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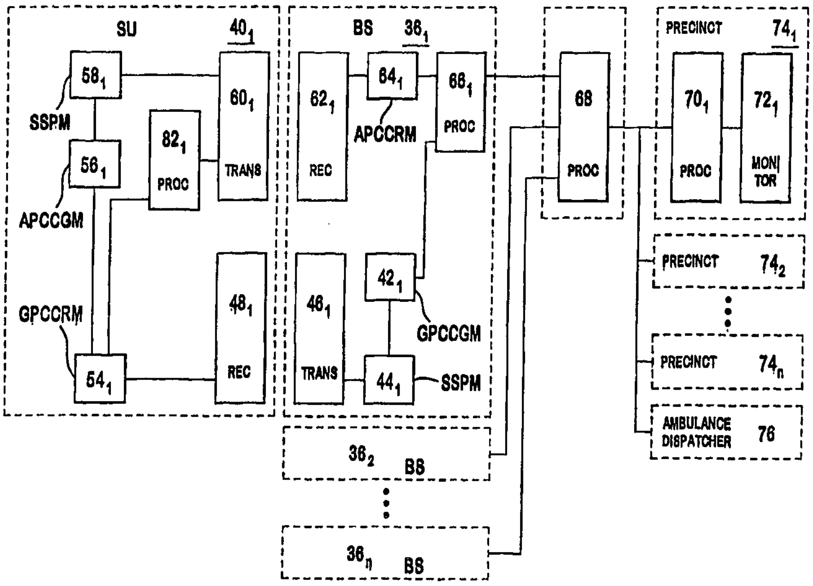

(57) Abstract

The invention determines the geographic location of a subscriber unit within a CDMA communication system. At least one base station transmits a spread spectrum signal with a chip code sequence unique to that base station. A subscriber unit receives the base station signal and transmits a spread spectrum signal wiht a unique chip code sequence time synchronized with the chip code sequence of the received base station signal. The base station receives the subscriber unit signal and compares the chip code sequence of the received subscriber unit singal with the chip code sequence signal transmitted by the base station to determine the location of the subscriber unit.

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METHOD AND SYSTEM FOR LOCATING A MOBILE SUBSCRIBER IN A CDMA COMMUNICATION SYSTEM

Field of the Invention

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

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.

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.

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.

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

The invention determines the geographic location of a subscriber unit within a CDMA communication system. At least one base station transmits a spread spectrum signal with a chip code sequence unique to that base station. A subscriber unit receives the base station signal and transmits a spread spectrum signal with a unique chip code sequence time synchronized with the chip code sequence of the received base station signal. The base station receives the subscriber unit signal and compares the chip code sequence of the received subscriber unit signal with the chip code sequence signal transmitted by the base station to determine the location of the subscriber unit.

BRIEF DESCRIPTION OF THE DRAWINGS

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 first embodiment of the present invention using at least three base stations.

Figure 7 is an illustration of locating a subscriber unit using the first embodiment of the present invention with at least three base stations.

Figure 8 is a block diagram of a second embodiment of the present invention showing components used in a subscriber unit.

Figure 9 is an illustration of locating a subscriber unit using the second embodiment of the present invention with two base stations.

Figure 10 is an illustration of locating a subscriber unit using the second embodiment of the present invention with more than two base stations.

Figure 11 is a detailed illustration of the third embodiment of the present invention having a base station with multiple antennas.

Figure 12 is an illustration of the third embodiment having a base station with multiple antennas.

Figure 13 is a block diagram of components used in the third embodiment.

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 fourth embodiment correcting for multipath.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout.

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.

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.

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 CDMA systems, for example a B-CDMA™ system, each subscriber unit sends a unique assigned pilot signal to synchronize transmissions in a reverse direction.

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

36_1, **36_2** ... **36_n** is in wireless communication with a plurality of subscriber units **40_1**, **40_2** ... **40_n**, which may be fixed or mobile. Each subscriber unit **40_1**, **40_2** ... **40_n** communicates with either the closest base station **36_1** or the base station **36_1** which provides the strongest communication signal. Each base station **36_1**, **36_2** ... **36_n** is in communication with other components within the communication system **30** as shown in **Figure 3**.

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

Figure 4 depicts a block diagram of the pertinent parts of an existing spread spectrum CDMA communication system. Each independent base station **36_1**, **36_2** ... **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.

A receiver 48_1 at a subscriber unit 40_1 receives available signals from a plurality of base stations $36_1, 36_2 \ldots 36_n$. 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:

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

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**.

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 $36_1, 36_2 \ldots 36_n$. 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.

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**.

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**.

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:

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

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.

Figure 6 is a block diagram of a first embodiment of 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**.

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.

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 τ_1, τ_2 ... τ_n and the respective distance d_1, d_2 ... d_n between the subscriber unit **40_1** and the respective base station **36_1, 36_2 ... 36_n**.

