201 with the associated normalized weights output from block 205. The resulting products are then summed to form the instantaneous downlink estimate.

Block 207: Low-pass filter Estimate.
This block takes as input the signals output from block 206.
It produces a low-pass filtered version of the downlink estimate. The time constant is optimized (a few seconds or less) to the characteristics of the scintillation.

The best mode embodiment of the present invention is to replace, in a conventional Uplink Power Control system, the usual use and configuration of the pilot signal 11 detector with a configuration including a "Multi channel Scintillation and Fading Processing Receiver". This box will together with the traditional UPC equipment perform the preferred steps of the embodiment as described in the exemplary embodiments above.

The Multi channel Scintillation and Fading Processing Receiver as shown in fig. 6 comprises carrier signal inputs 11, 31 with their respective receivers 310,320. The Analog to Digital Converter circuit 53 converts the signal levels of the carrier signals 31 and the level of the pilot signal 11 to binary form suitable for processing by the micro controller 52. The micro program running in the micro controller 52 performs the necessary steps of the invention as described above in the exemplary embodiments of the invention. The output of the micro program is fed through the Digital to Analog converter 54 to the AGC input of the UPC unit via the output means 55. The micro

program reads the pilot receiver 310 measuring the signal level of the pilot signal 11 and the RF reference 600 signal and the scanning receiver 320 measuring TDM 31 signal levels. The best way to implement the small multitasking real time program system in the micro controller 52 is to let the program measure the pilot signal 11 every 100ms to obtain continuously regulation of the power. Whilst the scanning rate of the TDMs 31 an be relaxed to be completed once per second or less.

The gateways 4 chosen to be part of the scheme (preferably at least 5) should be selected on basis of a statistical analysis based on received signal quality from a selection of possible stations 4 over a period of minimum 1 month. The stations 4 with the best signal quality should be used in the scheme to achieve the best resultant stability. The RF reference signal 600 is injected in the RF signal path by a directive RF coupler that gets its signal from a standard signal generator.

One of the main benefits of the present invention is the symmetry in the preferred embodiment when the invention is applied on several gateways in the same communication system. If we also implement this invention in a gateway 4, regarding it as gateway 3 as described in the preferred embodiment, and uses the gateway 3 as gateway 4 both gateway 3 and 4 will regulate their outbound signal power levels and thereby increase the total signal quality by regulating the signals that are used to regulate the uplink power in the communication system.

Patent Claims

1.

Method for up-link power control in a first gateway earth station (3) in a satellite communication system comprising a geostationary satellite (2) , a least two other geographically dispersed earth gateway stations (4) communicating signal carriers (30) via said satellite (2) and a plurality of user stations (5), comprising the steps of:

transmitting a first outbound signal (10) to said satellite from a first gateway (3);

receiving said first outbound signal (11) looped back from said satellite (2) in first said gateway (3) determining the said first outbound signal (10) power level;

characterized in:

receiving signal carriers (31) from at least a second gateway station (4) and at least a third gateway station (4) in the same said communication system from said satellite (2) in the first said gateway station (3), determining the signal power level of a signal (31) from said second gateway (4) and the signal power level from a signal (31) from said third gateway (4);

replacing the signal power level of any received signal (31) from said second gateway (4) or from said third gateway (4) in said first gateway (3) with a predefined nominal power value level if one of said signals (31) are below a first predefined threshold value for that said signal power level.

computing a mean value of the signal power level of the signals (31) from said second gateway station (4) and said third gateway station (4) in said first gateway station (3);

computing a first difference between said first signal (11) power level of said first outbound signal (10) from first said gateway (3) and a nominal signal power level of an outbound signal looped back from said satellite (2) to first said gateway (3);

computing a second difference between said mean signal power level of said second signal (31) from said second gateway (4) and said third signal (31) from said third

gateway (4) and a nominal mean power level of a signal from said second gateway (4) and a signal from said third gateway (4);

computing an error signal formed by the difference of the first said difference and the second said difference;

adjusting the power level of said first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.

2.
Method according to claim 1 characterized in the step of:

filtering all said received signal levels of signals (31) in said first gateway (3) that are above said first predefined threshold value with a high-pass filter of the form:

$$TMP_t = K_1 * P + (1 - K_1) * TMP_{t-1}$$

$$P'_t = P - TM\ P_t$$

where TMP_t is a temporary variable at a current time t, K_1 is a coefficient set to be between 0 and 1, P is the current measured power of signal (11,31) the gateway (3) is receiving at time t, TMP_{t-1} is the previous sample value of the temporary variable TMP and P'_t is the desired high-pass filter value of said signal power level (31).

