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United States Patent
Gross , et al.

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Apparatus and methods for controlling a cellular communications network having airborne transceivers

Abstract

A cellular communications network (200, FIG. 2) includes one or more aircraft (210), which provide communication channels to cellular communications units, and also communicate with one or more base transceiver stations (206) and a control center (214). The control center receives (502, 602) telemetry and flight parameter information from the aircraft, and calculates (510, 606) network parameters based on the information. The control center transmits (512, 608) messages to the cellular network, including the aircraft, based on the calculated network parameters, and the aircraft and cellular network controls (612) its operations according to information within these messages.

Inventors: **Gross; Jonathan H.** (Gilbert, AZ), **Emmons, Jr.; Thomas Peter** (Mesa, AZ), **Tessler; Michael A.** (Plano, TX)

Assignee: **Motorola, Inc.** (Schaumburg, IL)

6. The method as claimed in claim 1, wherein sending the message to the device comprises sending the message to a mobile switching office (MSO) within the cellular communications network, wherein the MSO uses information within the message to control the operations of one or more BTS.
7. The method as claimed in claim 1, wherein sending the message to the device comprises sending the message to the aircraft, wherein the aircraft uses information within the message to control the operations of the aircraft.
8. The method as claimed in claim 1, wherein calculating one or more network parameters comprises calculating a table of network parameters, wherein each entry in the table corresponds to a location of the aircraft along a flight pattern.
9. The method as claimed in claim 8, wherein calculating the table of network parameters comprises indexing each entry based on a radial location of the aircraft along the flight pattern.
10. The method as claimed in claim 1, wherein sending the message to the device comprises transmitting the message to the payload, wherein the payload uses the message to control operations of the payload.
11. The method as claimed in claim 10, wherein the aircraft uses the message to control a communication parameter of a cellular beam pattern provided by the payload.
12. A method for controlling operations of a cellular communications network, the method comprising: collecting information relevant to flight parameters of an aircraft in flight, wherein the aircraft carries a payload that provides communication channels to multiple cellular communication units via a cellular beam pattern, and also communicates with at least one base transceiver station of the cellular communications network; and transmitting the information to a control center, wherein the control center calculates one or more network parameters based on the information, and sends the one or more network parameters to a device within the cellular communications network, and wherein the device uses the one or more network parameters to control operations of the device.

access (TDMA, e.g. IS-136, GSM), code division multiple access (CDMA, e.g. IS95), or other type of digital or analog communication protocol.

BTS 103 also are coupled to a mobile switching office (MSO) 110. This can be a direct connection (e.g., using fiber optic or telephone (e.g., T1) links 105), or the connection 108 can be chained through other BTS.

When data originates from or is destined for a public switched telephone network (PSTN, not shown), this data is routed through a mobile switching office (MSO) 110. Essentially, the MSO 110 includes a switch that interfaces the cellular network and the PSTN.

Network 110 is optimized via various performance parameters. For example, these performance parameters include power control parameters, handoff parameters (e.g., thresholds, averaging parameters, and hysteresis), access parameters (e.g., the minimum received signal level required before a communication unit is granted access to the system), handoff candidate information for neighboring cells, and the designation of which channels are control channels and which are traffic channels.

In a well-designed network, these performance parameters are selected to achieve near optimal network performance. Usually, these performance parameters are determined only when major changes in the network configuration occur, such as during network installation or when additional cell sites are added (e.g., to improve network coverage or capacity). In a terrestrial network, thus, the network optimization process is relatively static. This is considered acceptable, because the network infrastructure and communications quality are considered to be relatively stable. The infrastructure is geographically fixed in a terrestrial cellular network, and the communications quality is not substantially affected by or the system design considers variables such as weather (e.g., thunderstorms, high winds).

In order to increase capacity in a terrestrial cellular network, additional BTS must be added to the network. Adding such additional equipment may take weeks or months, and in some cases it is impossible to incorporate new equipment into an existing infrastructure. Therefore, prior art terrestrial networks cannot rapidly respond to a level of user demand that exceeds the network's then-current capacity. . . .

new flight pattern or may affect the aircraft's attitude. These conditions could make it impossible for the aircraft to maintain continuous coverage over the geographic area using the same flight pattern. In addition, some of the conditions may cause the aircraft to project beams into other areas where RF energy from such beams is not desired.