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.

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**.

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:

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

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

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

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.

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.

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.

Figure 8 is a second 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.

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).

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:

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

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

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

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.

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.

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:

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

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.

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.

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**.

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.

Another embodiment shown in **Figures 11, 12** and **13** uses a 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.

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.

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 $\propto$ can be determined by the following geometric relationship:

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

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

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

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:

$$\lambda = c/f.$$

Equation (11)

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.

An alternate embodiment uses 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**.

A fourth embodiment corrects for multipath. **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**.

Figure 13 is a graph showing the impulse response **136** 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 **106** shows the collective signal magnitude of all the multipath components received at each propagation delay.

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**.

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., incorporated here by reference. A processor **82_1** within the subscriber unit **40_1** analyzes the impulse response **100** of the received global pilot signal **50_1**.

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**.

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.

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 without departing from the scope of the invention as disclosed in the teachings herein.

* * *

CLAIMS

1. A method for geographically locating a subscriber unit within a CDMA communication system having base stations with fixed locations, the method comprising:

(a) transmitting a first spread spectrum signal with a first pseudo random chip code sequence from a base station;

(b) receiving of said first spread spectrum signal including first signal multipath components at said subscriber unit;

(c) determining a first received component of the received first signal multipath components;

(d) transmitting a second spread spectrum signal with a second pseudo random chip code sequence from said subscriber unit, said second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal;

(e) receiving said second spread spectrum signal including second signal multipath components at said base station;

(f) determining a first received component of the received second signal multipath components;

(g) determining a distance between said base station and said subscriber unit based on the first received component of said second signal; and

(h) determining said subscriber unit's geographic location based on said distance determination.

2. The method of claim 1 wherein steps (a)-(g) are performed respectively for each of three base stations, each base station associated with a different fixed location, and step (h) determines said subscriber unit's geographic location based on said distance determinations for each of said three base stations.

3. The method of claim 1 further comprising the steps of:

performing steps (a)-(g) for both a first and a second base station, each base station associated with a different fixed location;

time synchronizing said first base station's first spread spectrum signal with said second base station's first spread spectrum signal; and

determining a time difference between said first base station's and said second base station's first spread spectrum signals received at said subscriber unit; and

wherein step (h) determines said subscriber unit's geographic location using said distance determinations and said determined time difference.

4. The method of claim 1 further comprising the steps of:

performing steps (a)-(g) for both a first and a second base station, each base station associated with a different fixed location;

receiving at said second base station said second spread spectrum signal which is time synchronized with said first base station's spread spectrum signal, said first base station's second signal received at said second base station including first base station's second signal multipath components;

determining a first received component of said received first base station's second signal multipath components at said second base station; and

determining a time difference between said first base station's second spread spectrum signal received at said first base station and at said second base station; and

wherein step (h) determines said subscriber unit's geographic location using said distance determinations and said determined time difference.

5. The method of claim 1 wherein said base station has first and second antennas each associated with a different fixed location and said second spread spectrum signal is received separately by said first and second antennas, further comprising the steps of:

determining the phase difference between the respective second spread spectrum signals received by said first and second antennas; and calculating an angle associated with said base station and said subscriber unit based on said phase difference and the distance between the first and second antenna's fixed locations; and

wherein step (h) determines said subscriber unit's geographic location based on said distance determination and said calculated angle.

6. The method of claim 1 wherein said first signal and said second signal are pilot signals.

7. The method of claim 1 wherein said base station's fixed location is associated with a latitude and a longitude and step (h) determines said subscriber unit's geographical location based on said latitude, said longitude, and said distance determination.

8. The method of claim 1 further comprising the step of displaying said subscriber unit's geographic location on a map.

9. The method of claim 1 further comprising the step of displaying said subscriber unit's geographic location as an address.

10. The method of claim 1 wherein step (h) determines said subscriber unit's geographic location using said distance determination in a maximum likelihood estimation.

11. A method for determining a distance between a subscriber unit and a base station in a CDMA communication system, the method comprising:

(a) transmitting a first spread spectrum signal with a first pseudo random chip code sequence from a base station;

(b) receiving of said first spread spectrum signal including first signal multipath components at said subscriber unit;

(c) determining a first received component of the received first signal multipath components;

(d) transmitting a second spread spectrum signal with a second pseudo random chip code sequence from said subscriber unit, said second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal;

(e) receiving said second spread spectrum signal including second signal multipath components at said base station;

(f) determining a first received component of the received second signal multipath components; and

(g) determining a distance between said base station and said subscriber unit based on the first received component of the second signal.

