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(54) IDENTIFYING STARTING TIME FOR MAKING TIME OF ARRIVAL MEASUREMENTS

(76) Inventors: **Erik Larsson**, Kista (SE); **Ari Kangas**, Uppsala (SE); **Sven Fischer**, Nurnberg (DE)

Correspondence Address:
JENKENS & GILCHRIST, P.C.
Suite 3200
1445 Ross Avenue
Dallas, TX 75202-2799 (US)

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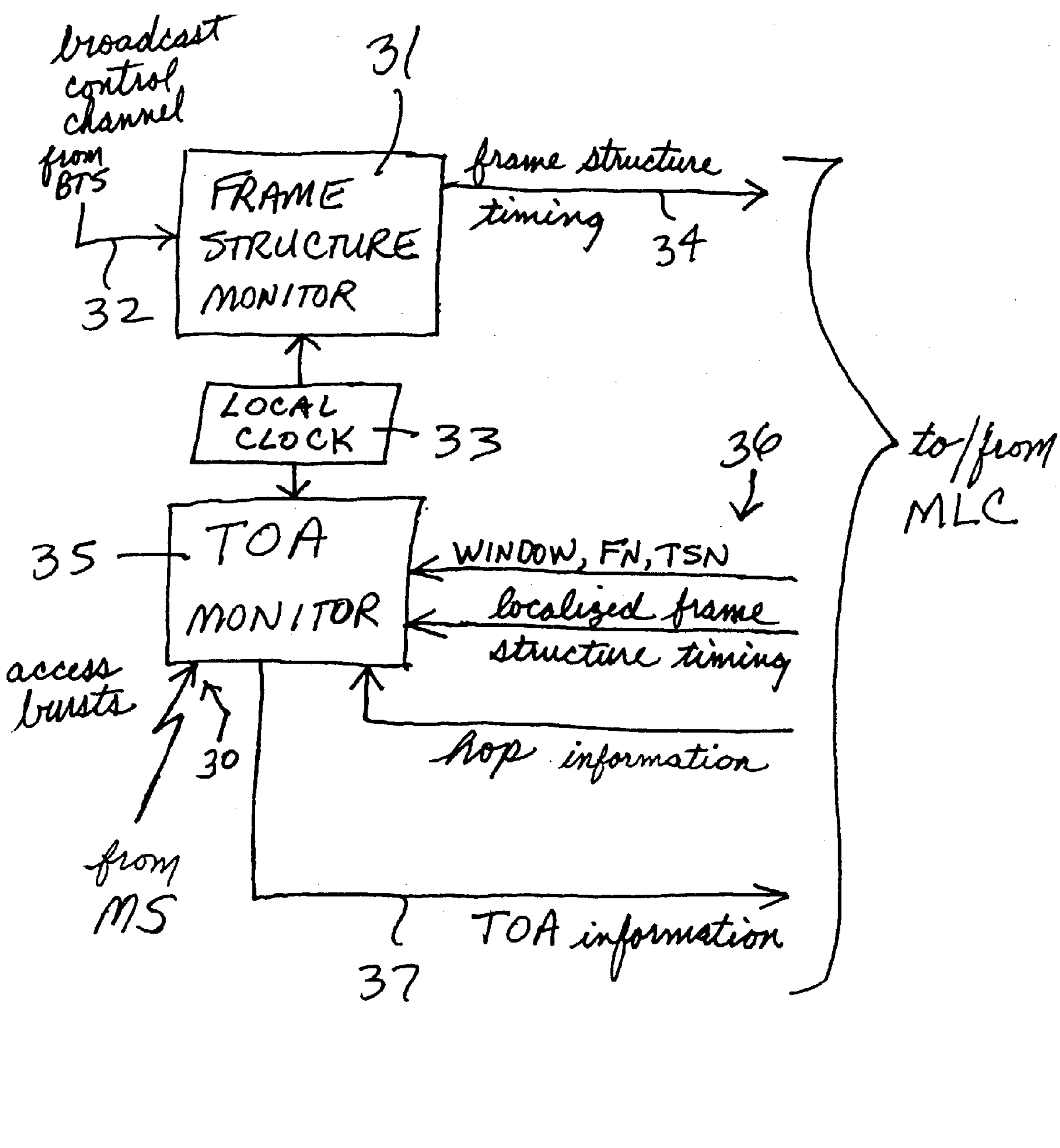
(57) **ABSTRACT**

A time of arrival measurement apparatus is used to measure the time of arrival of a radio signal transmitted by a mobile communication station operating in a wireless mobile communication network. The apparatus is provided with information indicative of a predetermined point in time at which the radio signal is to be transmitted. The time of arrival measurement apparatus monitors for arrival of the radio signal only during a period of time after the predetermined point in time.



