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(54) METHOD AND SYSTEM FOR LOCATING A MOBILE SUBSCRIBER IN A CDMA COMMUNICATION SYSTEM

VERFAHREN UND SYSTEM ZUR BESTIMMUNG DES AUFENTHALTSORTES EINES FUNKTEILNEHMERS IN EINEM CDMA-KOMMUNIKATIONSSYSTEM

PROCEDE ET SYSTEME DE LOCALISATION D'UN ABONNE MOBILE DANS UN SYSTEME DE TELECOMMUNICATIONS AMDC

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Description

Field of the Invention

[0001] This invention generally relates to spread spectrum code division multiple access (CDMA) communication systems. More particularly, the present invention relates to a system and method that determines the geographic location of a subscriber unit within a CDMA communication system.

Description of the Prior Art

[0002] Wireless systems capable of locating a subscriber are presently known in the art. One wireless technique uses the global positioning system (GPS). In GPS, the communication handset receives data transmitted continuously from the 24 NAVSTAR satellites. Each satellite transmits data indicating the satellite's identity, the location of the satellite and the time the message was sent. The handset compares the time each signal was received with the time it was sent to determine the distance to each satellite. Using the determined distances between the satellites and the handset along with the location of each satellite, the handset can triangulate its location and provide the information to a communication base station. However, the incorporation of a GPS within a subscriber unit increases its cost.

[0003] Another subscriber location technique is disclosed in U.S. Patent No. 5,732,354. A mobile telephone using time division multiple access (TDMA) as the air interface is located within a plurality of base stations. The mobile telephone measures the received signal strength from each of the base stations and transmits each strength to each respective base station. At a mobile switching center, the received signal strengths from the base stations are compared and processed. The result yields the distance between the mobile telephone and each base station. From these distances, the location of the mobile telephone is calculated.

[0004] Wireless communication systems using spread spectrum modulation techniques are increasing in popularity. In code division multiple access (CDMA) systems, data is transmitted using a wide bandwidth (spread spectrum) by modulating the data with a pseudo random chip code sequence. The advantage gained is that CDMA systems are more resistant to signal distortion and interfering frequencies in the transmission path than communication systems using the more common time division multiple access (TDMA) or frequency division multiple access (FDMA) techniques.

[0005] EP 0 865 223 A2 is a position estimation scheme for a cellular mobile system. A first and a second signal sequence are exchanged between the mobile station and the base station. These signals may be CDMA signals. A phase difference between the first and second sequence is used to determine a distance between the mobile and base station. Using multiple base stations, the position is estimated using triangulation.

[0006] U.S. Patent No. 5,600,706 is a position system using a range determination in a CDMA system. The system uses pilot signals and time difference of arrival (TDOA) and absolute time of arrival (TOA) in the position determination.

[0007] WO 98/18018 discloses locating a mobile terminal using two antennas of an array in a time division multiple access communication system. A phase difference in the signals received by the two antennas is used to determine an angle from the centerline of the antennas to the mobile terminal. Received signal strength is used to estimate the terminal's distance. The terminal's location is determined using the determined angle and distance.

[0008] WO 97/47148 discloses determining a position of a mobile terminal within a cellular system. A signal is transmitted at a low power level. The power level is temporarily increased. The signal transmitted at the increased power level is used to make a position measurement of the terminal.

[0009] U.S. Patent No. 5,736,964 discloses a CDMA system for locating a communication unit. A base station transmits a location request to the unit. The unit transmits a receive time of the message to the base station. A group of base stations also determine a receive time of a symbol sequence in the unit's transmissions. Using the time measurements, the location of the unit is determined.

[0010] U.S. Patent No. 5,506,864 discloses a system for determining a distance between a base station and a remote unit in a CDMA system. The base station transmits a base CDMA signal to the remote unit. The remote unit transmits a remote CDMA signal to the base station. The remote CDMA signal has its timing synchronized to the received base CDMA signal. The base station determines the distance to the remote unit by comparing the chip code sequences of the transmitted base CDMA signal and the received remote CDMA signal.

[0011] There exists a need for an accurate mobile subscriber unit location system that uses data already available in an existing CDMA communication system.

SUMMARY OF THE INVENTION

[0012] A subscriber unit is geographically located using a plurality of base stations in a wireless CDMA communication system. Each base station transmits a first spread spectrum signal having a first code. For each received first signal, the subscriber unit transmits a second spread spectrum signal having a second code. The second spread spectrum signal is time synchronized with its received first signal. An impulse response of each received first signal is analyzed to determine a first received component. At each base station, an impulse response of that base station's received second signal is analyzed to determine a first received component. A distance between each base station and the subscriber unit is determined. The distance determination is based on in part a timing difference between the received signal and the transmitted signal and the determined first received component for the second signals. The location of the subscriber unit is based on in part the determined distances, a fixed location of each base station and a maximum likelihood estimation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Figure 1 is an illustration of a simplified, prior art CDMA system.
Figure 2 is an illustration of a prior art CDMA system.
Figure 3 is a block diagram of major components within a prior art CDMA system.
Figure 4 is a block diagram of components within a prior art CDMA system.
Figure 5 is an illustration of a global pilot signal and an assigned pilot signal being communicated between a base station and a subscriber unit.
Figure 6 is a block diagram of a system using at least three base stations.
Figure 7 is an illustration of locating a subscriber unit using the system of Figure 6.
Figure 8 is a block diagram showing components used in a subscriber unit.
Figure 9 is an illustration of locating a subscriber unit using a system with two base stations.
Figure 10 is an illustration of locating a subscriber unit using a system with more than two base stations.
Figure 11 is a detailed illustration of a system having a base station with multiple antennas.
Figure 12 is an illustration of a system having a base station with multiple antennas.
Figure 13 is a block diagram of components used in the system of Figure 11.
Figure 14 is an illustration of multipath.
Figure 15 is a graph of a typical impulse response of multipath components.
Figure 16 is a block diagram of components within a system correcting for multipath.

[0014] The invention will be described with reference to the drawing figures where like numerals represent like elements throughout. Figures 6-12 illustrate systems which may be used to implement an embodiment of the invention described in connection with Figures 14-16.

[0015] Shown in **Figure 1** is a simplified CDMA communication system. A data signal with a given bandwidth is mixed with a spreading code generated by a pseudo random chip code sequence generator producing a digital spread spectrum signal. Upon reception, the data is reproduced after correlation with the same pseudo random chip code sequence used to transmit the data. Every other signal within the transmission bandwidth appears as noise to the signal being despread.

[0016] For timing synchronization with a receiver, an unmodulated pilot signal is required for every transmitter. The pilot signal allows respective receivers to synchronize with a given transmitter, allowing despreading of a traffic signal at the receiver.

[0017] In a typical CDMA system, base stations send global pilot signals to all subscriber units within their communicating range to synchronize transmissions in a forward direction. Additionally, in some COMA systems, for example a B-CDMA™ system, each subscriber unit sends a unique assigned pilot signal to synchronize transmissions in a reverse direction.

[0018] **Figure 2** illustrates a CDMA communication system **30**. The communication system **30** comprises a plurality of base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. Each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ is in wireless communication with a plurality of subscriber units $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$, which may be fixed or mobile. Each subscriber unit $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$ communicates with either the closest base station $\mathbf{36_1}$ or the base station $\mathbf{36_1}$ which provides the strongest communication signal. Each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ is in communication with other components within the communication system **30** as shown in **Figure 3**.

[0019] A local exchange **32** is at the center of the communications system **30** and communicates with a plurality of network interface units (NIUs) $\mathbf{34_1}$, $\mathbf{34_2}$ ... $\mathbf{34_n}$. Each NIU is in communication with a plurality of radio carrier stations (RCS) $\mathbf{38_1}$, $\mathbf{38_2}$ ... $\mathbf{38_n}$ or base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. Each (RCS) $\mathbf{38_1}$, $\mathbf{38_2}$ ... $\mathbf{38_n}$ or base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ communicates with a plurality of subscriber units $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$ within its communicating range.

[0020] **Figure 4** depicts a block diagram of the pertinent parts of an existing spread spectrum CDMA communication system. Each independent base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ generates a unique global pilot signal using a global pilot chip code generating means **42_1** and spread spectrum processing means **44_1**. The global pilot chip code generating means **42_1** generates a unique pseudo random chip code sequence. The unique pseudo random chip code sequence is used to spread the resultant signals bandwidth such as to 15 MHZ as used in the B-CDMA™ air interface. The spread spectrum processing means modulates the global pilot chip code sequence up to a desired center frequency. The global pilot signal is transmitted to all subscriber units **40_1** by the base station's transmitter **46_1**.

[0021] A receiver **48_1** at a subscriber unit **40_1** receives available signals from a plurality of base stations **36_1, 36_2** ... **36_n**. As shown in **Figure 5**, the global pilot **50_1** travels from the base station **36_1** to the subscriber unit **40_1** and can be represented as:

$$\tau_1 = \frac{d_1}{c}. \qquad \text{Equation (1)}$$

The time the signal travels from the base station **36_1** to the subscriber unit **40_1**, τ_1, equals the distance between the base station **36_1** and subscriber unit **40_1**, d_1, divided by the speed of light, **c**.

[0022] Referring back to **Figure 4**, a global pilot chip code recovery means **54_1** within the subscriber unit **40_1** can receive global pilot chip code sequences from a plurality of base stations **36_1, 36_2** ... **36_n**. The subscriber unit **40_1** generates a replica of a global pilot chip code sequence and synchronizes the generated replica's timing with the received global pilot **50_1**. The subscriber unit **40_1** also has a processor **82_1** to perform the many analysis functions of the subscriber unit **40_1**.

[0023] The subscriber unit **40_1** generates an assigned pilot signal **52_1** using assigned pilot chip code generating means **56_1** and spread spectrum processing means **58_1**. The assigned pilot chip code generating means **56_1** generates a pseudo random chip code sequence with its timing synchronized with the recovered global pilot chip code sequence. As a result, the assigned pilot chip code sequence is delayed by τ_1 with respect to the base station **36_1, 36_2** ... **36_n**. The spread spectrum processing means **58_1** generates the assigned pilot signal **52_1** by modulating the assigned pilot chip code sequence up to a desired center frequency. The assigned pilot signal **52_1** is transmitted to all base stations **36_1, 36_2** ... **36_n** within range to receive the assigned pilot signal **52_1**.

[0024] The base station **36_1** receives the assigned pilot signal **52_1** with the base station's receiver **62_1**. The received assigned pilot **52_1** travels the same distance d_1 as the global pilot signal **50_1** as shown in **Figure 5**. Accordingly, the received assigned pilot signal will be delayed by τ_1 with respect to the mobile unit **40_1** and by $2\tau_1$ with respect to the global pilot **50_1** generated at the base station **36_1**.

[0025] Since the chip code sequence of the assigned pilot **52_1** received at the base station **36_1** will be delayed by $2\tau_1$ with respect to the chip code sequence of the global pilot signal **50_1** generated at the base station **36_1**, the round trip propagation delay, $2\tau_1$, can be determined by comparing the timing of the two chip code sequences. Using the round trip propagation delay, $2\tau_1$, the distance d_1 between the base station **36_1** and subscriber unit **40_1** can be determined by:

$$d_1 = c \cdot \frac{2\tau_1}{2}. \qquad \text{Equation (2)}$$

If a spreading sequence having a chipping rate of at least 80ns is used and the communication system has the ability to track 1/16th of a chip, the distance d_1 can be measured to within 2 meters.

[0026] **Figure 6** is a block diagram of a system for implementing the present invention. No additional hardware is required in the subscriber unit **40_1**. The only changes are implemented by software within the subscriber unit's processor **82_1** and the processors **66_1, 66_2** ... **66_n, 68, 70_1, 70_2** ... **70_n** located within the base station **36_1**, NIU **34_1** or Local Exchange **32_1**, Precincts **74_1, 74_2** ... **74_n** and Ambulance Dispatcher **76**.

[0027] The subscriber unit **40_1** is sent a signal by a base station **36_1** indicating that a 911 call was initiated and to begin the subscriber location protocol. Upon receipt, the subscriber unit **40_1** will sequentially synchronize its transmission chip code sequence to at least three base stations' chip code sequences. To allow reception by the base stations **36_2, 36_3** ... **36_n** outside of the subscriber unit's normal communicating range, these transmissions will be sent at a higher than normal power level temporarily over-riding any adaptive power control algorithms.