12. A spread spectrum CDMA communication system capable of geographically locating a subscriber unit, the system comprising:

means for determining said subscriber unit's geographic location based on a distance determination; and

at least one base station, each of said at least one base stations comprising:

means for transmitting a first spread spectrum signal with a first pseudo random chip code sequence;

means for receiving a second spread spectrum signal including second signal multipath components;

means for determining a first received component of said received second signal multipath components; and

means for determining a distance between said base station and said subscriber unit as said distance determination based on the first received component of said second signal; and

said subscriber unit comprising:

means for receiving said first spread spectrum signal including first signal multipath components;

means for determining a first received component of said received first signal multipath components; and

means for transmitting a second spread spectrum signal with a second pseudo random chip code sequence, said second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal.

13. The system of claim 12 wherein:

said at least one base station is three base stations, each base station associated with a different fixed location;

said subscriber unit receiving means receives from each of said three base stations said respective first spread spectrum signal including respective first signal multipath components;

said subscriber unit first component determining means determines a respective first received component for each of said respective received first signal multipath components;

said subscriber unit transmitting means transmits three second spread spectrum signals, each associated with one of said three base stations, each with a respective second pseudo random chip code sequence, said respective second pseudo random chip code sequence being time synchronized with said respective received first spread spectrum signal from said respective one of said three base stations; and said geolocation determining means determines said subscriber unit's geographic location based on said distance determination from each of said three base stations

14. The system of claim 12 wherein:

said at least one base station is two base stations, each base station associated with a different fixed location;

said subscriber unit receiving means receives from each of said two base stations said respective first spread spectrum signal including respective first signal multipath components;

said subscriber unit first component determining means determines a respective first received component for each respective received first signal multipath components;

said subscriber unit transmitting means transmits two second spread spectrum signals, each associated with one of said two base stations, each with a respective second pseudo random chip code sequence, said respective second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal from said respective base station;

said subscriber unit further comprising time difference means for determining a time difference between said first base station's and said second base station's first spread spectrum signals received at said subscriber unit;

said geographic location determining means determines said subscriber unit's geographic location using said distance determinations and said time difference; and

said first base station's first spread spectrum signal transmitted at said first base station is time synchronized with said second base station's first spread spectrum signal transmitted at said second base station.

15. The system of claim 12 wherein:

said at least one base station is two base stations, each base station associated with a different fixed location;

said first base station's first spread spectrum signal transmitted at said first base station is time synchronized with said second base station's first spread spectrum signal transmitted at said second base station;

said subscriber unit receiving means receives from each of said two base stations said respective first spread spectrum signal including respective first signal multipath components;

said subscriber unit first component determining means determines a respective first received component for each of said respective received first signal multipath components;

said subscriber unit transmitting means transmits two second spread spectrum signals, each associated with one of said two base stations, each with a respective second pseudo random chip code sequence, each of said respective second pseudo random chip code sequences being time synchronized with said received first spread spectrum signal from said respective one of said two base stations; and

said second base station further comprising:

means for receiving said second spread spectrum signal which is time synchronized with said first base station's spread spectrum signal, said received first base station's second signal including first base station's second signal multipath components;

means for determining a first received component of said received first base station's second signal multipath components at said second base station; and

said geographic location determining means determines said subscriber unit's geographic location using said distance determinations and a determined time difference; and

the system further comprising:

means for determining a time difference between said first base station's second spread spectrum signal received at said first base station and at said second base station as said determined time difference.

16. The system of claim 12 wherein:

said base station further comprising:

a first and second antenna, each associated with a different fixed location and said second spread spectrum signal is received separately by said first and second antennas;

means for determining the phase difference between the respective second spread spectrum signals received by said first and second antennas; and

means for calculating an angle associated with said base station and said subscriber unit based on said phase difference and the distance between the first and second antennas fixed locations; and

wherein said geographic location determining means determines said subscriber unit's geographic location based on said distance determination and said calculated angle.

17. The system of claim 12 further comprising means for displaying said subscriber unit's geographic location on a map.

18. The system of claim 12 further comprising means for displaying said subscriber unit's geographic location as a street address.

19. A CDMA communication system capable of determining a distance between a subscriber unit and a base station, the system comprising:

means for determining a distance between said base station and said subscriber unit based on the first received component of the second signal;

said base station comprising:

means for transmitting a first spread spectrum signal with a first pseudo random chip code sequence;

means for receiving a second spread spectrum signal including second signal multipath components; and

means for determining a first received component of the received second signal multipath components;

said subscriber unit comprising:

means for receiving said first spread spectrum signal including first signal multipath components;

means for determining a first received component of said received first signal multipath components; and means for transmitting a second spread spectrum signal with a second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal.