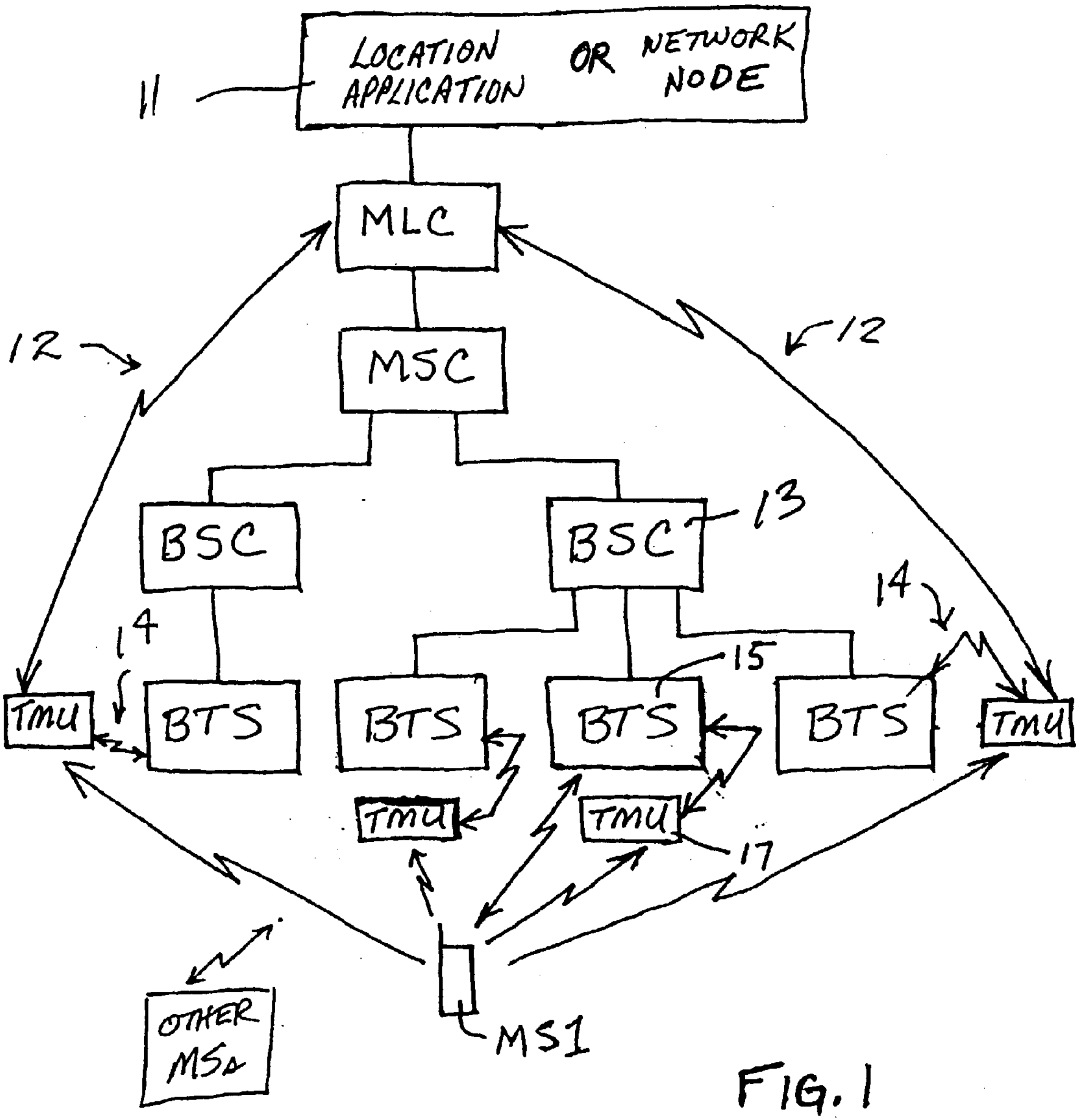

LOCATION APPLICATION OR NETWORK NODE
11
MLC
MSC
12
12
BSC
BSC
13
14
14
15
TMU
BTS
BTS
BTS
BTS
TMU
TMU
TMU
17
OTHER MSs
MS1