[0028] A processor **66_1** within each base station **36_1, 36_2** ... **36_n** is coupled to the assigned pilot chip code recovery means **64_1** and the global pilot chip code generator **42_1**. The processor **66_1** compares the two chip code sequences to determine the round trip propagation delay $\tau_1, \tau_2 \ldots \tau_n$ and the respective distance $d_1, d_2 \ldots d_n$ between the subscriber unit **40_1** and the respective base station **36_1, 36_2** ... **36_n**.

[0029] Within either a NIU **34_1** or the local exchange **32**, a processor **68** receives the distances $d_1, d_2 \ldots d_n$ from the processors **66_1, 66_2** ... **66_n** within all the base stations **36_1, 36_2** ... **36_n**. The processor **68** uses the distances $d_1, d_2 \ldots$

d_n to determine the location of the subscriber unit **40**$_1$ as follows.

[0030] By using the known longitude and latitude from three base stations **36**$_1$, **36**$_2$, **36**$_3$ and distances d_1, d_2, d_3, the location of the subscriber unit **40**$_1$ is determined. As shown in **Figure 7** by using the three distances d_1, d_2, d_3, three circles **78**$_1$, **78**$_2$, **78**$_3$ with radiae **80**$_1$, **80**$_2$, **80**$_3$ are constructed. Each circle **78**$_1$, **78**$_2$, **78**$_3$ is centered around a respective base station **36**$_1$, **36**$_2$, **36**$_3$. The intersection of the three circles **78**$_1$, **78**$_2$, **78**$_3$ is at the location of the subscriber unit **40**$_1$.

[0031] Using the Cartesian coordinates, the longitude and latitude corresponding with each base station **36**$_1$, **36**$_2$ ... **36**$_n$ is represented as X_n, Y_n, where X_n is the longitude and Y_n is the latitude. If X, Y represents the location of the subscriber unit **40**$_1$, using the distance formula the following equations result:

$$(X_1-X)^2 + (Y_1-Y)^2 = d_1^{\,2} \qquad \text{Equation (3)}$$

$$(X_2-X)^2 + (Y_2-Y)^2 = d_2^{\,2} \qquad \text{Equation (4)}$$

$$(X_3-X)^2 + (Y_3-Y)^2 = d_3^{\,2} \qquad \text{Equation (5)}$$

[0032] In practice due to small errors in calculating the distances d_1, d_2, d_3, **Equations 3, 4** and **5** cannot be solved using conventional algebra. To compensate for the errors, a maximum likelihood estimation is used to determine the location and are well known to those skilled in the art. For increased accuracy, additional base stations **36**$_4$, **36**$_5$ ... **36**$_n$ can be used to calculate additional distances for inclusion in the estimation analysis.

[0033] The subscriber unit's location is sent through the communication system **30** to at least one precinct **74**$_1$, **74**$_2$ ... **74**$_n$ and an ambulance dispatcher **76**. A processor **70**$_1$ within each precinct **74**$_1$, **74**$_2$ ... **74**$_n$ and the ambulance dispatcher **76** receives the location of all 911 calls originating in the system and displays the location on a conventional computer monitor **72**$_1$. The display comprises a listing of all 911 calls and addresses on a geographic map.

[0034] An alternate approach reduces the number of processors by transmitting raw data through the communication system **30** and processing the raw data at a single site.

[0035] **Figure 8** is a further embodiment of a location system. At least two base stations **36**$_1$, **36**$_2$ ... **36**$_n$ have their internal timing synchronized with each other and transmit their respective global pilot signals **52**$_1$, **52**$_2$ ... **52**$_n$ with time synchronized chip code sequences. The subscriber unit **40**$_1$ receives the global pilots **52**$_1$, **52**$_2$ ... **52**$_n$. However, the received global pilots **52**$_1$, **52**$_2$ ... **52**$_n$ are not synchronized. The global pilot **52**$_1$ from a first base station **36**$_1$ will travel distance d_1 and is delayed by τ_1. The global pilot **52**$_2$ from a second base station **36**$_2$ travels distance d_2 and is delayed by τ_2. The subscriber unit **40**$_1$ recovers each base station's global pilot chip code sequence with its global pilot chip code recovery means **54**$_1$. A processor **82**$_1$ within the subscriber unit **40**$_1$ is coupled to each global pilot chip code recovery means **54**$_1$, **52**$_2$ ... **54**$_n$. The processor **82**$_1$ compares the chip code sequences of each pair of pilot chip code sequences and calculates the time differences Δt_1, Δt_2 ... Δt_n between the sequences as follows.

[0036] Within the subscriber unit **40**$_1$, the chip code sequences used by each base station **36**$_1$, **36**$_2$ ... **36**$_n$ are stored. After synchronizing with the first base station's pilot **36**$_1$, the processor **82**$_1$ will store where within the sequence synchronization was obtained. This process is repeated for the other base stations **36**$_2$, **36**$_3$ ... **36**$_n$. The synchronization process can be done sequentially (synchronizing to the first base station's chip code sequence then the second, etc.) or in parallel (synchronizing to all base stations at the same time).

[0037] By using the relative time difference between τ_1, τ_2, ... τ_n each base station's chip code sequence and knowing that each base station's pilot was sent at the same time, with two base stations the time differences are calculated as follows:

$$\Delta t_1 = \tau_2 - \tau_1 \qquad \text{Equation (6)}$$

$$\Delta t_2 = \tau_3 - \tau_2 \qquad \text{Equation (7)}$$

The time differences Δt_1, Δt_2 ... Δt_n are transmitted to at least one of the base stations **36**$_1$.

[0038] At least one base station **36**$_1$ recovers the time difference data from the received signals using time difference recovery means **84**$_1$. The time difference data is sent with the distance data d_1 through the communications system to a processor **68**. The processor 68 determines the location of the subscriber unit **40**$_1$ using the time difference data

Δt_1, Δt_2 ... Δt_n and the distance data d_1, d_2 ... d_n as follows.

[0039] Using information from only two base stations 36_1, 36_2 as shown in **Figure 9**, the processor uses distances d_1, d_2 to create two circles 78_1, 78_2. Using the time difference, Δt_1, a hyperbola 86_1 can be constructed as follows.

[0040] All the points along the hyperbola 86_1 receive the global pilot signals 52_1, 52_2 from the synchronized base stations 36_1, 36_2 with the same time difference, Δt_1. The time difference Δt_1 can be converted to a distance difference Δd_1 by substituting Δt_1 for t_1 and Δd_1 for d_1 in **Equation 1**. Using the distance formula and X, Y as the location of the subscriber unit 40_1, the following equation results:

$$\Delta d_1 = \sqrt{(X_1 - X)^2 + (Y_1 - Y)^2} - \sqrt{(X_2 - X)^2 + (Y_2 - Y)^2} \qquad \text{Equation (8)}$$

[0041] By using **Equation 8** with **Equations 3** and **4** in a maximum likelihood estimation, the location of the subscriber unit 40_1 can be determined. The subscriber unit's location is subsequently sent to the nearest police precinct 74_1, 74_2 ... 74_n and ambulance dispatcher **76** in the cellular area.

[0042] For improved accuracy, additional base stations 36_1, 36_2 ... 36_n are used. **Figure 10** shows the invention used with three base stations 36_1, 36_2, 36_3. The distances d_1, d_2, d_3 are used to create three circles 78_1, 78_2, 78_3. Using time differences Δt_1, Δt_2, two intersecting hyperbolas 86_1, 86_2 are constructed. With maximum likelihood estimation, the subscriber units' location calculated with two hyperbolas 86_1, 86_2, and three circles 78_1, 78_2, 78_3 yields greater accuracy.

[0043] As shown in **Figure 8**, the subscriber unit 40_1 is required to process each global pilot chip code sequence to determine the time differences Δt_1, Δt_2 ... Δt_n. An alternate approach removes the processing from the subscriber unit 40_1.

[0044] With reference to **Figure 6**, the mobile unit 40_1 will synchronize the assigned pilot to one of the base station's global pilot chip code sequences, such as the nearest base station 36_1 with a delay of τ_1. The assigned pilot 50_1 is transmitted to all base stations 36_1, 36_2 ... 36_n. The assigned pilot 50_1 will be received at each base station with a respective delay, $\tau_1 + \tau_1$, $\tau_1 + \tau_2$, $\tau_1 + \tau_3$. Each base station 36_1, 36_2 ... 36_n will send the delayed chip code sequence along with the calculated distance to a processor **68** located in a NIU 34_1 or local exchange **32**. The processor **68** will calculate the time differences Δt_1, Δt_2 ... Δt_n by comparing the received assigned pilot chip code sequences. Since all received assigned pilot chip code sequences are delayed by τ_1, the τ_1 delay will cancel out of the resultant time differences Δt_1, Δt_2 ... Δt_n. Accordingly, the subscriber unit 40_1 can be located using hyperbolas 86_1, 86_2 as previously described.

[0045] **Figures 11, 12** and **13** show base station 36_1 with multiple antennas 88_1, 88_2 ... 88_n. Two of the antennas 88_1, 88_2 lie along a centerline **92** at a known distance, l, apart as shown in **Figure 11**. Both antennas 88_1, 88_2 receive the assigned pilot signal 90_1, 90_2 from the subscriber unit 40_1. However, the antenna 88_2 further away from the subscriber unit 40_1 receives the signal over a slightly longer distance d_1' and with a slight delay with respect to the nearer antenna 88_1. This delay results in a carrier phase difference, ϕ, between the signals received at each antenna as shown on **Figure 13**. A processor **66** using the received carrier phase difference and the chip code sequence recovered by each assigned pilot chip code recovery means 96_1, 96_2 ... 96_n can determine the location of the subscriber unit 40_1 as follows.

[0046] As shown in **Figure 12**, the subscriber unit 40_1 is located at distance d_1 at angle α from the centerline **92** of the antennas 88_1, 88_2. As seen at the scale of **Figure 12** both received assigned pilot signals 90_1, 90_2 appear to be coincident. However, as shown in **Figure 11**, the received assigned pilot signals 90_1, 90_2 are slightly separated. The received assigned pilot signal 90_1 returning to the first antenna 88_1 travels a distance d_1. The received assigned pilot signal 90_2 returning to the second antenna 88_2 travels a slightly longer distance d_1'. As shown in **Figure 11**, the difference between the two distances d_1, d_1' is a distance m.

[0047] Since the distances d_1, d_1' between the antennas 88_1, 88_2 and the subscriber unit 40_1 are much larger than the distance l between the antennae 88_1, 88_2 both received assigned pilot signals 90_1, 90_2 follow approximately parallel paths. By constructing a right triangle using a point **94** which is distance d_1 from the subscriber unit 40_1 as shown in **Figure 11**, the angle α can be determined by the following geometric relationship:

$$\alpha = \mathrm{COS}^{-1}\,(m/l). \qquad \text{Equation (9)}$$

[0048] The distance m can be determined by using the carrier phase difference, ϕ, between the two received signals 90_1, 90_2 as follows:

$$m = \frac{\phi \cdot \lambda}{2\pi} \qquad \text{Equation (10)}$$

The distance m equals the phase difference between the two signals, ϕ, in radians multiplied by the wavelength of the signal, λ, divided by 2π. The wavelength, λ, can be derived from the known frequency f of the assigned pilot signal as follows:

$$\lambda = c/f. \qquad \text{Equation (11)}$$

[0049] The processor **68** also compares the chip code sequences of the global pilot generating means **42_1** with the recovered assigned pilot chip code sequence to determine the distance d_1 as shown in **Figure 6.** Using both the angle $\propto$ and distance d_1, the processor **66_1** locates the subscriber unit **40_1** using simple geometry. There are many techniques well known to those skilled in the art to eliminate the ambiguity between locations above and below the antennas **88_1**, **88_2**. One such technique is using antennas employing sectorization. Subsequently, the subscriber unit's location is sent to the precincts **74_1**, **74_2** ... **74_n** and ambulance dispatcher **76**. Additional antennas may be used to improve on the accuracy of the system.

[0050] An alternative would be the use of more than one base station **36_1**, **36_2** ... **36_n**. A processor **68** located within either a NIU **34_1** or the local exchange **32** collects distance and angle information from more than one base station **36_1**, **36_2** ... **36_n** as well as the time differences Δt_1, Δt_2 ... Δt_n, between the base stations **36_1**, **36_2** ... **36_n**. Using the maximum likelihood estimation technique, the processor **68** determines a more accurate location of the subscriber unit **40_1**.

[0051] **Figure 14** illustrates multipath. A signal such as a global pilot signal is transmitted from a base station **36_1**. The signal follows a multitude of paths **98_1**, **98_2** ... **98_n** between the base station **36_1** and subscriber unit **40_1**.