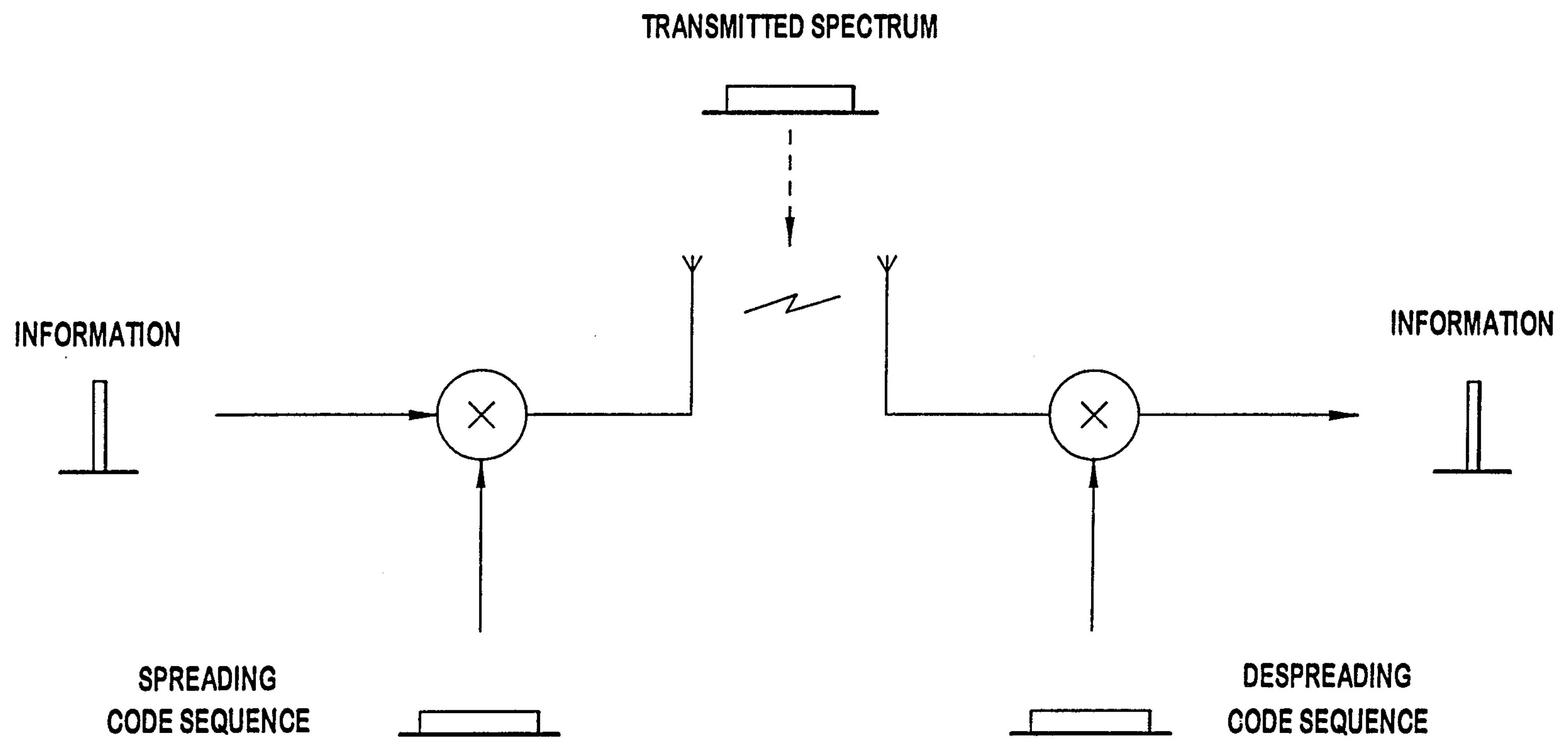
20. A subscriber unit for use in a CDMA communication system capable of geographically locating said subscriber unit, said subscriber unit comprising:

means for receiving a first spread spectrum signal with a first pseudo random chip code sequence, said first signal including first signal multipath components;

means for determining a first received component of said received first signal multipath components;