In one embodiment, each aircraft 306 sends information to the control center indicating the aircraft flight parameters. In addition, the control center receives information directly from a weather center regarding current and predicted weather conditions within an area serviced by an aircraft. Using the parameters and weather information, the control center can communicate with the terrestrial network to alter network parameters in order to achieve optimal network performance.

In various embodiments of the present invention, the network takes flight parameter deviations caused by weather, ATC, and other factors into account by rapidly adjusting network parameters. These adjusted network parameters are distributed to the relevant network devices, which adjust their operations accordingly. In addition, the network is able to adjust the network parameters when the status of a network subsystem has changed and caused network performance to be degraded. In this manner, the network is able to maintain network operations at an optimal or near optimal level at all times.

Essentially, the network of the various embodiments consumes information regarding the aircraft's flight pattern and attitude, and information regarding subsystem status (e.g., the status of the network's various receivers, amplifiers, transmitters, antennas, etc.). From this information, the network adjusts various tunable network parameters to minimize the impact of varying coverage, handoff characteristics, and subscriber link performance experienced when using the airborne segment of the network. For example, these performance parameters include power control parameters, handoff parameters (e.g., thresholds, averaging parameters, and hysteresis), access parameters (e.g., the minimum received signal level required before a communication unit is granted access to the system), handoff candidate information for neighboring cells, and the designation of which channels are control channels and which are traffic channels.

Below is a list of several ways in which the network adjusts network parameters in order to optimize

Occasionally, the aircraft's pilot will communicate with ATC 414, over wireless RF link 416, and receive instructions and other information. ATC 414 is not part of network 400, but the aircraft pilot is required to follow its instructions. Often, these instructions are to alter the aircraft's flight pattern and velocity, among other things. In some cases, the pilot will key in the new flight pattern and velocity into an autopilot system, which forms a part of AFMS 410.

Besides the autopilot system, AFMS 410 includes GPS equipment, avionics equipment, data collection equipment, and control equipment, in one embodiment. In other embodiments, AFMS 410 may include more, fewer or different elements. Essentially, AFMS 410 measures and controls the aircraft's flight parameters.

Aircraft payload 412 collects, from AFMS 410, information relevant to the aircraft's flight parameters, and periodically transmits that information to control center 404 over RF link 418, in one embodiment. This flight parameter information could be an entire or partial description of the aircraft flight pattern, position, attitude or flight characteristics, describing the current or desired future state of the aircraft.

The aircraft position includes the aircraft's altitude, latitude, longitude, and/or other information (e.g., distance or direction from a landmark). The aircraft attitude includes the aircraft's roll, pitch, and/or yaw angles. Finally, the flight characteristics include the aircraft's velocity, heading, acceleration, and/or roll, pitch, and yaw rates.

In addition to collecting and transmitting flight parameter information to control center 404, aircraft payload 412 also provides communication channels to multiple cellular communication units 420 over RF links 422. As described previously, cellular communication units 420 send and receive data over wireless link 422 at a particular cellular frequency (e.g., in a range of about 800-1800 MHz) and using a particular cellular communication protocol (e.g., TDMA, CDMA, GSM or others). Aircraft payload 412 communicates this user data to one or more ART 424, via RF link 426. In one embodiment, as described previously, the information exchanged over link 426 is transmitted at a higher frequency (e.g., in a range of about 3-8 GHz) than the information exchanged over link 422.

parameters.

For example, based on flight pattern information received from aircraft 402, SS&C 430 may determine that aircraft 402 should alter one or more flight parameters or alter the cellular beam pattern provided by its payload. Upon the aircraft's receipt of a control message from SS&C 430, aircraft 402 would respond by altering the appropriate flight parameter or cellular beam pattern, in accordance with the message. If aircraft 402 has altered a flight parameter as a result, aircraft 402 may transmit additional information to the control center 404 describing the new flight parameter.