[0052] **Figure 15** is a graph showing the impulse response **10** of the received multipath components. Since each received multipath component travels a unique path, it arrives at a receiver with a propagation delay determined by the length of the path **98_1**, **98_2** ... **98_n**. The impulse response **100** shows the collective signal magnitude of all the multipath components received at each propagation delay.

[0053] The previously described subscriber unit location techniques assumed the subscriber unit **40_1** synchronizes with the line of sight multipath component **98_1** traveling distance d_1. However, if the subscriber unit synchronizes with a non-line of sight multipath component **98_1**, **98_2** ... **98_n**, the distance calculation will be in error due to the delay **MD_1** as shown in **Figure 15.**

[0054] **Figure 16** is a system correcting for errors resulting from multipath. The global pilot **50_1** is sent from the base station **36_1** to subscriber unit **40_1**. The subscriber unit **40_1** collects all of the multipath components using a multipath receiver **102_1** such as disclosed in U.S. Patent Application No. 08/669,769, Lomp et al. A processor **82_1** within the subscriber unit **40_1** analyzes the impulse response **100** of the received global pilot signal **50_1**.

[0055] Since the line of sight multipath component **98_1** travels the shortest distance d_1, the first received component **98_1** is the line of sight component. If the line of sight component is not received, the first received component **98_1** will be the closest and, accordingly, the best available estimate for the line of sight component. The processor **82_1** compares the chip code sequence of the first received component **98_1** with the chip code sequence used to synchronize the assigned pilot chip code sequence. This comparison determines the delay due to multipath, **MD_1**. The multipath delay, **MD_1**, is transmitted to the base station **36_1**.

[0056] A processor **66_1** and multipath receiver **104_1** within the base station **36_1** perform the same analysis on the received assigned pilot signal. As a result, the multipath delay, **MD_2**, of the assigned pilot signal is determined. Additionally, multipath delay recovery means **106_1** recovers the transmitted global pilot signal's multipath delay **MD_1** for use by the processor **66_1**. The processor **66_1** compares the generated global pilot chip code sequence to the recovered assigned pilot chip code sequence to determine the round trip propagation delay **$2\tau_1$**. To correct for multipath, the processor **66_1** subtracts both the global pilot signal's multipath delay **MD_1** and the assigned pilot signals multipath delay **MD_2** from the calculated round trip propagation delay, **$2\tau_1$**. The corrected round trip propagation delay is used to determine the subscriber unit's location in one of the techniques as previously described.

[0057] Although the invention has been described in part by making detailed reference to certain specific embodiments, such detail is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation within the scope of the claims.

Claims

1. A method for geographically locating a subscriber unit (40_1) using a plurality of base stations (36) in a wireless

CDMA communication system, each base station (36) transmitting a first spread spectrum signal having a first code, for each received first signal, the subscriber unit (40_1) transmits a second spread spectrum signal having a second code to that received first signal's base station (36) time synchronized with that received first signal, the method **characterized by**:

for each received first signal at the subscriber unit (40_1), analyzing an impulse response of multipath components of that received first signal to determine a first received component;
at each base station (36), analyzing an impulse response of multipath components of that base station's received second signal to determine a first received component;
for each base station (36), determining a distance between that base station (36) and the subscriber unit (40_1) based on in part a timing difference between the second code of the received second signal and the first code of that base station's transmitted first signal and the determined first received component for that base station's received second signal; and
determining the location of the subscriber unit (40_1) based on in part the determined distances, a fixed location of each base station (36) and a maximum likelihood estimation.

2. The method of claim 1 further **characterized by** the base stations (36) are time synchronized to each other; the subscriber unit (40_1) determines a time difference of reception between the received first signals and transmits a representation of the time difference; and the maximum likelihood estimation uses the determined time difference to determine the subscriber unit location.

3. The method of claim 1 further **characterized by** the base stations (36) are time synchronized to each other; a time difference of reception between each base station's received second signal is determined; and the maximum likelihood estimation uses the determined time difference to determine the subscriber unit location.

4. The method of claim 2 or 3 further **characterized by** using a formula for a hyperbola associated with each time difference and a formula for a circle associated with each determined distance in the maximum likelihood estimation.

5. The method of claim 1, 2, 3 or 4 further **characterized by** the transmission of each second signal is time synchronized to the determined first received component of its received first signal.

6. The method of claim 1, 2, 3 or 4 further **characterized by** the subscriber unit (40_1) transmitting, for each base station (36), a representation of a time difference between the first received component and a synchronization time of the transmitted second signal of that base station (36).

7. A wireless CDMA communication system for locating a subscriber unit (40_1) using a plurality of base stations (36), each base station (36) transmitting a first spread spectrum signal having a first code, for each received first signal, the subscriber unit (40_1) transmits a second spread spectrum signal having a second code to that received first signal's base station (36) time synchronized with that received first signal, the system **characterized by**:

the subscriber unit (40_1) comprising means (82_1), for each received first signal, for analyzing an impulse response of multipath components of that received first signal to determine a first received component;
each base station (36) comprising means (66) for analyzing an impulse response of multipath components of that base station's received second signal to determine a first received component, means for determining a distance between that base station (36) and the subscriber unit (40) based on in part a timing difference between the second code of the received second signal and the first code of that base station's transmitted first signal and the determined first received component for that base station's received second signal; and
means (66, 68, 70) for determining the location of the subscriber unit based on in part the determined distances, a fixed location of each base station (36) and a maximum likelihood estimation.

8. The system of claim 7 further **characterized by** the base stations (36) are time synchronized to each other; the subscriber unit (40_1) having means (82_1) for determining a time difference of reception between the received first signals; and means (60_1) for transmitting a representation of the time difference; and the maximum likelihood estimation using the determined time difference to determine the subscriber unit location.

9. The system of claim 7 further **characterized by** the base stations (36) are time synchronized to each other; the system further comprising means (66, 68, 70) for determining a time difference of reception between each base

station's received second signal; and the maximum likelihood estimation using the determined time difference to determine the subscriber unit location.

10. The system of claim 8 or 9 further **characterized by** using a formula for a hyperbola associated with each time difference and a formula for a circle associated with each determined distance in the maximum likelihood estimation.

11. The system of claim 7, 8, 9 or 10 further **characterized by** the transmission of each second signal is time synchronized to the determined first received component of its received first signal.

12. The system of claim 7, 8, 9 or 10 further **characterized by** the subscriber unit (40_1) comprising means (60_1) for transmitting for each base station, a representation of a time difference between the closest line of sight component and a synchronization time of the transmitted second signal of that base station (36).

Patentansprüche

1. Verfahren zum geografischen Lokalisieren einer Teilnehmereinheit (40_1) unter der Verwendung mehrerer Basisstationen (36) in einem drahtlosen CDMA-Kommunikationssystem, wobei jede Basisstation (36) für jedes empfangene erste Signal, ein erstes Spreizspektrumssignal mit einem ersten Code sendet, die Teilnehmereinheit (40_1) ein zweites Spreizspektrumssignal mit einem zweiten Code an die Basisstation (36) dieses empfangenen ersten Signals zeitsynchronisiert mit diesem empfangenen ersten Signal sendet, wobei das Verfahren **gekennzeichnet ist durch** folgende Schritte:

   bei der Teilnehmereinheit (40_1) für jedes empfangene erste Signal, Analysieren einer Impulsantwort von Mehrwegekomponenten dieses empfangenen ersten Signals zum Bestimmen einer ersten empfangenen Komponente;
   bei jeder Basisstation (36), Analysieren einer Impulsantwort von Mehrwegekomponenten des empfangenen zweiten Signals dieser Basisstation zum Bestimmen einer ersten empfangenen Komponente;
   für jede Basisstation (36), Bestimmen einer Entfernung zwischen der Basisstation (36) und der Teilnehmereinheit (40_1) teilweise auf der Grundlage einer Zeitdifferenz zwischen dem zweiten Code des empfangenen zweiten Signals und dem ersten Code des gesendeten ersten Signals dieser Basisstation und der bestimmten ersten empfangenen Komponente für das empfangene zweite Signal dieser Basisstation; und
   Bestimmen des Standorts der Teilnehmereinheit (40_1) teilweise auf der Grundlage der bestimmten Entfernungen, einem festen Standort jeder Basisstation (36) und einer Maximum-Likelihood-Schätzung.

2. Verfahren nach Anspruch 1, weiter **dadurch gekennzeichnet, dass** die Basisstationen (36) miteinander zeitsynchronisiert sind; die Teilnehmereinheit (40_1) eine Zeitdifferenz des Empfangs zwischen den empfangenen ersten Signalen bestimmt und eine Darstellung der Zeitdifferenz aussendet; und die Maximum-Likelihood-Schätzung die bestimmte Zeitdifferenz zum Bestimmen des Teilnehmereinheitsstandorts verwendet.

3. Verfahren nach Anspruch 1, weiter **dadurch gekennzeichnet, dass** die Basisstationen (36) miteinander zeitsynchronisiert sind; eine Zeitdifferenz des Empfangs zwischen dem empfangenen zweiten Signal einer jeden Basisstation bestimmt wird; und die Maximum-Likelihood-Schätzung die bestimmte Zeitdifferenz zum Bestimmen des Teilnehmereinheitsstandorts verwendet.

4. Verfahren nach Anspruch 2 oder 3, weiter **dadurch gekennzeichnet, dass** bei der Maximum-Likelihood-Schätzung eine Formel für eine der jeweiligen Zeitdifferenz zugeordneten Hyperbel und einer Formel für einen der jeweiligen bestimmten Entfernung zugeordneten Kreis verwendet wird.

5. Verfahren nach Anspruch 1, 2, 3 oder 4, weiter **dadurch gekennzeichnet, dass** das Senden eines jeden zweiten Signals mit der bestimmten ersten empfangenen Komponente seines empfangenen ersten Signals zeitsynchronisiert ist.

6. Verfahren nach Anspruch 1, 2, 3 oder 4, weiter **dadurch gekennzeichnet, dass** die Teilnehmereinheit (40_1) für jede Basisstation (36) eine Darstellung einer Zeitdifferenz zwischen der ersten empfangenen Komponente und einer Synchronisationszeit des gesendeten zweiten Signals dieser Basisstation (36) sendet.

7. Drahtloses CDMA-Kommunikationssystem zum Lokalisieren einer Teilnehmereinheit (40_1) unter der Verwendung mehrerer Basisstationen (36), wobei jede Basisstation (36) für jedes empfangene erste Signal ein erstes Spreizspektrumssignal mit einem ersten Code sendet, wobei die Teilnehmereinheit (40_1) ein zweites Spreizspektrumssignal mit einem zweiten Code an die Basisstation (36) des empfangenen ersten Signals zeitsynchronisiert mit diesem empfangenen ersten Signal sendet, wobei das System **dadurch gekennzeichnet ist, dass:**

   die Teilnehmereinheit (40_1) eine Einrichtung (82_1) für jedes empfangene erste Signal zum Analysieren einer Impulsantwort von Mehrwegekomponenten dieses empfangenen ersten Signals zum Bestimmen einer ersten empfangenen Komponente umfasst;
   jede Basisstation (36) eine Einrichtung (66) zum Analysieren einer Impulsantwort von Mehrwegekomponenten des empfangenen zweiten Signals dieser Basisstation zum Bestimmen einer ersten empfangenen Komponente, eine Einrichtung zum Bestimmen einer Entfernung zwischen dieser Basisstation (36) und der Teilnehmereinheit (40) teilweise auf der Grundlage einer Zeitdifferenz zwischen dem zweiten Code des empfangenen zweiten Signals und dem ersten Code des gesendeten ersten Signals und der bestimmten ersten empfangenen Komponente für das empfangene zweite Signal dieser Basisstation umfasst; und
   eine Einrichtung (66, 68, 70) zum Bestimmen des Standorts der Teilnehmereinheit teilweise auf der Grundlage der bestimmten Entfernungen, einem festen Standort jeder Basisstation (36) und einer Maximum-Likelihood-Schätzung.

8. System nach Anspruch 7, weiter **dadurch gekennzeichnet, dass** die Basisstationen (36) miteinander zeitsynchronisiert sind; die Teilnehmereinheit (40_1) eine Einrichtung (82_1) zum Bestimmen einer Zeitdifferenz des Empfangs zwischen den empfangenen ersten Signalen; und eine Einrichtung (60_1) zum Aussenden einer Darstellung der Zeitdifferenz aufweist; und die Maximum-Likelihood-Schätzung die bestimmte Zeitdifferenz zum Bestimmen des Teilnehmereinheitsstandorts verwendet.