means for determining a delay associated with said first received component; and

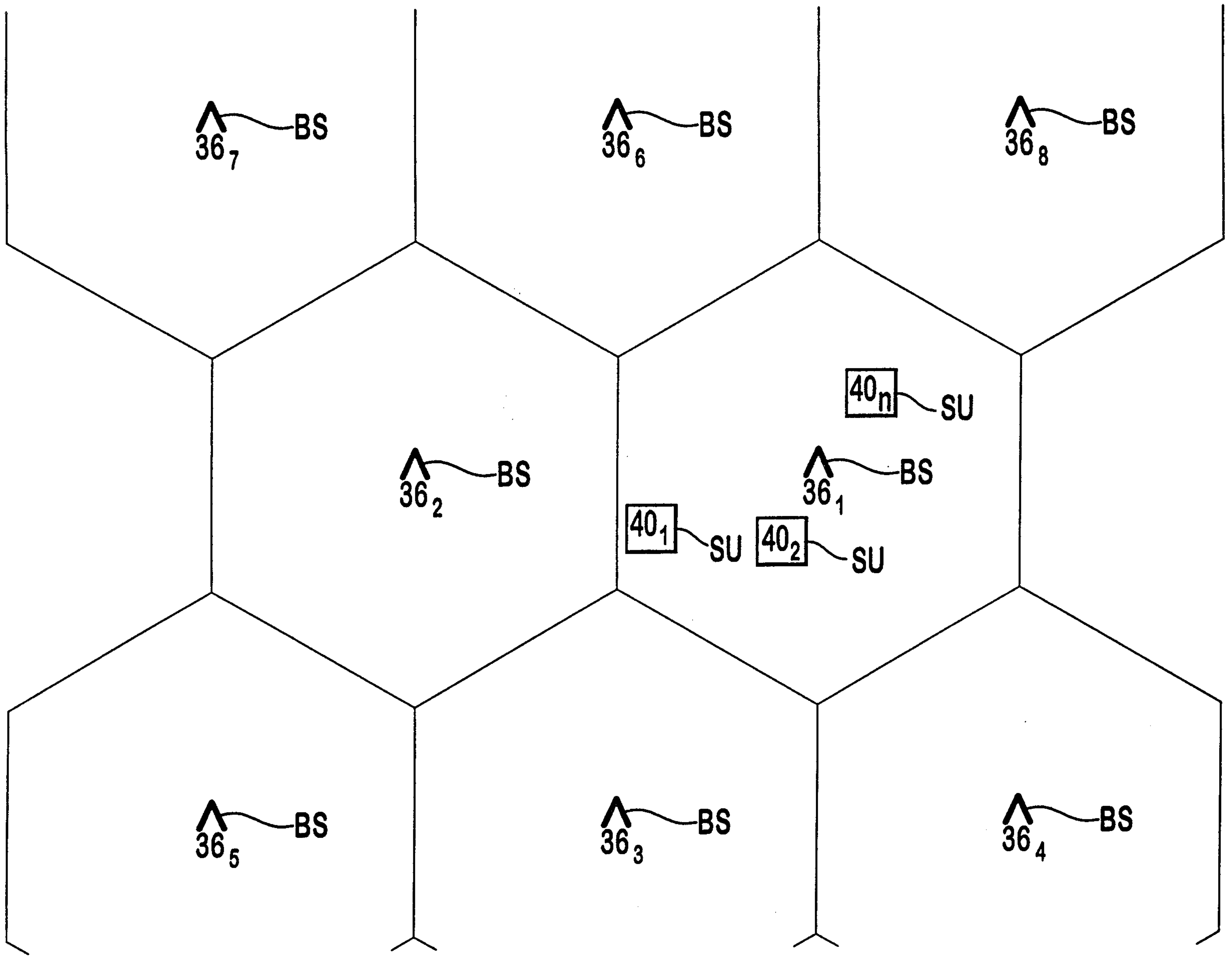
means for transmitting a second spread spectrum signal with a second pseudo random chip code sequence and a signal including said determined delay, said second pseudo random chip code sequence being time synchronized with said received first spread spectrum signal.