FIG. 1

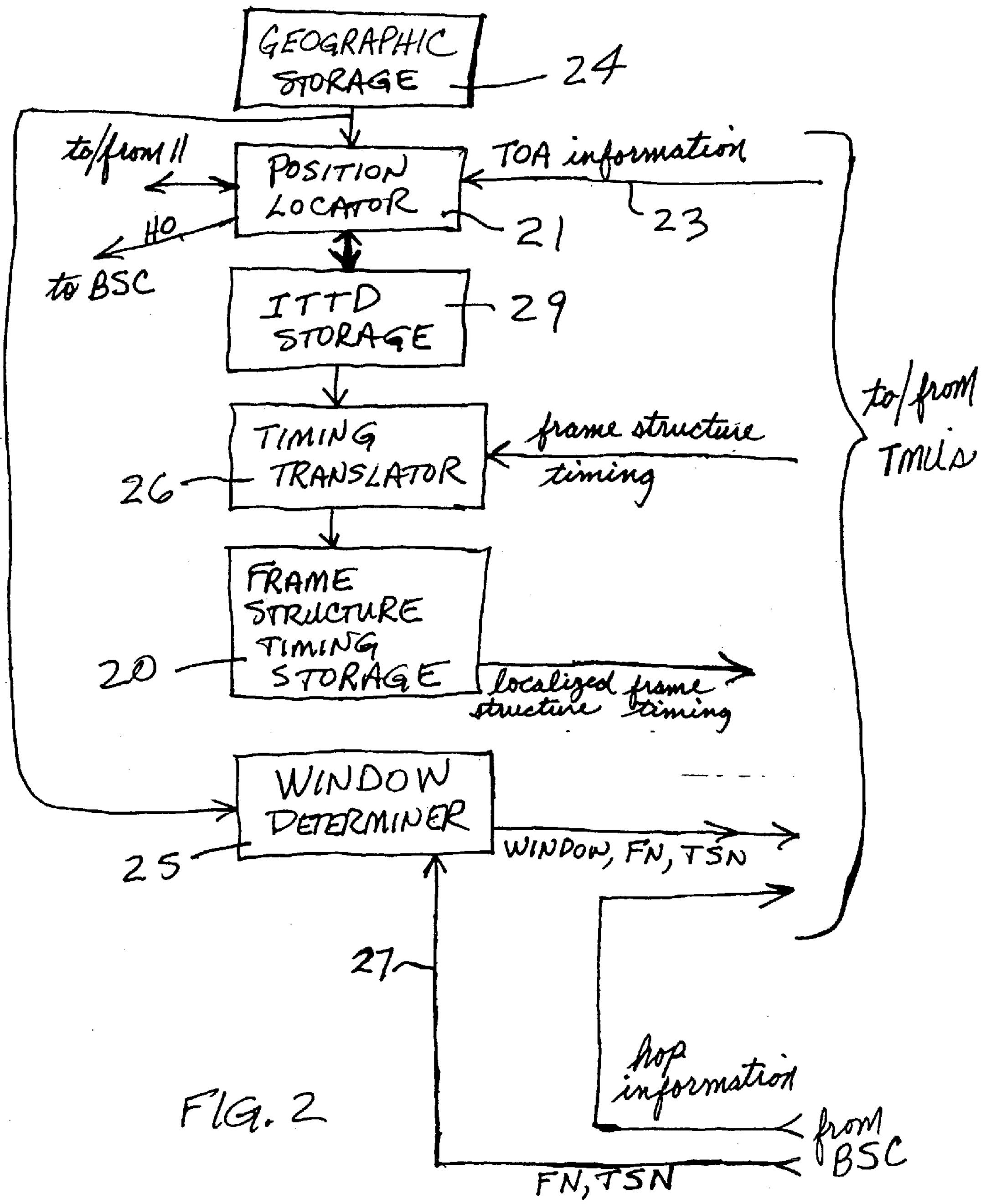

GEOGRAPHIC STORAGE
24
to/from 11
POSITION LOCATOR
TOA information
HO
to BSC
21
23
ITTD STORAGE
29
TIMING TRANSLATOR
frame structure timing
26
to/from TMUs
FRAME STRUCTURE TIMING STORAGE
20
localized frame structure timing
WINDOW DETERMINER
25
WINDOW, FN, TSN
27
hop information
from BSC
FN, TSN

FIG. 2

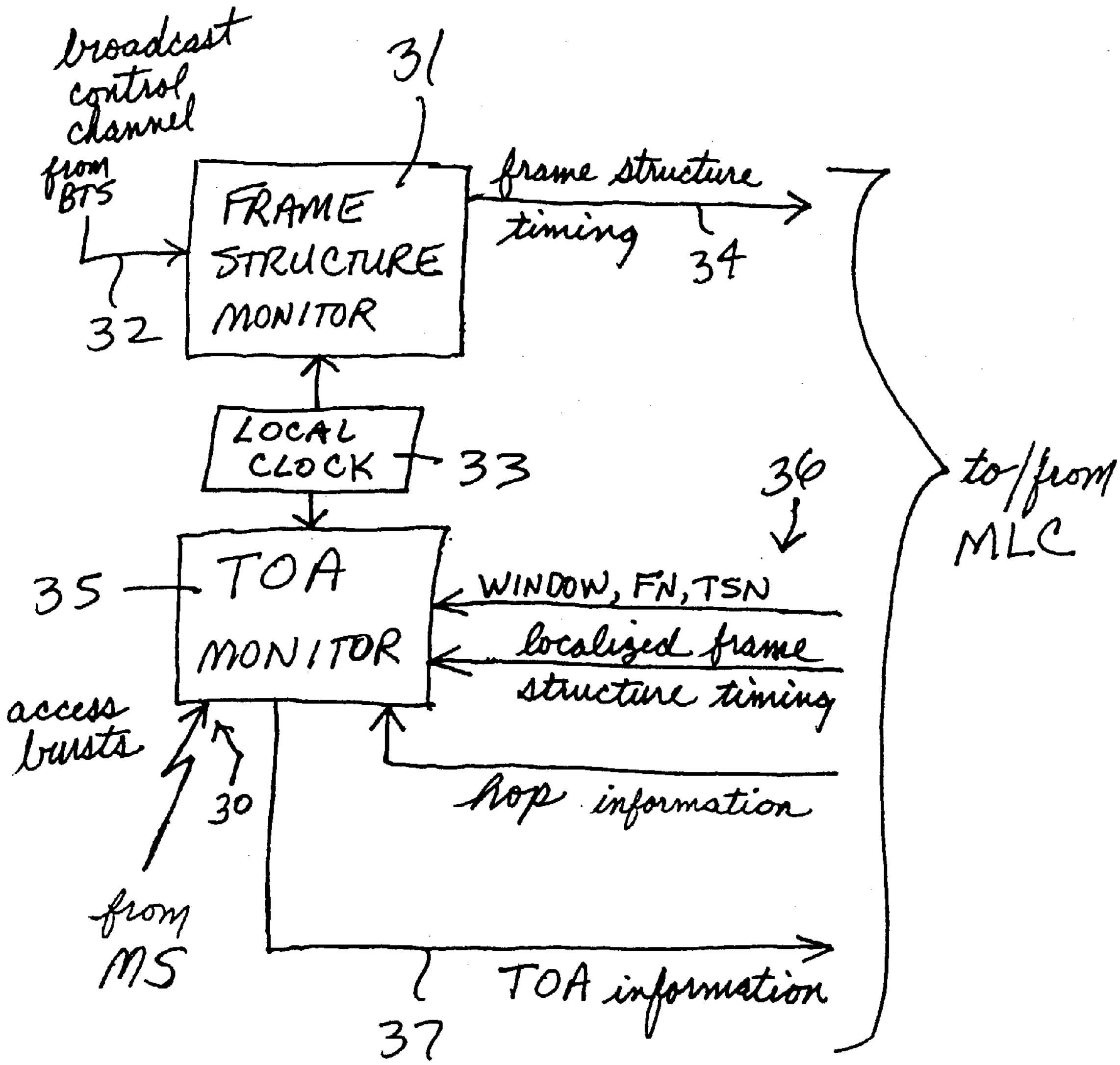

broadcast control channel from BTS
31
FRAME STRUCTURE MONITOR
frame structure timing
34
32
LOCAL CLOCK
33
36
to/from MLC
35
TOA MONITOR
WINDOW, FN, TSN
localized frame structure timing
access bursts
30
hop information
from MS
TOA information
37