9. System nach Anspruch 7, weiter **dadurch gekennzeichnet, dass** die Basisstationen (36) miteinander zeitsynchronisiert sind; das System weiter eine Einrichtung (66, 68, 70) zum Bestimmen einer Zeitdifferenz des Empfangs zwischen dem empfangenen zweiten Signal einer jeden Basisstation umfasst; und die Maximum-Likelihood-Schätzung die bestimmte Zeitdifferenz zum Bestimmen des Teilnehmereinheitsstandorts verwendet.

10. System nach Anspruch 8 oder 9, weiter **dadurch gekennzeichnet, dass** bei der Maximum-Likelihood-Schätzung eine Formel für eine der jeweiligen Zeitdifferenz zugeordneten Hyperbel und einer Formel für einen der jeweiligen bestimmten Entfernung zugeordneten Kreis verwendet wird.

11. System nach Anspruch 7, 8, 9 oder 10, weiter **dadurch gekennzeichnet, dass** das Senden eines jeden zweiten Signals mit der bestimmten ersten empfangenen Komponente seines empfangenen ersten Signals zeitsynchronisiert ist.

12. System nach Anspruch 7, 8, 9 oder 10, weiter **dadurch gekennzeichnet, dass** die Teilnehmereinheit (40_1) eine Einrichtung (60_1) zum Senden für jede Basisstation (36) einer Darstellung einer Zeitdifferenz zwischen der Komponente der kürzesten Luftlinie und einer Synchronisationszeit des gesendeten zweiten Signals dieser Basisstation (36) umfasst.

Revendications

1. Procédé pour localiser géographiquement l'appareil d'un abonné (40_1) en utilisant plusieurs stations de base (36) dans un système de télécommunication AMDC sans fil, chaque station de base (36) émettant un premier signal à spectre étalé ayant un premier code, pour chaque premier signal reçu, l'appareil de l'abonné (40_1) émet un second signal à spectre étalé ayant un second code à la station de base de ce premier signal reçu (36) synchronisé en temps avec ce premier signal reçu, le procédé étant **caractérisé par** :

   pour chaque premier signal reçu à l'appareil de l'abonné (40_1), l'analyse d'une réponse impulsionnelle des composants de propagation par trajets multiples de ce premier signal reçu pour déterminer un premier composant reçu ;
   à chaque station de base (36), l'analyse d'une réponse impulsionnelle des composants de propagation par trajets multiples du second signal reçu de cette station de base pour déterminer un premier composant reçu ;
   pour chaque station de base (36), la détermination d'une distance entre cette station de base (36) et l'appareil

de l'abonné (40_1) sur la base en partie d'une différence de temps entre le second code du second signal reçu et le premier code du premier signal émis de cette station de base et le premier composant reçu déterminé pour le second signal reçu de cette station de base ; et
la détermination de la localisation de l'appareil de l'abonné (40_1) sur la base en partie des distances déterminées, une localisation fixe de chaque station de base (36) et une estimation du maximum de vraisemblance.

2. Procédé selon la revendication 1 **caractérisé de plus en ce que** les stations de base (36) sont synchronisées en temps entre elles ; l'appareil de l'abonné (40_1) détermine une différence de temps de réception entre les premiers signaux reçus et émet une représentation de la différence de temps ; et l'estimation du maximum de vraisemblance utilise la différence de temps déterminée pour déterminer la localisation de l'appareil de l'abonné.

3. Procédé selon la revendication 1 **caractérisé de plus en ce que** les stations de base (36) sont synchronisées en temps entre elles ; une différence de temps de réception entre le second signal reçu de chaque station de base est déterminée ; et l'estimation du maximum de vraisemblance utilise la différence de temps déterminée pour déterminer la localisation de l'appareil de l'abonné.

4. Procédé selon la revendication 2 ou 3 **caractérisé de plus par** l'utilisation d'une formule pour une hyperbole associée à chaque différence de temps et une formule pour un cercle associé à chaque distance déterminée dans l'estimation du maximum de vraisemblance.

5. Procédé selon la revendication 1, 2, 3 ou 4 **caractérisé de plus en ce que** la transmission de chaque second signal est synchronisée en temps au premier composant reçu déterminé de son premier signal reçu.

6. Procédé selon la revendication 1, 2, 3 ou 4 **caractérisé de plus par le fait que** l'appareil de l'abonné (40_1) émet, pour chaque station de base (36) une représentation d'une différence de temps entre le premier composant reçu et un temps de synchronisation du second signal émis de cette station de base (36).

7. Système de télécommunication AMDC sans fil pour localiser l'appareil d'un abonné (40_1) en utilisant plusieurs stations de base (36), chaque station de base (36) émettant un premier signal à spectre étalé ayant un premier code, pour chaque premier signal reçu, l'appareil de l'abonné (40_1) émet un second signal à spectre étalé ayant un second code à la station de base (36) de ce premier signal reçu synchronisé en temps avec ce premier signal reçu, le système étant **caractérisé en ce que** :

   l'appareil de l'abonné (40_1) comprend un moyen (82_1), pour chaque premier signal reçu, pour analyser une réponse impulsionnelle des composants de propagation par trajets multiples de ce premier signal reçu pour déterminer un premier composant reçu ;
   chaque station de base (36) comprend un moyen (66) pour analyser une réponse impulsionnelle des composants de propagation par trajets multiples du second signal reçu de cette station de base pour déterminer un premier composant reçu, un moyen pour déterminer une distance entre cette station de base (36) et l'appareil de l'abonné (40) sur la base en partie d'une différence de temps entre le second code du second signal reçu et le premier code du premier signal émis de cette station de base et le premier composant reçu déterminé pour le second signal reçu de cette station de base ; et
   un moyen (66, 68, 70) pour déterminer la localisation de l'appareil de l'abonné sur la base en partie des distances déterminées, une localisation fixe de chaque station de base (36) et une estimation du maximum de vraisemblance.

8. Système selon la revendication 7 **caractérisé de plus en ce que** les stations de base (36) sont synchronisées en temps entre elles ; l'appareil de l'abonné (40_1) ayant un moyen (82_1) pour déterminer une différence de temps de réception entre les premiers signaux reçus ; et un moyen (60_1) pour émettre une représentation de la différence de temps ; et l'estimation du maximum de vraisemblance en utilisant la différence de temps déterminée pour déterminer la localisation de l'appareil de l'abonné.

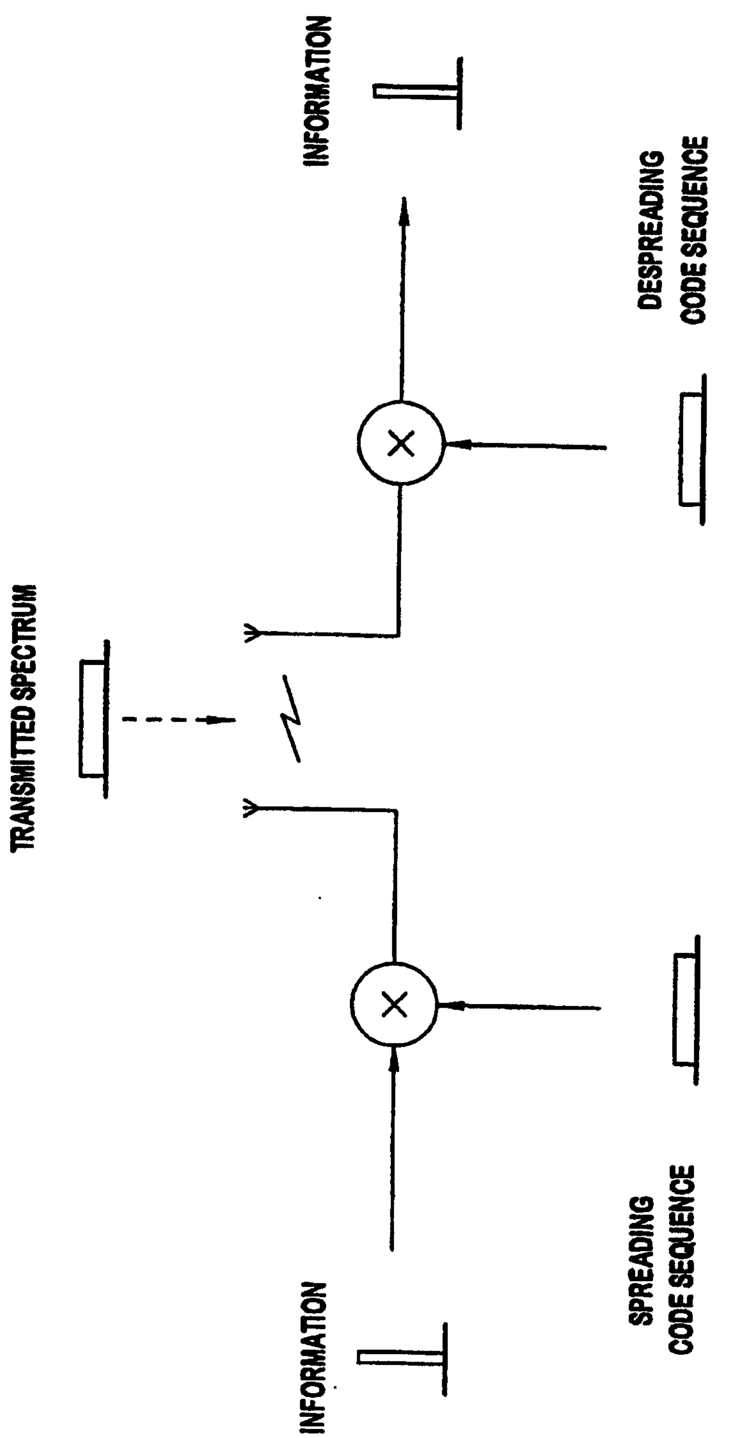
9. Système selon la revendication 7 **caractérisé de plus en ce que** les stations de base (36) sont synchronisées en temps entre elles ; le système comprenant de plus un moyen (66, 68, 70) pour déterminer une différence de temps de réception entre le second signal reçu de chaque station de base ; et l'estimation du maximum de vraisemblance en utilisant la différence de temps déterminée pour déterminer la localisation de l'appareil de l'abonné.

10. Système selon la revendication 8 ou 9 **caractérisé de plus par** l'utilisation d'une formule pour une hyperbole

associée à chaque différence de temps et une formule pour un cercle associé à chaque distance déterminée dans l'estimation du maximum de vraisemblance.

11. Système selon la revendication 7, 8, 9 ou 10 **caractérisé de plus en ce que** la transmission de chaque second signal est synchronisée en temps au premier composant reçu déterminé de son premier signal reçu.