PRIOR ART

FIG. 1

FIG. 2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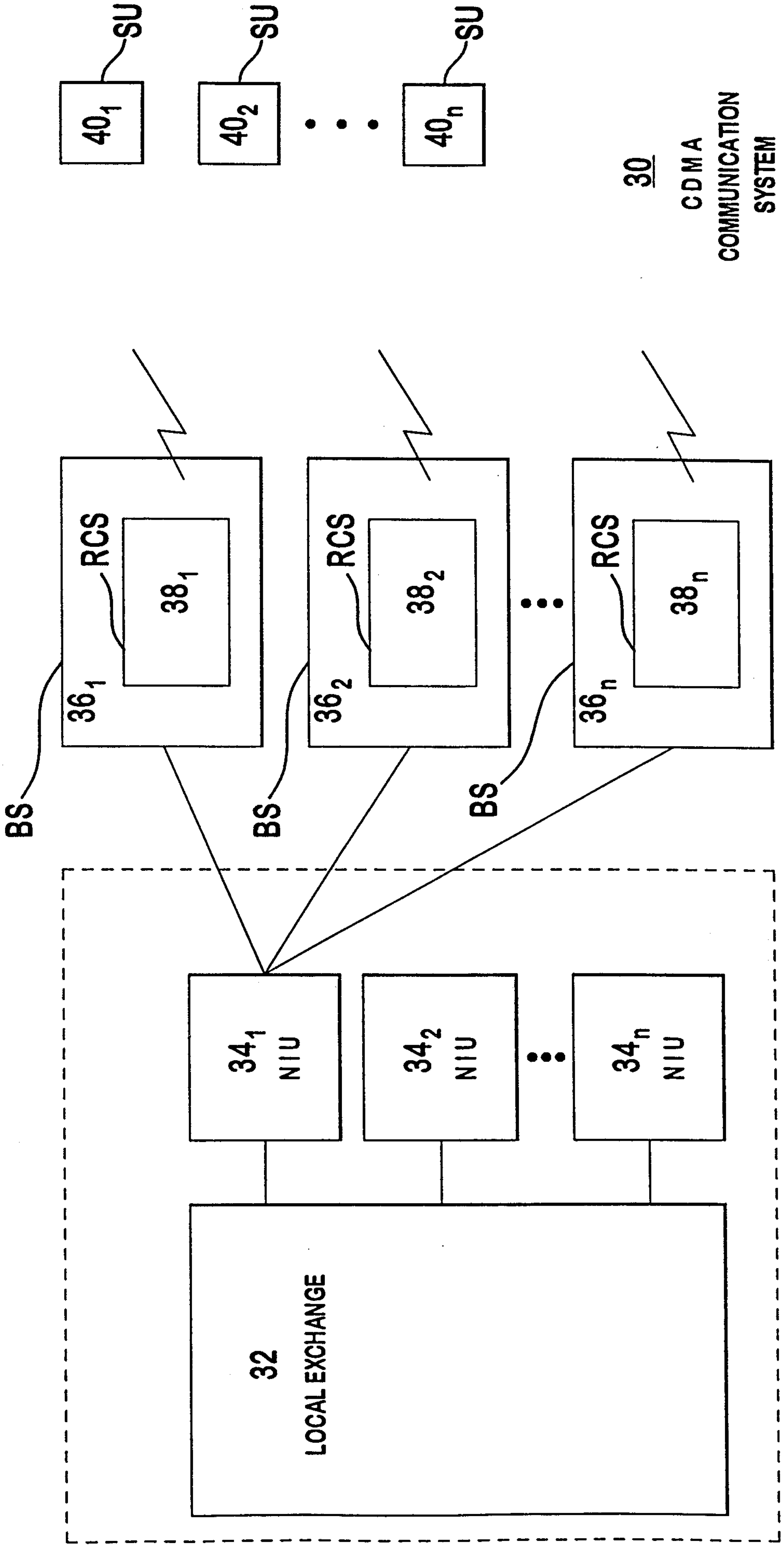
36_4 BS