FIG. 3

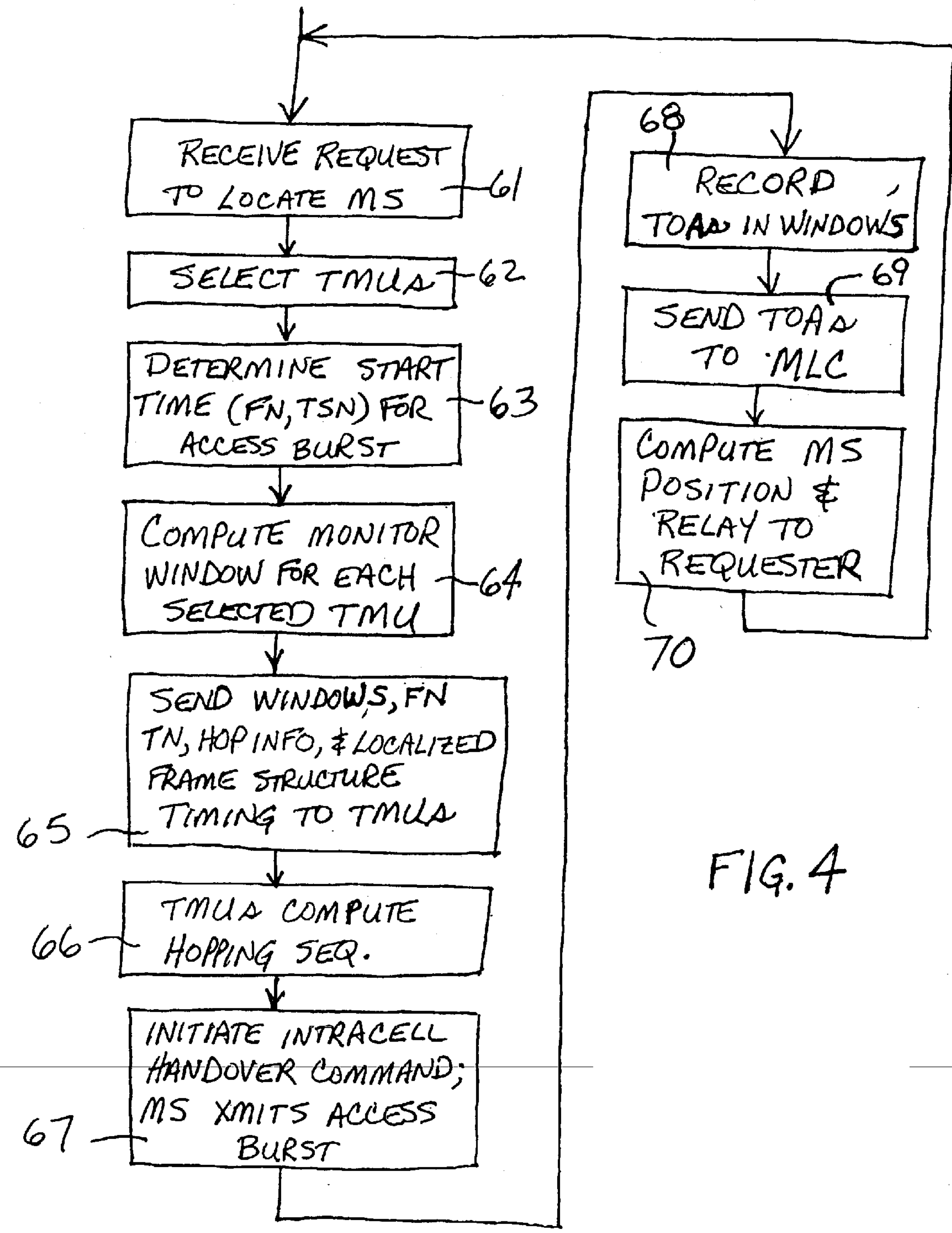

RECEIVE REQUEST TO LOCATE MS
61
SELECT TMUs
62
DETERMINE START TIME (FN, TSN) FOR ACCESS BURST
63
COMPUTE MONITOR WINDOW FOR EACH SELECTED TMU
64
SEND WINDOWS, FN TN, HOP INFO, & LOCALIZED FRAME STRUCTURE TIMING TO TMUs
65
TMUs COMPUTE HOPPING SEQ.
66
INITIATE INTRACELL HANDOVER COMMAND; MS XMITS ACCESS BURST
67
68
RECORD TOAs IN WINDOWS
SEND TOAs TO MLC
69
COMPUTE MS POSITION & RELAY TO REQUESTER
70