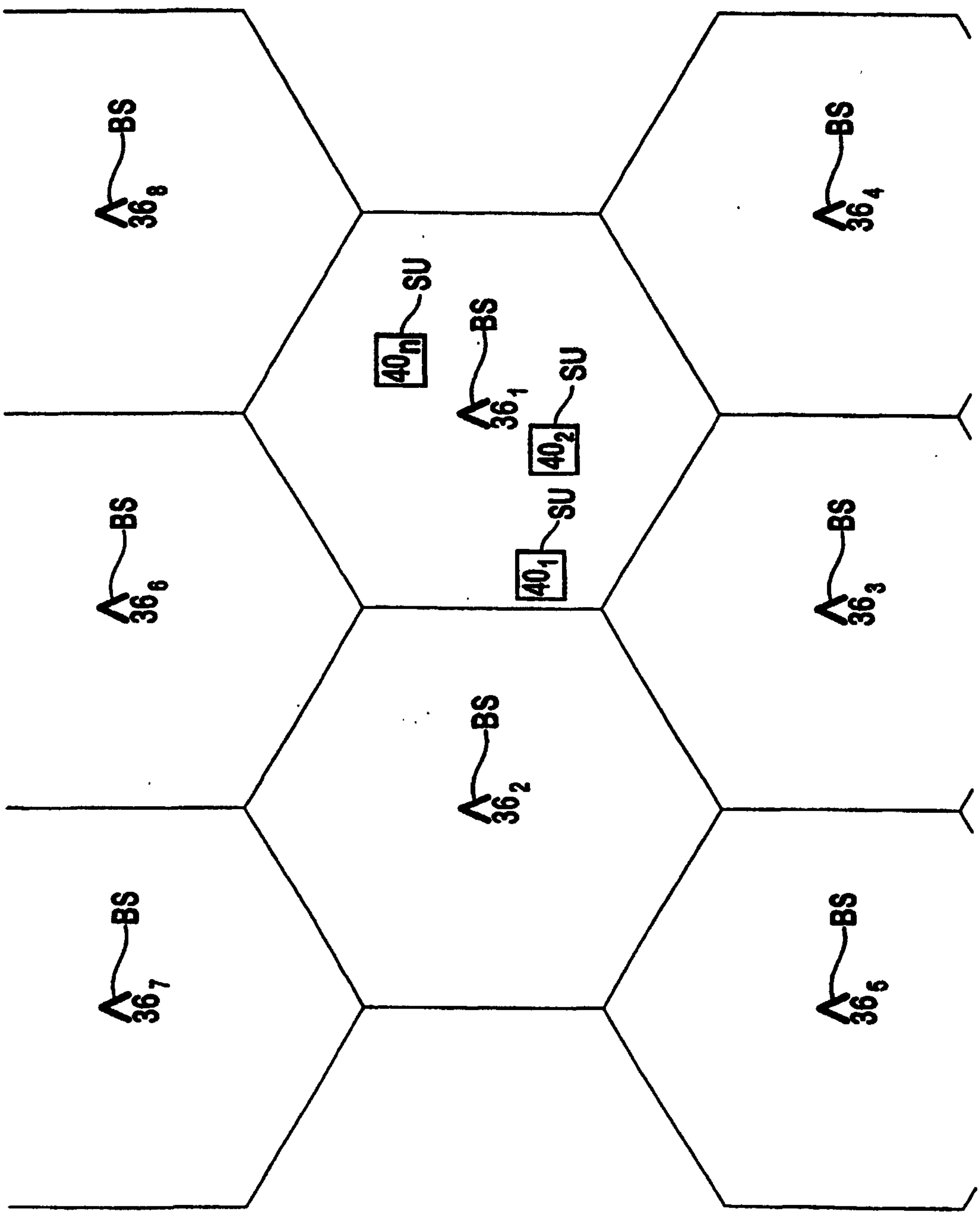
12. Système selon la revendication 7, 8, 9 ou 10 **caractérisé de plus en ce que** l'appareil de l'abonné (40_1) comprend un moyen (60_1) pour émettre pour chaque station de base une représentation d'une différence de temps entre le composant de visibilité directe la plus proche et un temps de synchronisation du second signal émis de cette station de base (36).



PRIOR ART

FIG. 1

FIG. 2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36_1
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36_2
BS
36_3
BS
36_4
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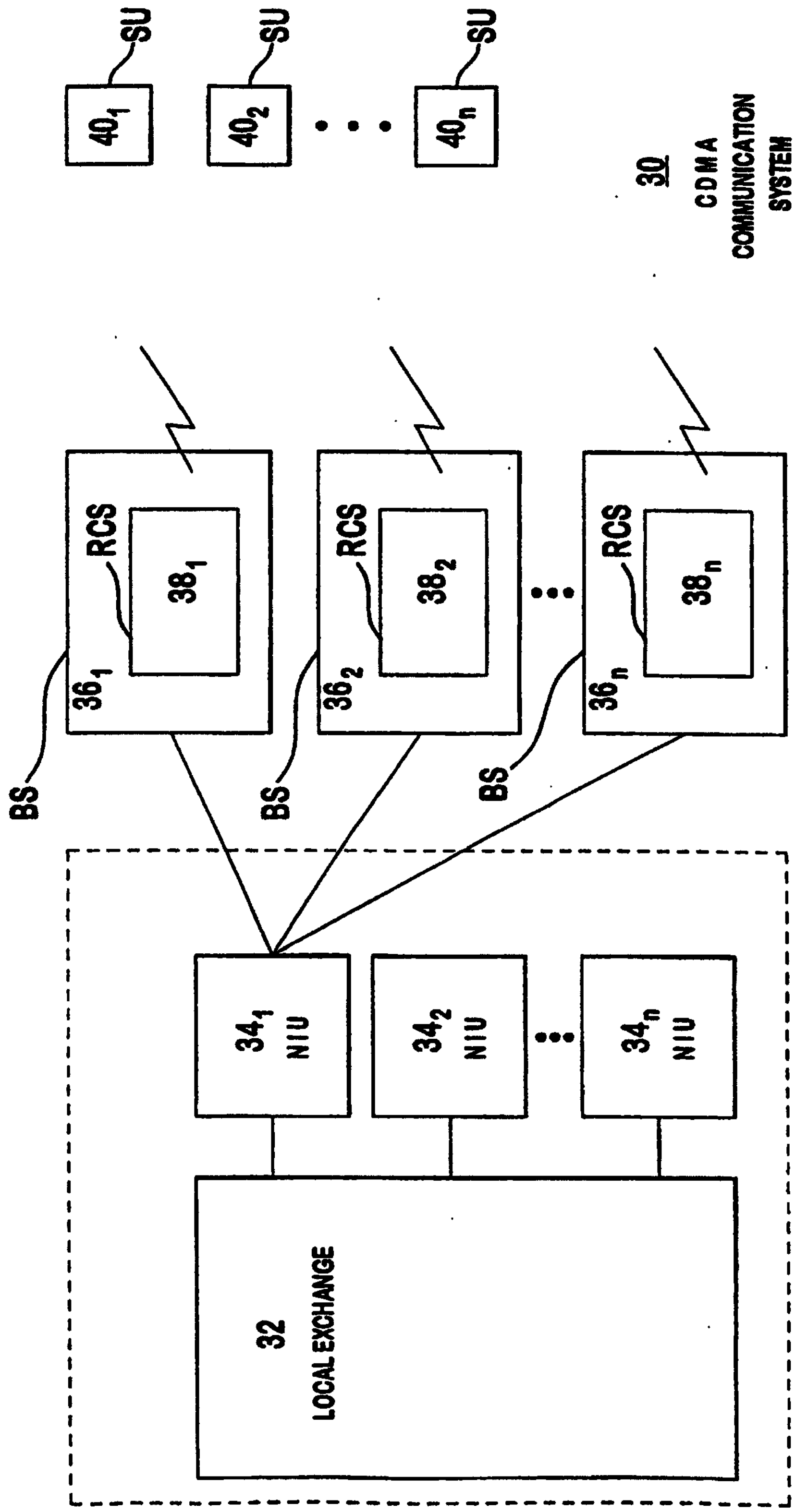
36_5
BS
36_6
BS
36_7
BS
36_8
SU
40_1
SU
40_2
SU
40_n

FIG. 3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SU
SU
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40_2
40_n
30
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SYSTEM
RCS
RCS
RCS
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38_n
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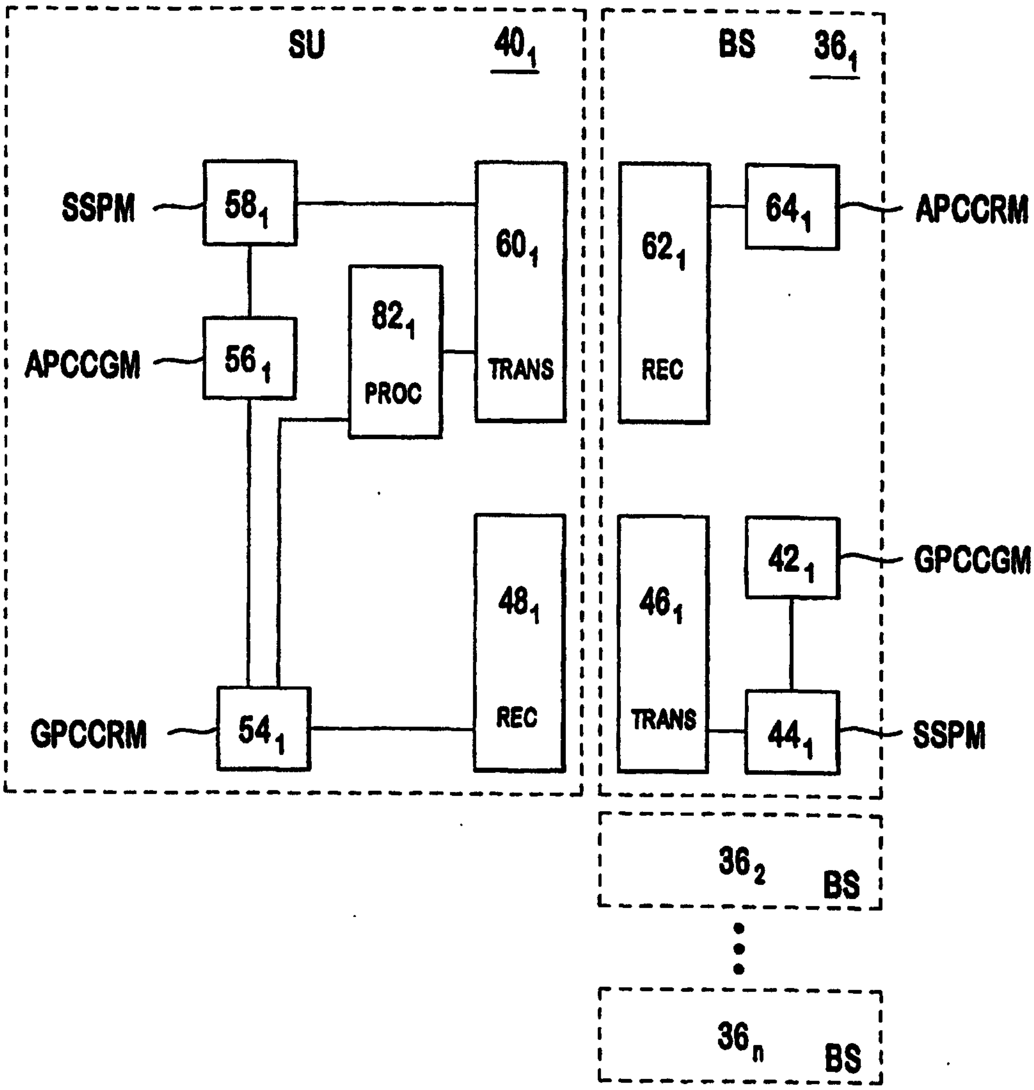
NIU
32
LOCAL EXCHANGE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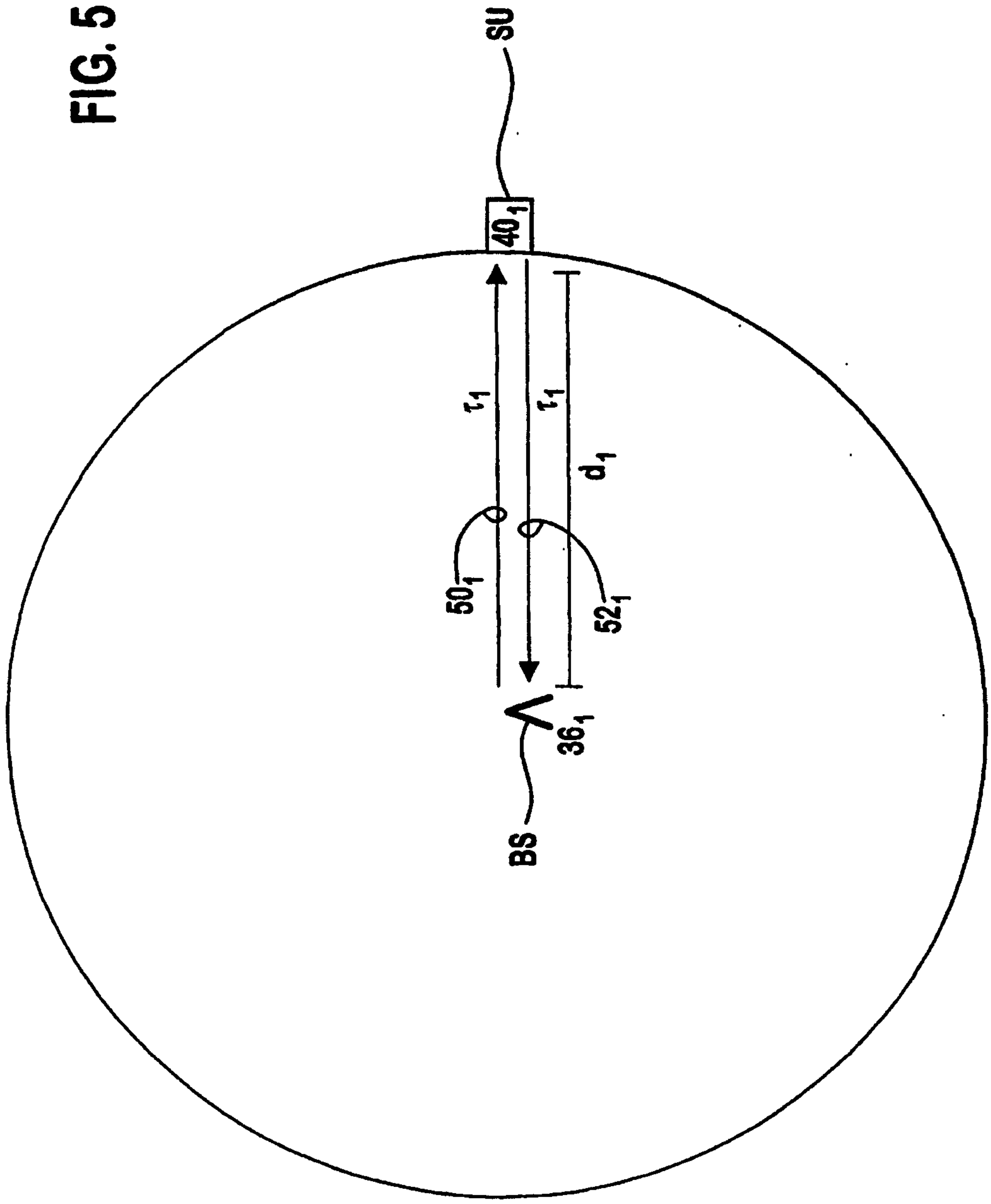
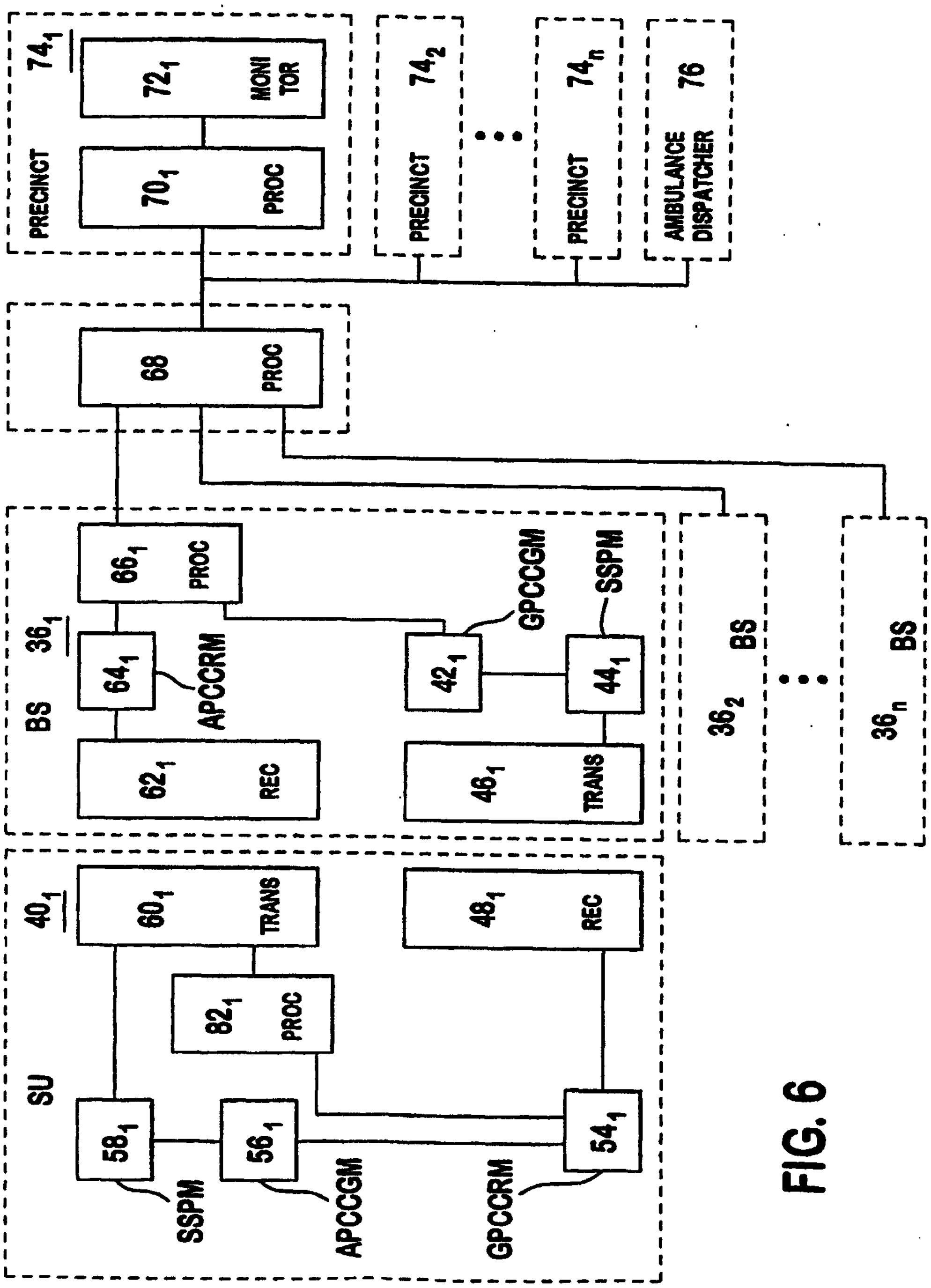
SSPM
58_1
APCCGM
56_1
82_1
PROC
60_1
TRANS
GPCCRM
54_1
48_1
REC
BS
36_1
62_1
REC
64_1
APCCRM
46_1
TRANS
42_1
GPCCGM
44_1
SSPM
36_2
BS
36_n
BS