3.
Method according to claim 2 further characterized in the step of:

replacing the output of the said high-pass filter with zero if said received level of signal (31) is below said first threshold value.

4.
Method according to claim 1 characterized in the step of:

replacing the current received signal power level (31) with a constant nominal value in the averaging process if the received signal power level (31) deviates from the current

average signal power level of said second received power level signal (31) and said third power level signal (31) with more than a second predefined threshold value.

5.

Method according to claim 1 characterized in the step of:

low-pass filtering the mean value of the signal level of said second signal (31) from said second gateway (4) and the signal level of said third signal (31) from the said third gateway (4) with a low-pass filter of the form:

$$D'_t = K_2 * D + (1 - K_2) * D'_{t-1}$$

if a third difference between said current mean value and the said mean value of one processing step earlier is below a third threshold value; and where D'_t is the filter output at the current sample time t; K_2 is a parameter set to a first value of two different values between 0 and 1 depending on the absolute rate of change of the third difference being above or below the said predefined third threshold value; D is the prevailing said third difference and D'_{t-1} is the mean value of one processing step earlier.

6.

Method according to claim 5 further characterized in the step of:

replacing said parameter K_2 with a second value between 0 and 1 if said mean value exceeds said third threshold value to enable tracking of scintillations.

7.

Method according to claim 1, 5 or 6 characterized in the steps of:

computing a fourth difference between an injected reference signal level and said signals nominal value of the signal level; and

computing an error signal formed by the difference between said low-pass filtered signals said third difference and said fourth difference; and

adjusting the power level of said first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.

8.

Device for up-link power control in a first gateway earth station (3) in a satellite communication system comprising a geostationary satellite (2) , a least two other geographically dispersed earth gateway stations (4) communicating signal carriers (30) via said satellite (2) and a plurality of user stations (5), comprising:

means for transmitting a first outbound signal (10) to said satellite from a first gateway (3);

means for receiving said first outbound signal (11) looped back from said satellite (2) in first said gateway (3) determining the said first outbound signal (10) power level;

characterized in:

means for receiving signal carriers (31) from at least a second gateway station (4) and at least a third gateway station (4) in the same said communication system from said satellite (2) in the first said gateway station (3), determining the signal power level of a signal (31) from said second gateway (4) and the signal power level from a signal (31) from said third gateway (4);

means for replacing the signal power level of any received signal (31) from said second gateway (4) or from said third gateway (4) in said first gateway (3) with a predefined nominal power value level if one of said signals (31) are below a first predefined threshold value for that said signal power level.

means for computing a mean value of the signal power level of the outbound signals (31) from said second gateway station (4) and said third gateway station (4) in said first gateway station (3);

means for computing a first difference between said first signal (11) power level of said first outbound signal (10) from first said gateway (3) and a nominal signal power level of an outbound signal looped back from said satellite (2) to first said gateway (3);

means for computing a second difference between said mean signal power level of said second signal (31) from said second gateway (4) and said third signal (31) from said third gateway (4) and a nominal mean power level of a signal from said second gateway (4) and a signal from said third gateway (4);

means for computing an error signal formed by the difference of first said difference and second said difference;

means for adjusting the power level of said first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.

9.

Device according to claim 8 characterized in:

means for filtering all said received signal levels of signals (31) in said first gateway (3) that are above said first predefined threshold value with a high-pass filter of the form:

$$TMP_t = K_1 * P + (1 - K_1) * TMP_{t-1}$$

$$P'_t = P - TM\ P_t$$

where TMP_t is a temporary variable at a current time t, K_1 is a coefficient set to be between 0 and 1, P is the current measured power of signal (31) the gateway (3) is receiving at time t, TMP_{t-1} is the previous sample value of the temporary variable TMP and P'_t is the desired high-pass filter value of said signal power level (31).

10.

Device according to claim 9 further characterized in:

means for replacing the output of the said high-pass filter with zero if said received level of signal (31) is below said first threshold value.

11.
Device according to claim 8 characterized in:

means for replacing the current received signal power level (31) with a constant nominal value in the averaging process if the received signal power level (31) deviates from the current average signal power level of said second received power level signal (31) and said third power level signal (31) with more than a second predefined threshold value.