FIG. 4

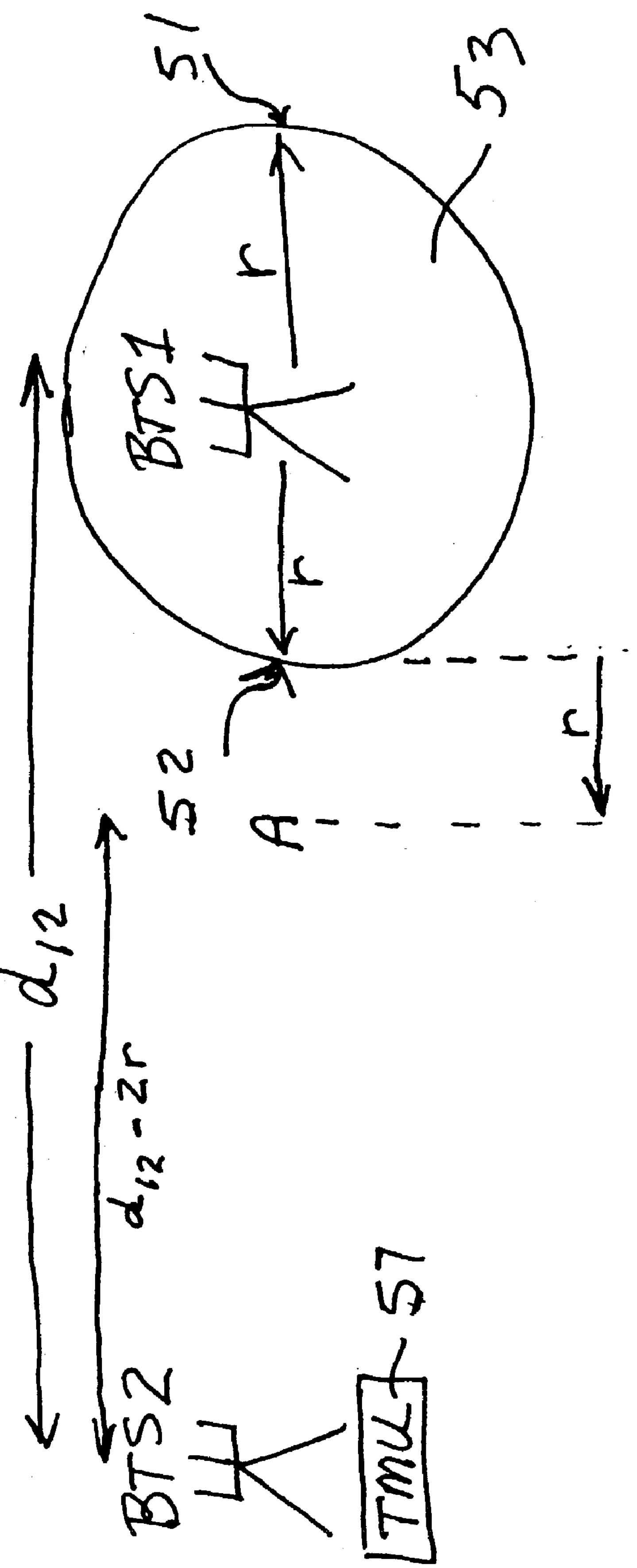


FIG. 5

IDENTIFYING STARTING TIME FOR MAKING TIME OF ARRIVAL MEASUREMENTS

FIELD OF THE INVENTION

[0001] The invention relates generally to locating the position of a mobile communication unit in a wireless communication network and, more particularly, to uplink time of arrival measurements.

BACKGROUND OF THE INVENTION

[0002] The ability to locate the position of a mobile communication unit operating in a wireless communication system provides many well known advantages. Exemplary uses of such position locating capability include security applications, emergency response applications, and travel guidance applications. Among several possible techniques for providing position locating capability, uplink time of arrival (TOA) techniques are attractive because they normally do not require any changes to the mobile communication units.

[0003] One example of an uplink time of arrival approach will now be described with respect to the Global System for Mobile Communication (GSM), which is exemplary of a wireless communication system in which uplink time of arrival techniques are applicable. When an external application (or the GSM network itself) decides to locate the position of a mobile unit (also referred to as mobile station), a Mobile Location Center forces (via a base station controller) the mobile unit to perform a conventional intracell handover, whereupon the mobile unit transmits up to 70 uplink access bursts, one burst per TDMA frame (i.e., one burst every 8 time slots). The mobile unit transmits the access bursts in an attempt to comply with the intracell handover command.

[0004] The Mobile Location Center (MLC) orders a number of TOA Measurement Units (TMUs) to capture the access bursts and measure the time of arrival of each burst at each TMU. The TMUs then provide the MLC with their time of arrival measurements and reliability estimates for these measurements. In order to compute the position of the mobile station, the MLC uses the time of arrival values and corresponding reliability parameters, the geographic location coordinates of the TMUs, and information regarding time differences among the respective internal time bases of the TMUs. For example, each TMU can be provided with an absolute time reference (e.g., a Global Positioning System (GPS) clock), in which case the TMUs are all synchronized together, so that relative time differences among the TMUs are not a factor in the MLC's calculation of the position of the mobile station.

[0005] However, if the TMUs do not include an absolute time reference, then the relative differences among their respective local time references can be determined, for example, by having each TMU measure the time of arrival of an uplink burst from a stationary reference mobile station positioned at a known location in the network. The time of arrival information for the reference mobile station is then transmitted from the TMUs to the MLC. The MLC can use these time of arrival measurements to compute the relative differences in the timing references of the respective TMUs, also referred to as inter-TMU time differences (ITTDs).