FIG. 4

FIG. 5




PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
64_1
APCCRM
62_1
REC
42_1
GPCCGM
44_1
SSPM
46_1
TRANS
36_2
BS
36_n
BS
SU
40_1
60_1
TRANS
82_1
PROC
48_1
REC
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SSPM
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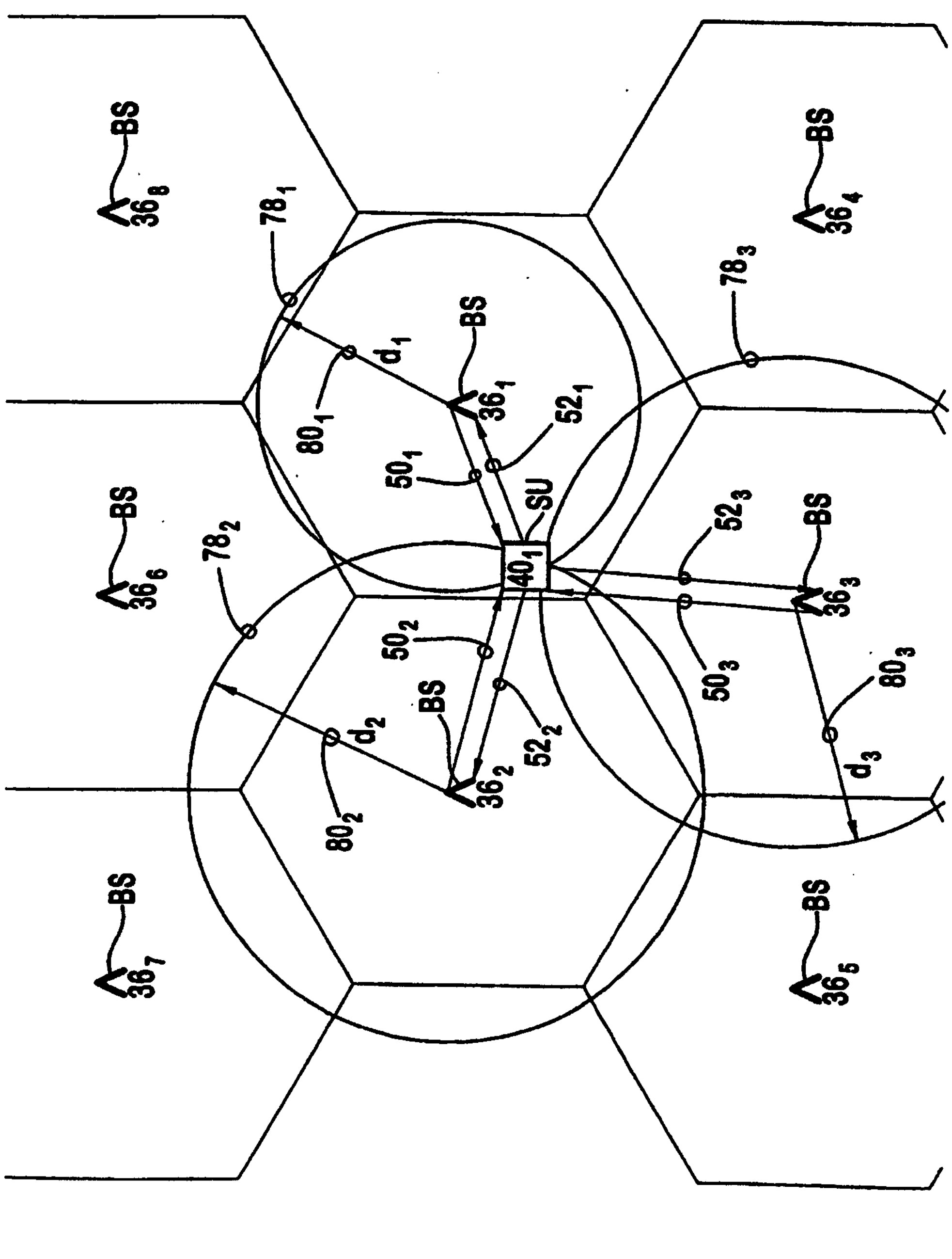
APCCGM
54_1
GPCCRM

FIG. 6

FIG. 7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BS
36_6
BS
36_7
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78_2
78_3
BS
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d_1
80_1
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40_1
50_2
52_2
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BS
36_4
BS
36_5

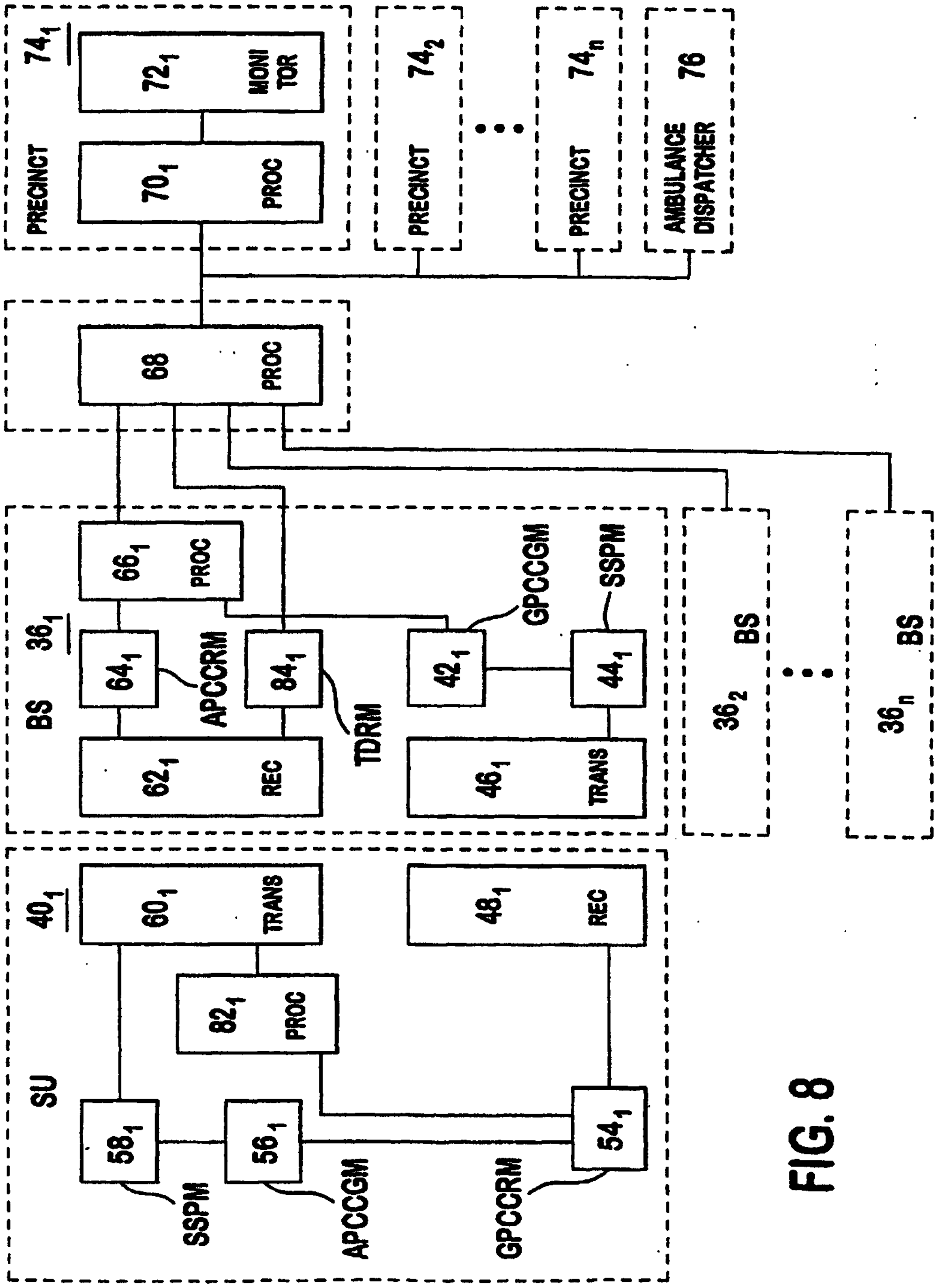

PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
64_1
APCCRM
84_1
TDRM
62_1
REC
42_1
GPCCGM
44_1
SSPM
46_1
TRANS
36_2
BS
36_n
BS
SU
40_1
60_1
TRANS
82_1
PROC
48_1
REC
58_1
SSPM
56_1
APCCGM
54_1
GPCCRM