FIG. 3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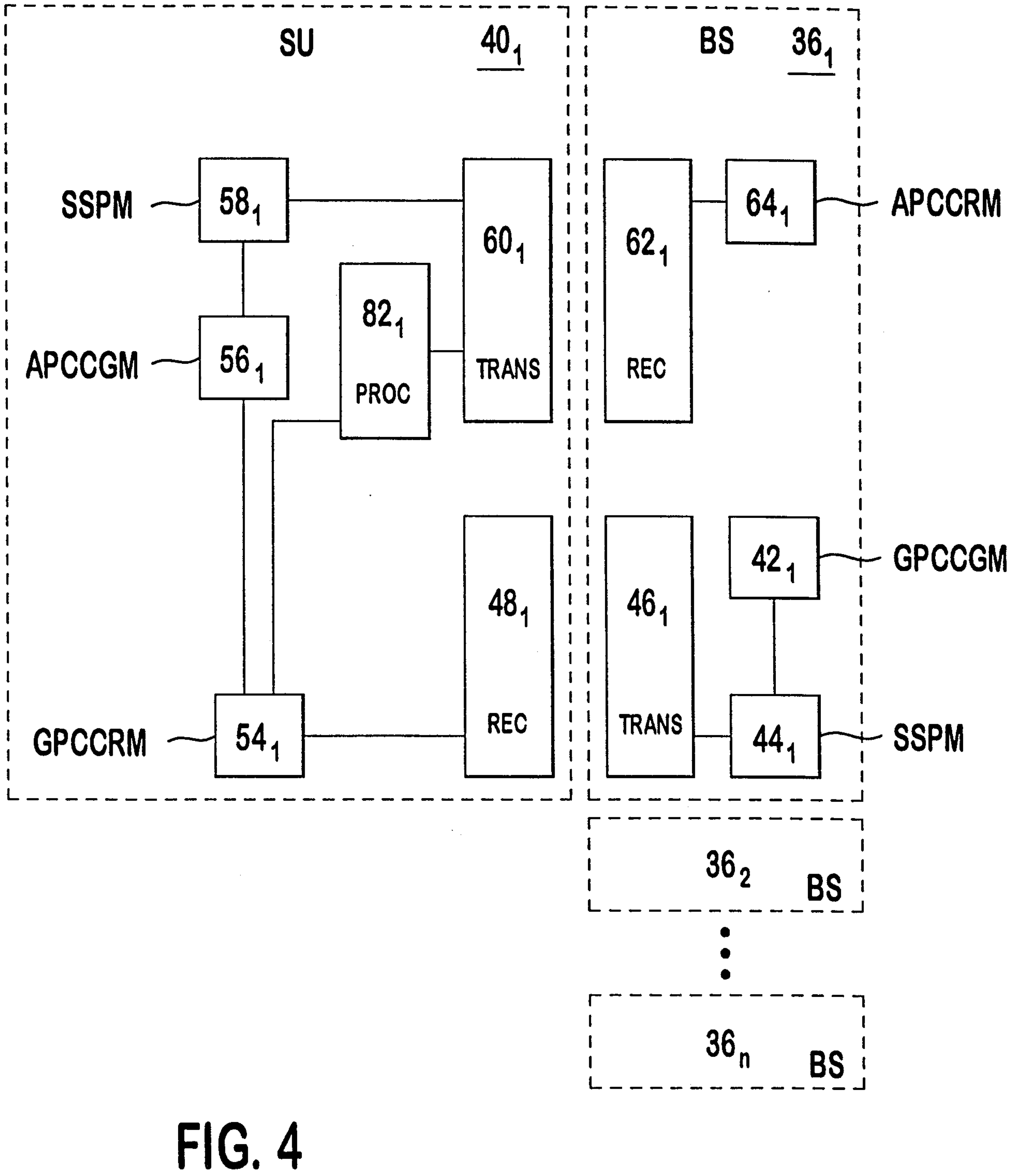
SU
30
CDMA COMMUNICATION SYSTEM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36_2
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36_n
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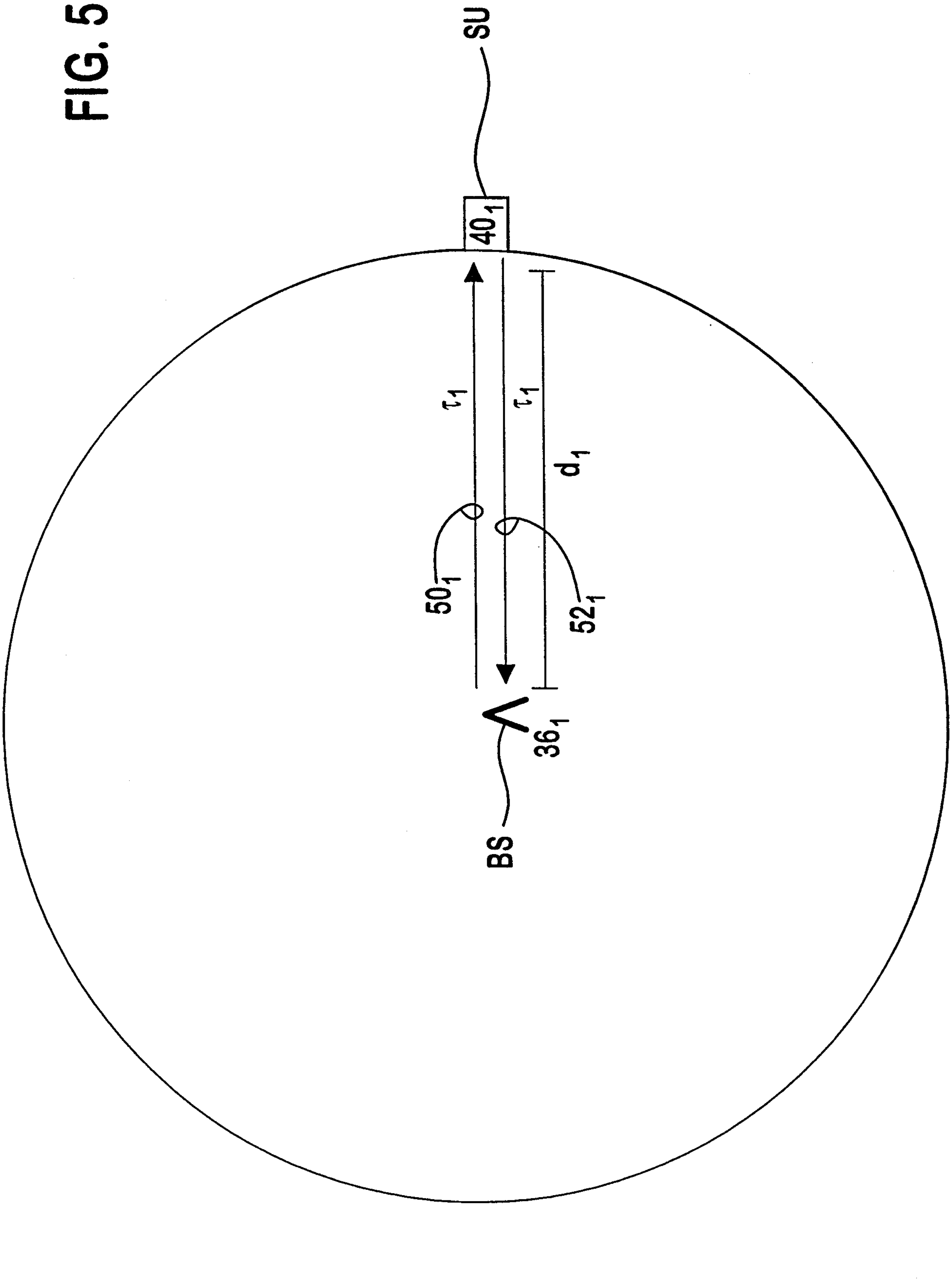