[0006] More specifically, because the MLC knows the location of the reference mobile station and also knows the locations of the TMUs, the MLC can easily calculate the expected difference (in absolute time) between the time of arrival of the burst at a first TMU and the time of arrival of the burst at a second TMU. Then, when the MLC receives the time of arrival information as actually observed at the first and second TMUs, it can compare the difference between observed arrival times to the expected difference as previously calculated. By this comparison, the actual time difference between the local time references of the first and second TMUs (the ITTD of the first and second TMUs) can be readily determined. Time of arrival measurements on the reference mobile station can be made periodically by the TMUs, and provided to the MLC for use in determining the ITTDs, so that MLC can maintain an updated record of the ITTDs.

[0007] In addition to the technique described above, other conventional techniques are also available for determining the ITTDS.

[0008] Because the MLC knows the ITTDs (or alternatively knows that the TMUs are all synchronized by a GPS system), it can calculate an estimate of the position of a given mobile station from the time of arrival information provided by the TMUs, using conventional Time Difference of Arrival (TDOA) techniques.

[0009] One problem with the above-described uplink time of arrival techniques is that the TMUs do not know when they should expect, or begin to monitor for, the access bursts from the mobile station. This has the following disadvantages. The sensitivity of conventional time of arrival measurement algorithms decreases as the uncertainty in the a priori knowledge of the arrival time increases. This is due to the fact that more noise and interference is received if the receiver does not know when the "meaningful" data is coming. Also, the TMU must monitor for a long time in order to be sure that it captures the desired bursts. Thus, the utilization efficiency of the TMU hardware is disadvantageously degraded.

[0010] Furthermore, in a frequency hopping system such as GSM, the access bursts are transmitted on a frequency hopped channel. In this situation, not only does the TMU not know when to begin monitoring for the access bursts, but it also does not know which frequency it should monitor. Thus, not only is an undesirably long monitoring time possible, but the TMU would also be required to include a receiver for each frequency in the hop sequence so that all possible frequencies could be monitored.

[0011] It is therefore desirable to provide time of arrival measuring devices with information indicative of when the access bursts can be expected to arrive, and which frequency will be used to transmit the access bursts. According to the present invention, such information is provided to time of arrival measuring devices, thereby avoiding the aforementioned problems associated with conventional time of arrival techniques.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a block diagram of an exemplary wireless communication system including uplink time of arrival capability according to the present invention.

[0013] FIG. 2 illustrates an example of the mobile location center of FIG. 1 in greater detail.

[0014] FIG. 3 illustrates an example of the TOA measurement units of FIG. 1 in greater detail.

[0015] FIG. 4 is a flow diagram which illustrates example operations of the structure of FIGS. 1-3 to implement uplink time of arrival techniques according to the present invention.

[0016] FIG. 5 illustrates how an example monitoring window is determined according to the invention.

DETAILED DESCRIPTION

[0017] FIG. 1 illustrates one example of a pertinent portion of a wireless communication system including the uplink time of arrival capability according to the present invention. The invention is implemented in a GSM network in the example of FIG. 1. As shown in FIG. 1, a GSM mobile switching center MSC is coupled for communication with a plurality of GSM base station controllers BSCs, which are in turn coupled to communicate with one or more GSM base transceiver stations BTSs. The base transceiver stations are capable of radio communication with a plurality of mobile stations MSs via the air interface. Communication from the MSC to the MSs via the BSCs and the BTSs is well known in the art.

[0018] FIG. 1 also includes time of arrival measurement units TMUs which communicate with respective base transceiver stations via radio signaling through the air interface. A mobile location center MLC is coupled to communicate with the mobile switching center MSC using conventional GSM signaling protocol. In FIG. 1, the MLC can receive a request to locate the position of a mobile station MS1. Such a request can be received from a node within the network itself, or from an external location application as illustrated at 11 in FIG. 1. In response to this request, the MLC interrogates the MSC to thereby determine the serving BTS 15 (i.e., the serving GSM cell) and to receive from the serving BSC 13 (via MSC) all available physical channel parameters associated with the serving cell, including all frequency hopping parameters. The MLC decides which TMUs should be involved in the uplink time of arrival measurements, and initiates a conventional intracell handover command (via MSC and BSC 13), which intracell handover command is then to be transmitted to the mobile station MS1 by BTS 15.

[0019] The intracell handover command in GSM includes starting frame and time slot information which directs the mobile station to begin the conventional access burst (responsive to the intracell handover command) at a specified TDMA time slot in a specified TDMA frame. When initiating the intracell handover command via communication with BSC 13, the MLC either specifies to BSC 13 the frame number and time slot number, or receives from BSC 13 the frame number and time slot number that have been specified by BSC 13.

[0020] Communications between the MLC and the TMUs can occur, for example, via conventional Short Message Service using the air interface between the MLC and the TMUs (see, e.g., 12 in FIG. 1), or via the air interface between the TMUs and BTSs (see, e.g., 14 in FIG. 1) and the network communication path from BTS through BSC and MSC to MLC.

[0021] The TMUs periodically monitor the broadcast control channels of the respective base transceiver stations with which they communicate. Each TMU provides the MLC with the frame structure timing of its associated BTS relative to the TMU's own local time reference. This frame structure timing information can be transmitted from the TMUs to the MLC via, for example, conventional Short Message Service utilizing the air interface between the TMU and the MLC. This frame structure timing information can be updated periodically by the TMUs and sent to MLC periodically. Thus, when the MLC initiates the intracell handover command, which specifies the frame number and time slot number for the access burst from the mobile station, the MLC also knows the frame structure timing currently used by the mobile station MS1 in communication with its serving base transceiver station 15.