FIG. 8

FIG. 9

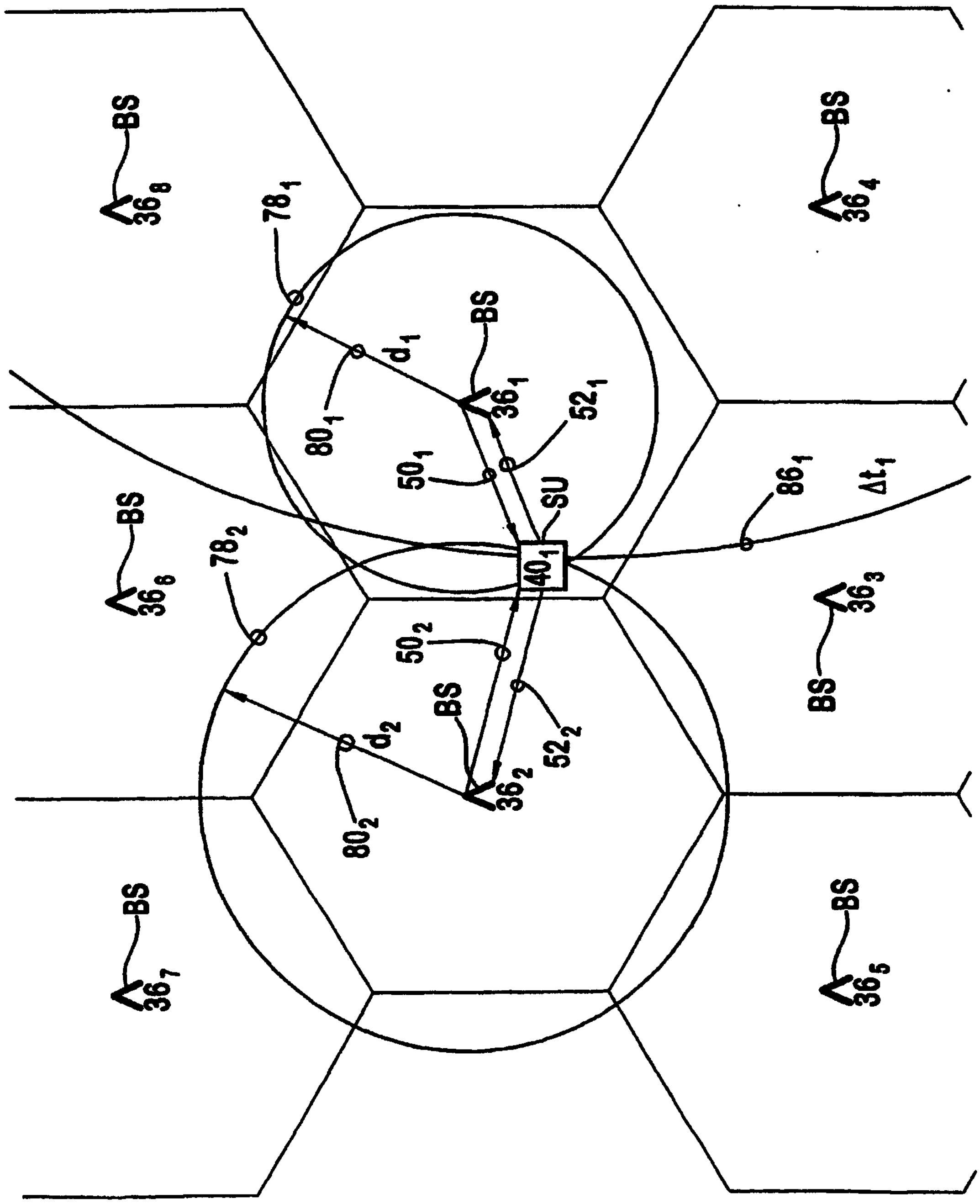
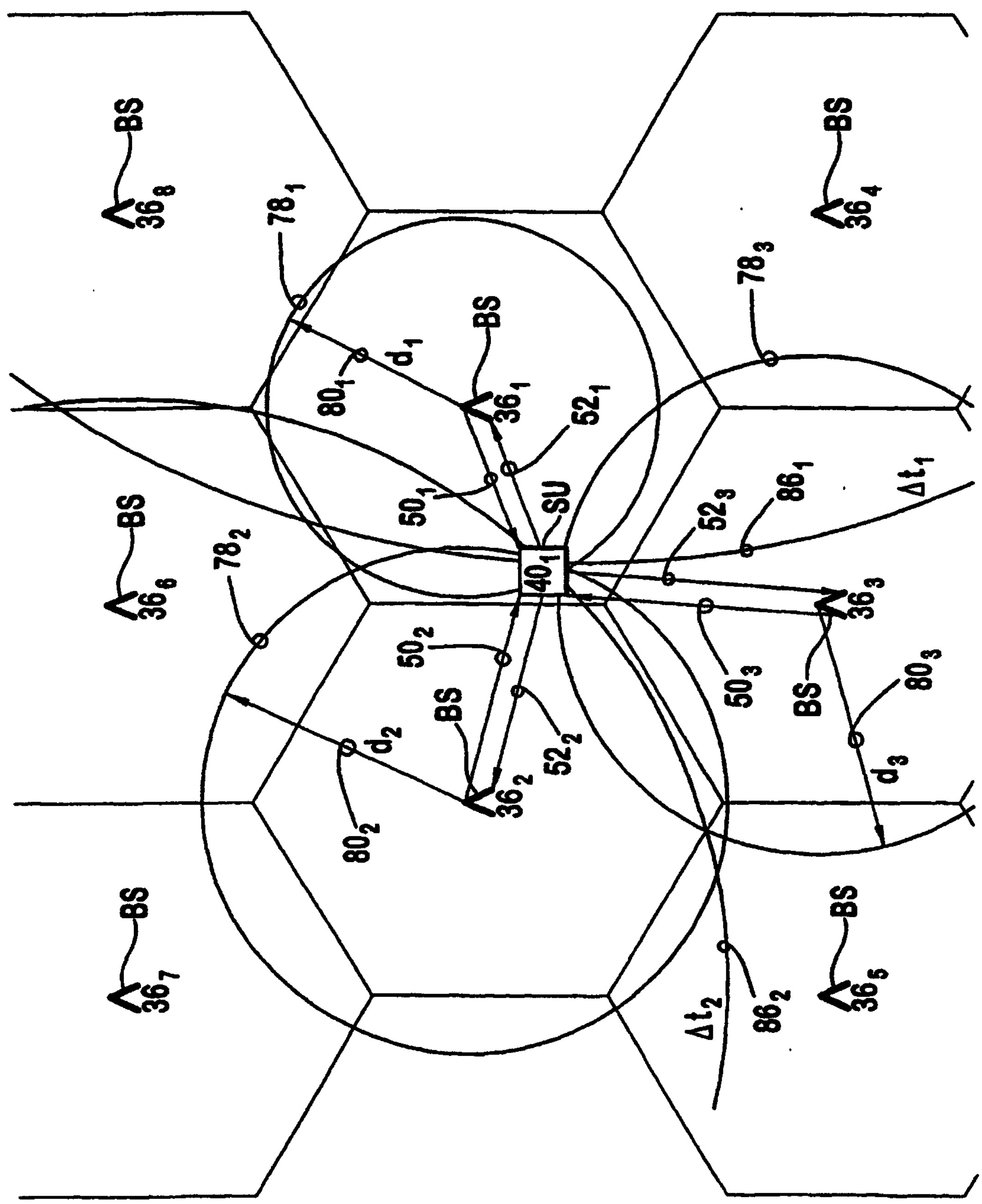

BS
368
BS
364
781
d1
BS
361
801
521
501
SU
401
861
Δt1
BS
366
782
363
BS
502
BS
d2
522
362
802
BS
367
BS
365

FIG. 10


BS
36₈
78₁
BS
36₄
78₃
d₁
80₁
BS
36₁
52₁
SU
50₁
BS
36₆
78₂
40₁
52₃
86₁
Δt₁
36₃
50₂
50₃
BS
80₃
BS
d₂
52₂
36₂
d₃
80₂
BS
36₇
Δt₂
86₂
BS
36₅