12.
Device according to claim 8 characterized in:

means for low-pass filtering the mean value of the signal level of said second signal (31) from said second gateway (4) and the signal level of said third signal (31) from the said third gateway (4) with a low-pass filter of the form:

$$D'_t = K_2 * D + (1 - K_2) * D'_{t-1}$$

if a third difference between said current mean value and the said mean value of one processing step earlier is below a third threshold value; and where D'_t is the filter output at the current sample time t; K_2 is a parameter set to a first value of two different values between 0 and 1 depending on the absolute rate of change of the third difference being above or below the said predefined third threshold value; D is the prevailing said third difference and D'_{t-1} is the mean value of one processing step earlier.

13.
Device according to claim 11 further characterized in:

means for replacing said parameter K_2 with a second value between 0 and 1 if said mean value exceeds said third threshold value to enable tracking of scintillations.

14.
Device according to claim 8, 12 or 13 characterized in:

means for computing a fourth difference between an injected reference signal level and said signals nominal value of the signal level; and

means for computing an error signal formed by the difference between said low-pass filtered signals said third difference and said fourth difference; and

means for adjusting the power level of said first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.

15.

Method for up-link power control in a first gateway earth station (3) in a satellite communication system comprising a geostationary satellite (2), a least three other geographically dispersed earth gateway stations (4) communicating signal carriers (30) via said satellite (2) and a plurality of user stations (5), comprising the steps of:

transmitting a first outbound signal (10) to said satellite from a first gateway (3);

receiving said first outbound signal (11) looped back from said satellite (2) in first said gateway (3) determining the said first outbound signal (10) power level;

characterized in:

receiving signal carriers (31) from at least a second gateway station (4) and at least a third gateway station (4) in the same said communication system from said satellite (2) in the first said gateway station (3), filtering any received signal (31) in an individual high pass filter of the form of subtracting a low pass filtered version of the signal from the signal itself producing an instantaneous change level signal;

compute an absolute change level signal by subtracting the said instantaneous change level signal from a mean of the changes of the changes of all the signal carriers (31), and compute an absolute value of said difference;

compute a variance for each of said signals (31) by raising the absolute value change level signal for each signal to a power in a range of 2 to 5 and filter the result in a lowpass filter.

compute a weight for each signal by taking the inverse of said variance such that when multiplied by the weight, each signal contributes the same variance;

compute a normalized weight for each said signals such that the sum of said normalized weights equal 1;

compute a downlink estimate by first multiplying said instantaneous change level signal with the associated normalized weight and sum all said products to form an instantaneous downlink estimate;

compute an error signal formed as a difference between said instantaneous downlink estimate and a received looped back pilot signal 11 and a RF reference signal;

adjusting the power level of sa first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.

16.
Device for up-link power control in a first gateway earth station (3) in a satellite communication system comprising a geostationary satellite (2), a least three other geographically dispersed earth gateway stations (4) communicating signal carriers (30) via said satellite (2) and a plurality of user stations (5), comprising:

mans for transmitting a first outbound signal (10) to said satellite from a first gateway (3);

means for receiving said first outbound signal (11) looped back from said satellite (2) in first said gateway (3) determining the said first outbound signal (10) power level;

characterized in:
means for receiving signal carriers (31) from at least three other gateway station (4) in the same said communication system from said satellite (2) in the first said gateway station (3), filtering any received signal (31) in an individual high pass filter of the form of subtracting a low pass filtered version of the signal from the signal itself producing an instantaneous change level signal;

means for computing a change level signal by subtracting said instantaneous change level signal from a mean of the changes of all the signal carriers (31) and computing an absolute value of said difference.

means for computing a variance for each of said signals (31) by raising the absolute value change level signal for each signal to a power in a range of 2 to 5 and filter the result in a lowpass filter.

means for computing a weight for each signal by taking the inverse of said variance such that when multiplied by the weight, each signal contribute the same variance; means for computing a normalized weight for each said signals such that the sum of said normalized weights equal 1;

means for computing a downlink estimate by first multiplying said instantaneous change level signal with the associated normalized weight and sum all said products to form an instantaneous downlink estimate;

means for lowpass filtering said downlink estimate;

means for computing an error signal formed as a difference between said instantaneous downlink estimate and a received looped back pilot signal 11 and a RF reference signal;

means for adjusting the power level of said first gateway stations (3) outbound signals an amount based on said error signal within the permissible range of said power level.