[0022] Moreover, the MLC also knows any inter-TMU timing differences (ITTDs) among the TMUs selected to make the uplink time of arrival measurements on the mobile station MS1. As described above in detail, the TMUs can all include a conventional absolute time reference, or the MLC can calculate the inter-TMU time differences among the TMUs using uplink time of arrival measurements made by the TMUs on a stationary reference mobile station located in a known position. The MLC can therefore determine the frame structure timing according to the local time reference of any TMU by simply translating the frame structure timing measurement from the local timing of the TMU that made the frame structure timing measurement (TMU 17 in the example of FIG. 1) to the local timing of any of the TMUs selected to make TOA measurements on MS1. Thus, when the MLC requests an intracell handover command specifying a frame number and time slot number of the access burst, the MLC can also communicate to the selected TMUs the frame number, the time slot number and the frame structure timing of the serving BTS (and thus the mobile station also) relative to the local timing of each respective TMU. Now, each TMU will know, relative to its own local timing reference, precisely when the mobile station will begin transmitting the first access burst.

[0023] In addition, the mobile location center can request from the base station controller 13 the conventional hopping sequence parameters associated with the serving base transceiver station 15. These parameters can also be transmitted from MLC to the TMUs along with the frame number, time slot number and frame structure timing. With knowledge of the conventional hopping sequence parameters and the frame and time slot numbers, the TMUs can then calculate the hopping sequence in conventional fashion. Thus, the TMUs will all know when (frame and time slot numbers), and on which frequency, to begin monitoring for the arrival of the access burst from the mobile station.

[0024] The MLC may also compute a monitor window beginning at the starting time as specified by the frame number and time slot number in the intracell handover command, and extending for a time period determined as shown in the example of FIG. 5. FIG. 5 illustrates one example of how monitoring windows can be established for the TMUs of FIG. 1. The example of FIG. 5 illustrates determination of a monitoring window for a TMU 57 that is substantially cosited with a base transceiver station designated as BTS2. The TMU illustrated in FIG. 5 will make time of arrival measurements on bursts received from a mobile station currently being served by the base transceiver station designated as **BTS1**. In this situation, the longest transmission time before the burst arrives at the TMU will occur when the mobile station is located at **51**, namely on the boundary of serving cell **53** opposite the TMU **57**. If TO designates the starting time of the access burst (as defined by the frame number and time slot number received by the mobile station in the intracell handover command), then the access burst from the mobile station will actually arrive at **BTS1** at the starting time TO due to the fact that the mobile station is synchronized to the serving **BTS1**. This operation is conventional in, for example, GSM systems.

[**0025**] Due to the aforementioned synchronization, the access burst will have already arrived at BTS1 at time **T0**, so the total transmission time to the TMU will be $T0+d_{12}/c$, where d_{12} is the distance between BTS1 and the TMU **57**, and c is the speed of light. On the other hand, the shortest transmission time between the mobile station and the TMU will occur when the mobile station is located at **52**, namely on the cell boundary of cell **53** nearest to the TMU. With the mobile station located at **52**, the access burst will have reached point A at time **T0**, so that the total transmission time to the TMU will be given by $T0+(d_{12}-2r)/c$, where r is the radius of the serving cell **53**. Thus, the monitoring window for the TMU **57** of **FIG. 5** would begin at time $T0+(d_{12}-2r)/c$, and would extend until time $T0+d_{12}/c$. This monitoring window is easily calculated by the MLC which has stored therein or available thereto the cell radius information of all cells covered by the MLC, and either the distances between all base transceiver stations (in the case of TMUs cosited with the base transceiver stations) or the geographic coordinates of all base transceiver stations and all TMUs (to accommodate architectures wherein the TMUs are not necessarily cosited with base transceiver stations).

[**0026**] Rather than using the cell radius r to calculate the search window, the MLC could alternatively use the current Timing Advance (TA) value, which is conventionally available from the serving BTS. The TA value gives a rough estimate of the distance between the mobile station and the serving BTS. Because the TA value will correspond to a distance less than or equal to the cell radius r, use of the TA value can often reduce the search window by locating the beginning point of the window later in time than it would be if the cell radius r were used.

[**0027**] **FIG. 2** illustrates one example of the mobile location center MLC of **FIG. 1** in greater detail. In the example of **FIG. 2**, the MLC includes a position locator **21** which receives the location requests from the location application or network mode at **11** in **FIG. 1**. The position locator is coupled to a geographic storage portion **24** for storing therein, for example, the geographic coordinates of the TMUs, the geographic coordinates of the base transceiver stations, and the cell radius of each cell covered by the MLC (or current TA value of any mobile station that is being located) The position locator includes an input **23** where time of arrival information (and associated reliability estimate) from the TMUs is received. The position locator **21** implements well-known time difference of arrival techniques in response to the time of arrival information.

[**0028**] For example, position locator **21** can operate to solve the equation OTD=GTD+ITTD where OTD is the observed time difference (difference between TMU-measured times of arrival), GTD is geographic time difference (difference between times of arrival in absolute time). Thus, the observed time differences differ from the geographic time differences due to ITTD as described above. When MLC is locating a mobile station, OTD and ITTD are known, so the equation is solved for GTD, and when MLC is determining the ITTDs using a stationary reference mobile, OTD and GTD are known, so ITTD can be calculated. When the position of the mobile station has been located by the position locator, the position locator outputs the position location information to the requesting node (network or external) from which the original location request was received. Position locator **21** can determine the ITTDs from time of arrival measurements made by TMUs on a stationary reference mobile station. The ITTDs are stored in storage portion **29**.

[**0029**] The position locator also outputs an intracell handover request (HO) to BSC, in which the position locator can specify the desired starting frame and time slot numbers.