In addition to sending messages derived from the network parameters to various network devices, SS&C 430 also determines, from the flight parameter and telemetry information, whether a maintenance operation should be performed on one of the network's devices. If so, then SS&C 430 sends a message describing the maintenance issue to an entity that schedules such maintenance operations. In one embodiment, this entity is the OMC 434, although it could be some other entity in another embodiment. For example, aircraft 402 could have sent a telemetry message to control center 404 indicating that a payload receiver has become non-functional. Upon receipt of this information, SS&C 430 would send a message to a maintenance entity to schedule repair of the aircraft's receiver. These maintenance operations could be scheduled for many pieces of equipment within the network's elements, including the aircraft 408, AFMS 410, payload 412, BTS 436, ART 424, and base station antenna 440.

As mentioned previously, SS&C 430 sends control messages to aircraft 402, and also to elements of the terrestrial network 406. In one embodiment, in order to affect the operations of one or more BTS 436, SS&C 430 sends control messages to MSO 438. MSO 438 in turn uses information within the control messages to control operations of one or more of the BTS 436. In some cases, MSO 438 sends the control message directly to BTS 436. In other cases, MSO 438 may evaluate the control message, and derive a modified control message to send to BTS 436.

When BTS 436 receives the original or modified control message from MSO 438, BTS 436 uses information within the message to control its operations. BTS 436 may receive the control message over a wired link or over a wireless link via base station antenna 440. In other embodiments, BTS 436 may

A coverage change could include, for example, a movement of the coverage footprint such that all or a portion of the geographic area that the aircraft is supposed to cover is not covered. This may occur, for example, if the aircraft is forced to change its flight pattern due to ATC commands, control center commands, evasive maneuvers, and/or weather events.

In addition, a coverage change could occur if the aircraft changes its attitude. For example, if the aircraft is forced to roll, pitch or yaw due to wind, turbulence or other factors, the beam pattern could be projected into a different direction from the intended direction. In addition, turbulence might introduce additional frequency modulation on the subscriber links. And, an aircraft that is rolling (e.g., due to wind conditions) could induce rapid changes in signal strength, causing a user to be rapidly handed off between the aircraft's adjacent beams. The various weather factors could result in poor communication quality, a lack of coverage in some areas, and the projection of beams into areas where their RF energy is not intended.

A coverage change also could occur if a subsystem or component failure impacts the coverage capability of the aircraft, as described briefly in conjunction with blocks 504 and 506. If an aircraft experiences a coverage degradation, that gap is swept over a potentially very large geographical area as the aircraft executes its flight pattern.

If no performance or coverage impact has been encountered, the method continues to iterate as shown in FIG. 5. If a performance or coverage impact has resulted from the subsystem status change, then the control center calculates new network parameters, in block 510. New network parameters could apply to the operations of the aircraft payload, BTS, ART, and base station antennas, among other subsystems.

In block 512, the control center sends a message derived from the new network parameters to the appropriate device. If the new network parameters apply to other network subsystems, then the control center would send the message to the devices associated with those subsystems, as well. For example, if the new network parameters applied to the BTS, then the control center would send the message to the MSO, which in turn would create one or more messages to affect the BTS operations.

When the control message is received, in block 514, by the appropriate device or devices, then that device or those devices control their operations using the information within the message, in block 516. As mentioned previously, this could mean that the device alters its power control, handoff or acquisition processes, to name a few examples. The method then iterates as shown in FIG. 5.

While FIG. 5 illustrates a relatively generic method for calculating network parameters, FIGS. 6-8 illustrate various embodiments of the method shown in FIG. 5 for specific network parameters. In particular, FIG. 6 illustrates a flowchart of a method for changing handoff parameters, when appropriate, in accordance with one embodiment of the present invention.

As an aircraft experiences roll, pitch, and/or yaw, variations in the projected beam pattern occur. These variations can cause an excessive handoff rate, meaning that cellular units on the ground are handed off with more frequency than they would be if the aircraft were not experiencing the unplanned roll, pitch, and/or yaw characteristics. In one embodiment, the effects on the beam pattern due to roll, pitch, and/or yaw characteristics are mitigated, by measuring aircraft flight parameters, and tuning associated network parameters (e.g., handoff hysteresis and handoff threshold parameters) based on calculations using these measurements.