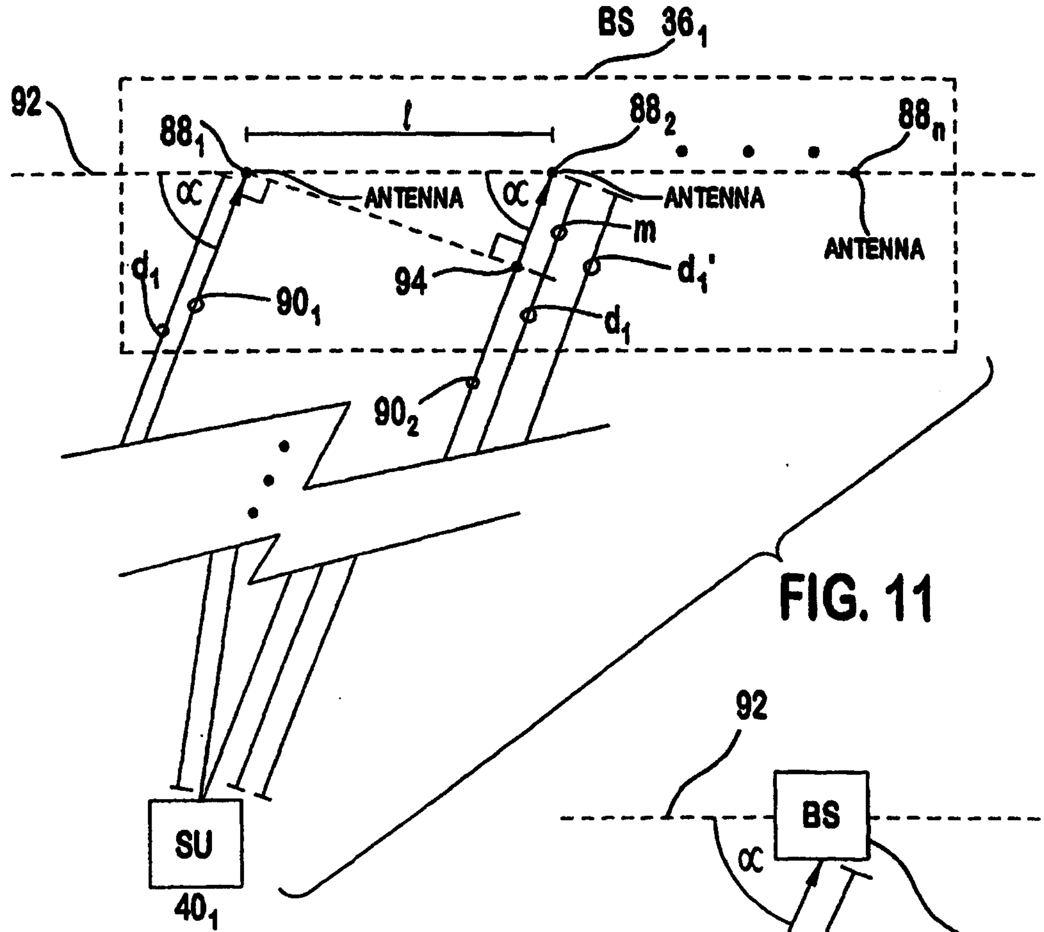

BS 36
92
88
88
88
ANTENNA
ANTENNA
ANTENNA
m
94
d
90
90
40
SU

FIG. 11

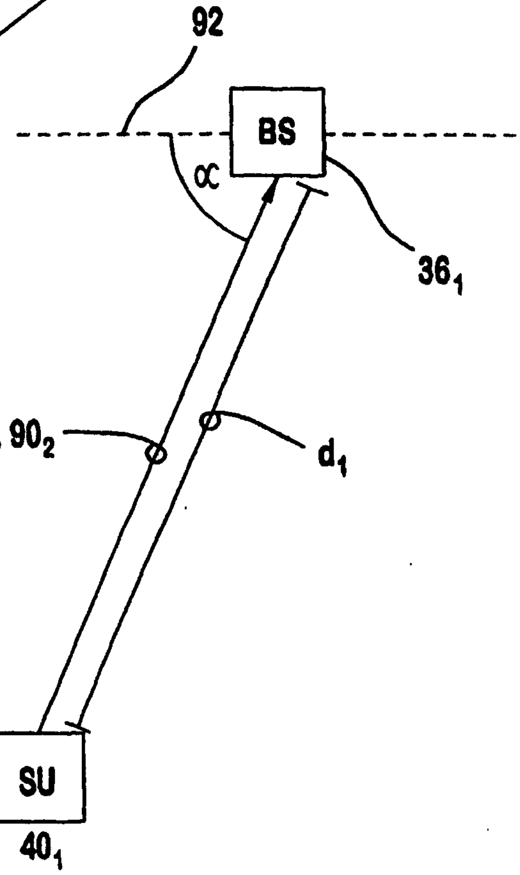

92
BS
36
90, 90
d
SU
40

FIG. 12

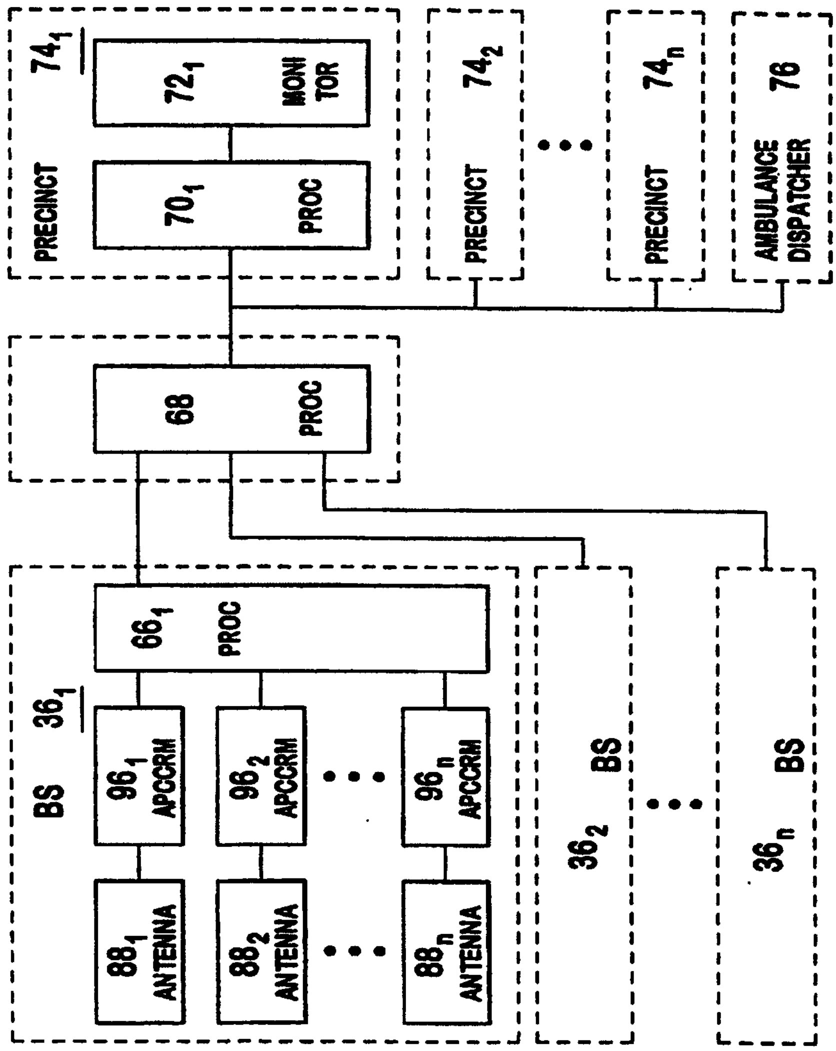

PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
96_1
APCCRM
96_2
APCCRM
96_n
APCCRM
88_1
ANTENNA
88_2
ANTENNA
88_n
ANTENNA
36_2
BS
36_n
BS

FIG. 13

FIG. 14

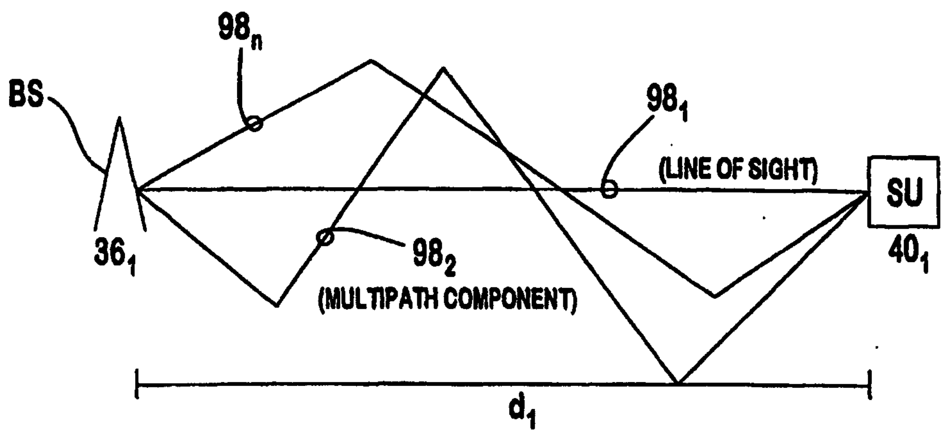
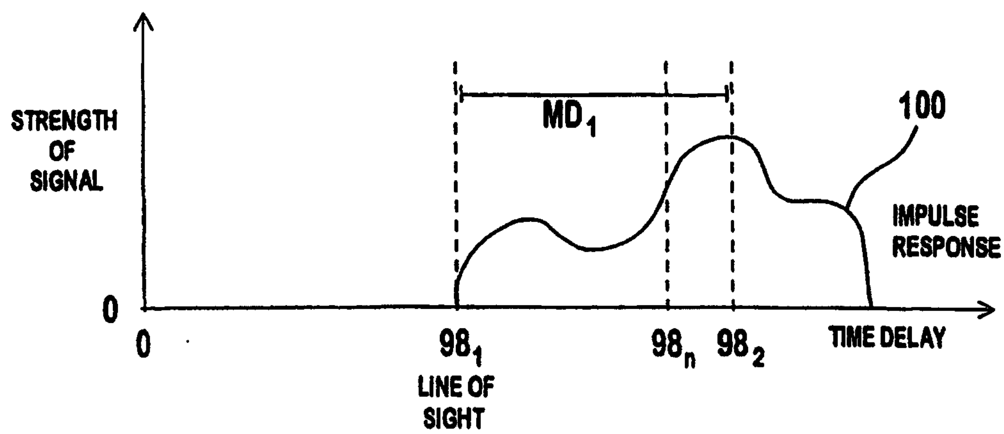

98n
BS
98 1
(LINE OF SIGHT)
SU
36 1
98 2
40 1
(MULTIPATH COMPONENT)
d 1

FIG. 15


STRENGTH
OF
SIGNAL
MD 1
100
IMPULSE
RESPONSE
0
0
98 1
LINE OF
SIGHT
98n
98 2
TIME DELAY

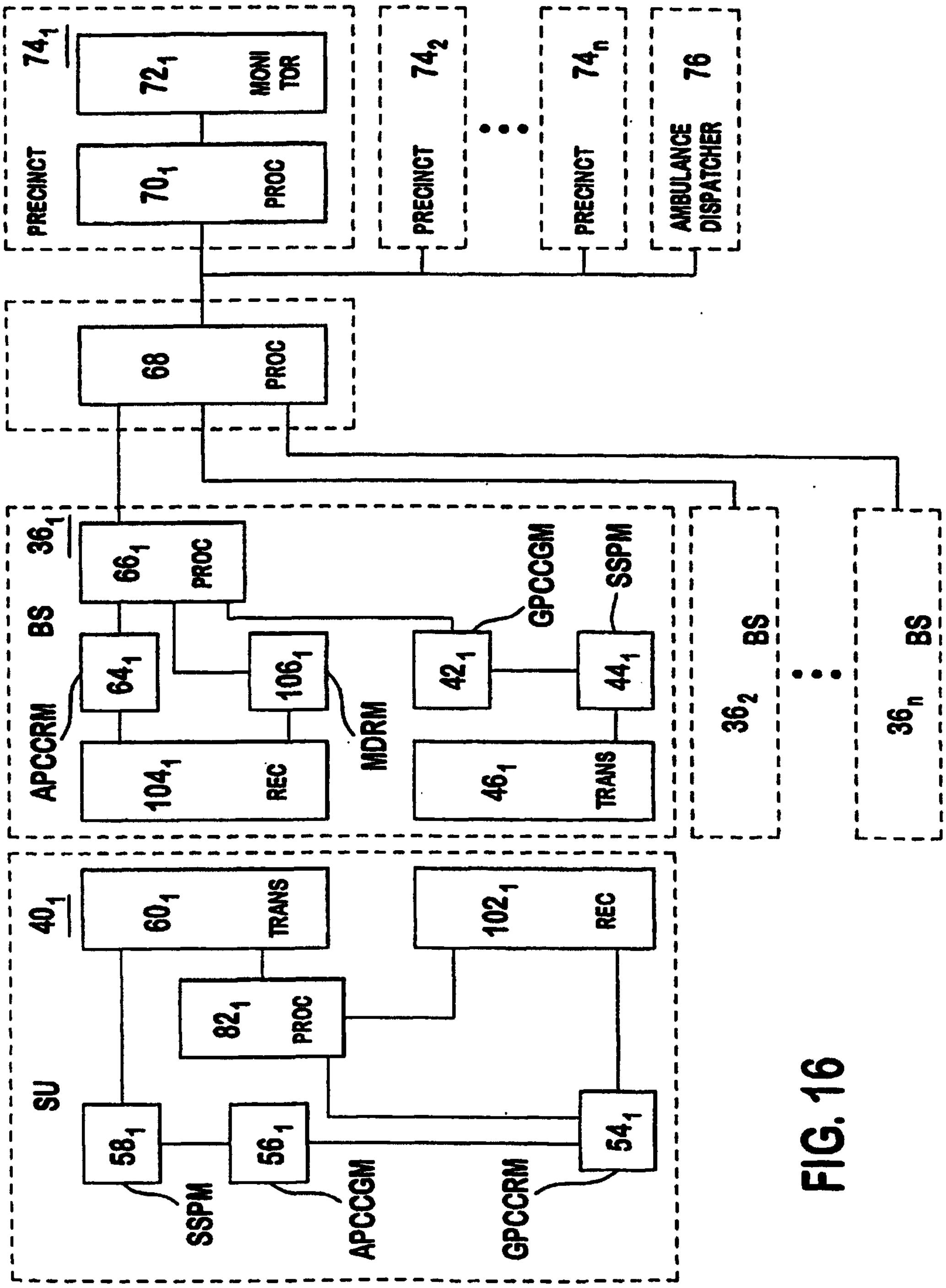

PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
64_1
APCCRM
104_1
REC
106_1
MDRM
42_1
GPCCGM
44_1
SSPM
46_1
TRANS
36_2
BS
36_n
BS
SU
40_1
60_1
TRANS
82_1
PROC
102_1
REC
58_1
SSPM
56_1
APCCGM
54_1
GPCCRM

FIG. 16