[**0030**] The MLC further includes a window determiner **25** which determines the monitoring window for each TMU, for example, in the manner described above with respect to **FIG. 5**. The window determiner has an input **27** for receiving the starting time (frame number FN and time slot number TSN) from the BSC **13** (via MSC). Window determiner **25** is also coupled to geographic storage portion **24** to permit access to geographic location information needed to compute the monitoring windows. A timing translator **26** receives frame structure timing information for each BTS from the associated TMU assigned to measure that BTS, and uses the ITTDs stored at **29** to translate the frame structure timing information into the timing reference of every other TMU. Frame structure timing information for every BTS relative to every TMU's local timing reference is stored in storage portion **20**.

[**0031**] The MLC includes a further input for receiving the hopping sequence information from the BSC **13**(via MSC). The MLC provides as output a positioning measurement command to the selected TMUs (via MSC, BSC and BTS), the command including (1) monitoring window information and the frame number FN and time slot number TSN from window determiner **25**, (2) hopping sequence information as received at MLC from BSC, and (3) localized frame structure timing from storage portion **20**.

[**0032**] **FIG. 3** illustrates an example embodiment of the TMUs of **FIG. 1**. The TMU of **FIG. 3** includes a frame structure monitor **31** including an input **32** for monitoring the broadcast control channel (or other channel suitable for determining frame structure timing) of the associated base transceiver station of **FIG. 1**, and an output **34** for providing the frame structure timing information to the MLC (via BTS, BSC and MSC). The frame structure monitor receives its timing from the TMU's local clock **33**. As discussed above, the frame structure monitor receives the broadcast control channel of the associated BTS and determines the frame structure timing of the BTS relative to the TMU's local clock. This frame structure timing information is then transmitted to the MLC at **34**.

[**0033**] The TMU of **FIG. 3** further includes a time of arrival monitor **35** which includes an input **30** for receiving the access bursts from a mobile station, and a further input **36** for receiving the positioning measurement command information provided by MLC as described above. The time of arrival monitor also includes an output **37** for providing time of arrival information (and associated reliability estimates) to the MLC. The time of arrival monitor **35** can monitor the input **30** for access bursts during the window as defined by the received window information. The window information and starting frame and time slot numbers (FN and TSN) are interpreted by the TOA monitor **35** in conjunction with the localized frame structure timing information, so the monitoring window is properly adjusted to the local clock timing of the TMU.

[**0034**] The time of arrival monitor also uses the hopping sequence information, in conjunction with the starting frame and time slot numbers to compute the hopping sequence used by the mobile station and its serving base transceiver station. Such computation of a frequency hopping sequence is a well known conventional procedure. Thus, the TMU will advantageously monitor the access bursts on the correct frequency and during a limited window of time which includes the arrival time of the access bursts. The window is of course easily re-used to measure subsequent access bursts in the (potentially) **70** burst sequence. Even without receiving the window information, the monitor would still know the burst starting time from FN, TSN and the localized frame structure timing, and thus could alternatively monitor for a predetermined default window time beginning at the known starting time.

[**0035**] **FIG. 4** illustrates exemplary operations of the wireless communication system portion of **FIG. 1**, including the uplink time of arrival techniques of the present invention. At **61**, the MLC receives a request to locate the position of a particular mobile station. At **62**, the MLC determines the serving cell, obtains transmission parameters of the mobile station (including hopping sequence parameters), and selects which TMUs should be involved in the time of arrival measurement. At **63**, the starting frame number and time slot number for the first access burst is specified, either by MLC or from BSC. At **64**, the MLC computes the monitoring window for each selected TMU. At **65**, the MLC sends the monitoring windows and hopping sequence information to the selected TMUs along with the starting frame and time slot numbers and the localized frame structure timing information. At **66**, the selected TMUs compute the hopping sequence. At **67**, the intracell handover commend is sent to the mobile station, and the mobile station transmits the access burst in response thereto. At **68**, the TMUs record the time of arrival of the access burst within their respective monitoring windows. At **69**, the TMUs send the time of arrival information to the MLC. At **70**, the MLC computes the position of the mobile station and relays the position information to the requesting node.

[**0036**] As mentioned above, the MLC receives from each TMU the frame structure timing of the associated BTS relative to the TMU's own local time reference. This information, when combined with conventional downlink time of arrival measurements made on BTSs by a stationary reference mobile station, permits the MLC to calculate the ITTDs. If the reference mobile station makes time of arrival measurements on two BTSs, for example, by monitoring the broadcast control channel of each BTS, then the MLC can receive this information (e.g., via BTS, BSC and MSC) and calculate the timing difference between the BTSs. Because the MLC also knows the timing of each BTS's broadcast control channel frame structure relative to the associated TMU, the MLC can easily calculate the ITTD between the two TMUs associated with the two BTSs measured by the reference mobile station. This technique for determining the ITTDs according to the present invention advantageously permits the reference mobile station simply to monitor existing downlink signals from the BTSS, rather than transmit uplink signals to be measured by the TMUs, thus requiring no additional traffic in the network for performing ITTD determinations.

[**0037**] Although exemplary embodiments of the present invention have been described above in detail, this does not limit the scope of the invention, which can be practiced in a variety of embodiments.

What is claimed is:

1. A method of using a time of arrival measurement apparatus to measure the time of arrival of a radio signal transmitted by a mobile communication station operating in a wireless mobile communication network, comprising:

providing the time of arrival measurement apparatus with information indicative of a predetermined point in time at which the radio signal is to be transmitted; and

using the time of arrival measurement apparatus to monitor for arrival of the radio signal only during a period of time after said predetermined point in time.

* * * * *