The method begins, in block 602, by the control center receiving telemetry information, which specifically includes the aircraft flight characteristics (i.e., roll, pitch, yaw, and/or the rates of each of these flight characteristics). From this information, the control center calculates the link margin variation due to the aircraft's instability, in block 604. The control center then uses the calculated link margin variation, in block 606, to calculate the impact of the varying flight characteristics on the handoff rate. Typically, the less stable the aircraft roll, pitch, and yaw angles and rates, the greater the link margin variation and the greater the handoff rate. For example, an aircraft could be flying through severe turbulence, which causes the signal power to fluctuate dramatically and handoffs to occur with excessive frequency.

In one embodiment, the network determines that a handoff is warranted based on at least two handoff parameters. Thus, the handoff rate also is related to these two parameters. These handoff parameters include handoff hysteresis and handoff threshold. The handoff threshold parameter indicates that a

handoff to another beam should not occur unless the other beam's control channel power is at or above a certain threshold signal strength.

Used in conjunction with the handoff threshold parameter, the handoff hysteresis parameters is based on signal strength, time or other factors. Instead of always handing off to the strongest beam, a hysteresis parameter could indicate that a handoff should occur only if another beam's strength is some amount of decibels stronger than the beam that the communication unit is currently using. Additionally or alternatively, a hysteresis parameter could indicate that a communication unit that has just handed off to another beam must wait some period of time before it can be handed off again. In other embodiments, more, fewer or different handoff parameters could be used to determine whether a handoff is warranted.

Referring back to FIG. 6, a determination is made, in block 608, whether the predicted handoff rate warrants a change in the then-current handoff parameters. A positive determination is made, in one embodiment, if the handoff rate exceeds a threshold. If no change in the handoff parameters is warranted, then the method iterates to block 602 as shown.

If a change in the handoff parameters is warranted, then the control center calculates new handoff hysteresis and/or threshold parameters, in block 610. The new handoff parameters are calculated so that the handoff rate will be within an acceptable range. In some cases, the parameters could be calculated to increase the handoff rate, and in other cases, the parameters could be calculated to decrease the handoff rate.

In block 612, the control center sends, to the MSO, a control message that includes the new handoff parameters. After the MSO receives the message, in block 614, the MSO controls operations of one or more BTS using the new handoff parameters, in block 616. Specifically, the MSO allows handoffs between BTS only when the new handoff parameters indicate that a handoff should occur. The method then iterates as shown.

In an alternative embodiment, the parameters may control the configuration of the aircraft payload also. In this case these new parameters are transmitted to the payload to be implemented. In another alternative

embodiment, this information can also be used to modify the operation of the flight pattern. By adjusting the location of the flight pattern, better cellular performance may be obtained.

Besides controlling operations using handoff parameters, the network also controls some operations using MAPT (minimum acquisition power threshold) parameters, as described previously. FIG. 7 illustrates a flowchart of a method for changing MAPT parameters, when appropriate, in accordance with one embodiment of the present invention.

Again, as the aircraft experiences roll, pitch, and/or yaw flight characteristics, the variations in the projected beam pattern may cause an excessive fluctuation in signal power or link margin. In addition, changing the aircraft's flight pattern (e.g., flying a circular pattern with a larger radius) could also change the link margin variation over an iteration of the flight pattern.

These variations can result in an excessive dropped call rate (i.e., the rate at which communication units in the process of a call are dropped). In one embodiment, an excessive dropped call rate due to an altered flight pattern and/or the aircraft's flight characteristics is mitigated by measuring aircraft flight parameters, including the flight pattern itself, and tuning the MAPT parameter based on calculations using these measurements.

The method begins, in block 702, by the control center receiving telemetry information, which specifically includes the aircraft flight characteristics. In addition, the control center receives or maintains data describing the aircraft flight pattern. From this information, the control center calculates the link margin variation over one or more revolutions of the flight pattern, in block 704. The control center then uses the calculated link margin variation, in block 706, to calculate the impact of the varying flight characteristics and/or flight pattern on the dropped call rate. Typically, the less stable the aircraft roll, pitch, and yaw angles and rates, the greater the link margin variation and the greater the dropped call rate. For example, as with handoffs, if an aircraft is flying through severe turbulence, the signal power will fluctuate dramatically, and calls are likely to be dropped with excessive frequency.

A determination is made, in block 708, whether the predicted dropped call rate warrants a change in the

then-current MAPT parameters. A positive determination is made, in one embodiment, if the dropped call rate exceeds a threshold. If no change in the MAPT parameters is warranted, then the method iterates as shown.

If a change in the MAPT parameters is warranted, then the control center calculates new MAPT parameters, in block 710. The new MAPT parameters are calculated so that the dropped call rate will be within an acceptable range. In some cases, the parameters could be calculated to increase the dropped call rate, and in other cases, the parameters could be calculated to decrease the dropped call rate.

In one embodiment, the MAPT parameters are calculated for one whole revolution around the aircraft flight pattern, and a table is generated for parameters versus aircraft location. The table uses the radial location of the aircraft on the circular pattern as its index, in one embodiment, although other indexes could be used in other embodiments. During operation, the MSO determines where the aircraft is via the telemetry link, reads the table entry corresponding to that location, and sends the proper parameters to one or more of the BTS. As the aircraft circles around, the MSO cycles through this table. This process is described in more detail in conjunction with FIG. 9. In block 712, the control center sends, to the MSO, a control message that includes the new MAPT parameters (or a table, as described above). After the MSO receives the message, in block 714, the MSO controls operations of one or more BTS using the new MAPT parameters, in block 716. Specifically, the MSO allows users to access the network only when their acquisition power meets or exceeds the MAPT. The method then iterates as shown.

In an alternative embodiment, the parameters may control the configuration of the aircraft payload also. In this case these new parameters are transmitted to the payload to be implemented. In another alternative embodiment, this information can also be used to modify the operation of the flight pattern. By adjusting the location of the flight pattern, better cellular performance may be obtained.

Another parameter that the network can tune to optimize its performance is the control channel power level. FIG. 8 illustrates a flowchart of a method for changing a control channel power parameter, when appropriate, in accordance with one embodiment of the present invention.

could be calculated to increase the control channel power, thus effectively increasing the size of the beam and the number of subscribers the beam may be called on to support. In other cases, the parameters could be calculated to decrease the control channel power, thus effectively decreasing the size of the beam and the number of subscribers the beam may be called on to support.

In one embodiment, the control channel power parameters are calculated for one whole revolution around the aircraft flight pattern, and a table is generated for parameters versus aircraft location. This is similar to the process, described in conjunction with FIG. 7, of calculating multiple MAPT parameters based on aircraft location. This process is described in more detail in conjunction with FIG. 9.

In one embodiment, the control channel power parameters for each beam are time varying, meaning that the parameters may change during a revolution of the aircraft around its flight pattern. In another embodiment, the parameter for each beam is fixed for the duration of the flight pattern.

In block 812, the control center sends, to the MSO, a control message that includes the new control channel power parameters. After the MSO receives the message, in block 814, the MSO controls operations of one or more BTS using the new control channel power parameters, in block 816. The method then iterates as shown.

In an alternative embodiment, the parameters may control the configuration of the aircraft payload also. In this case these new parameters are transmitted to the payload to be implemented. In another alternative embodiment, this information can also be used to modify the operation of the flight pattern. By adjusting the location of the flight pattern, better cellular performance may be obtained.

FIG. 9 illustrates a flowchart of a method for using a parameter table to determine parameters based on aircraft location in accordance with one embodiment of the present invention. The method begins, in block 902, by receiving telemetry, as is described in conjunction with block 702 (FIG. 7) or block 802 (FIG. 8), above. In one embodiment, the telemetry indicates the aircraft's location. In block 904, the location is converted to radial coordinates. The parameters associated with those coordinates are then identified in the parameter table, in block 906. A determination is made, in block 908, whether the newly calculated

handoffs also could occur and control channels also could be provided in various cells or sectors.

This application is intended to cover any adaptations or variations of the present invention that fall within its scope. The foregoing detailed description, therefore, is not to be taken in a limiting sense, and it will be readily understood by those skilled in the art that various changes in the details, materials, and arrangements of the parts and operations which have been described and illustrated in order to explain the nature of this invention may be made without departing from the spirit and scope of the invention as expressed in the appended claims.

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