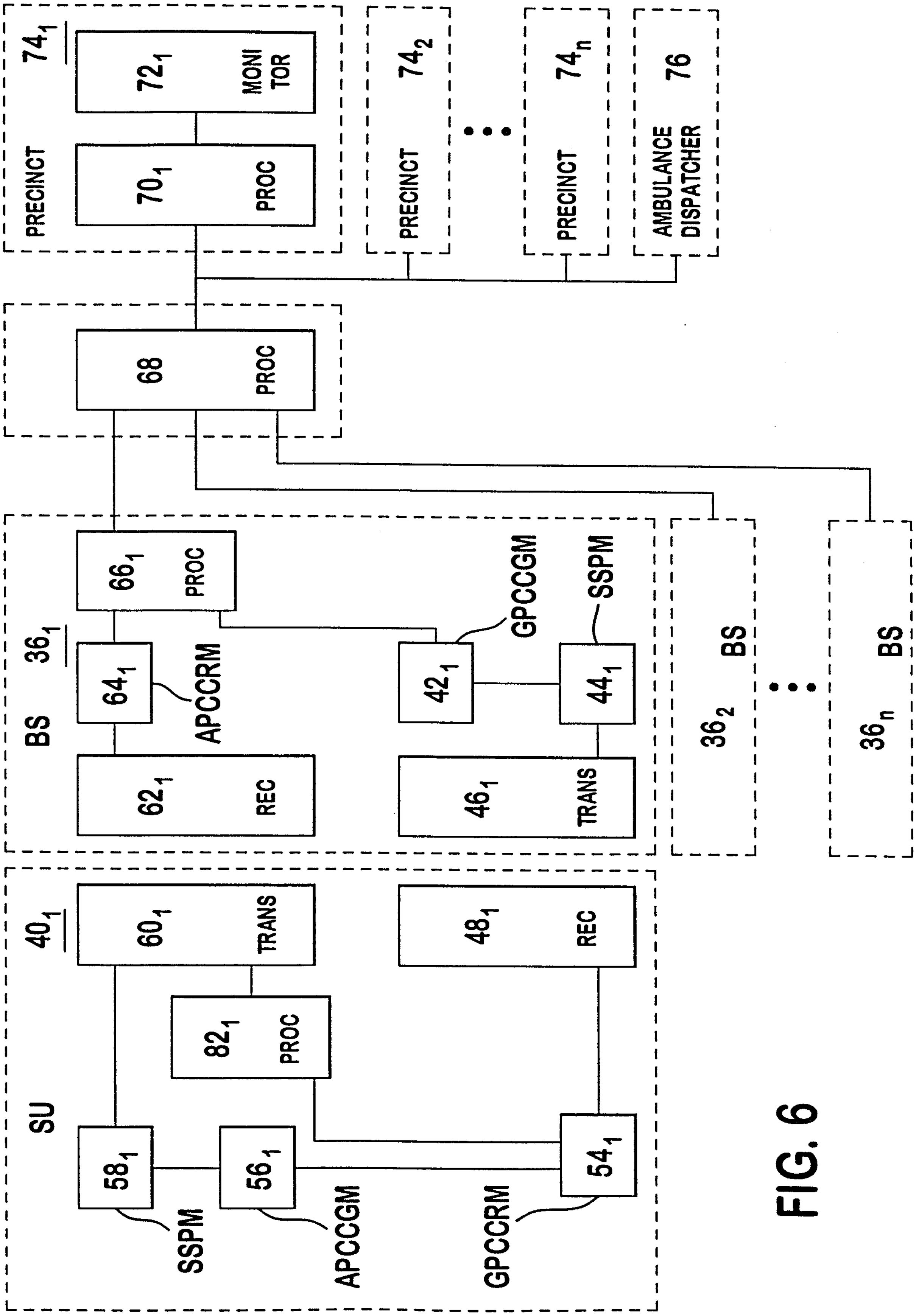
FIG. 4

FIG. 5

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64_1
APCCRM
66_1 PROC
42_1
GPCCGM
44_1
SSPM
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36_n BS
68 PROC
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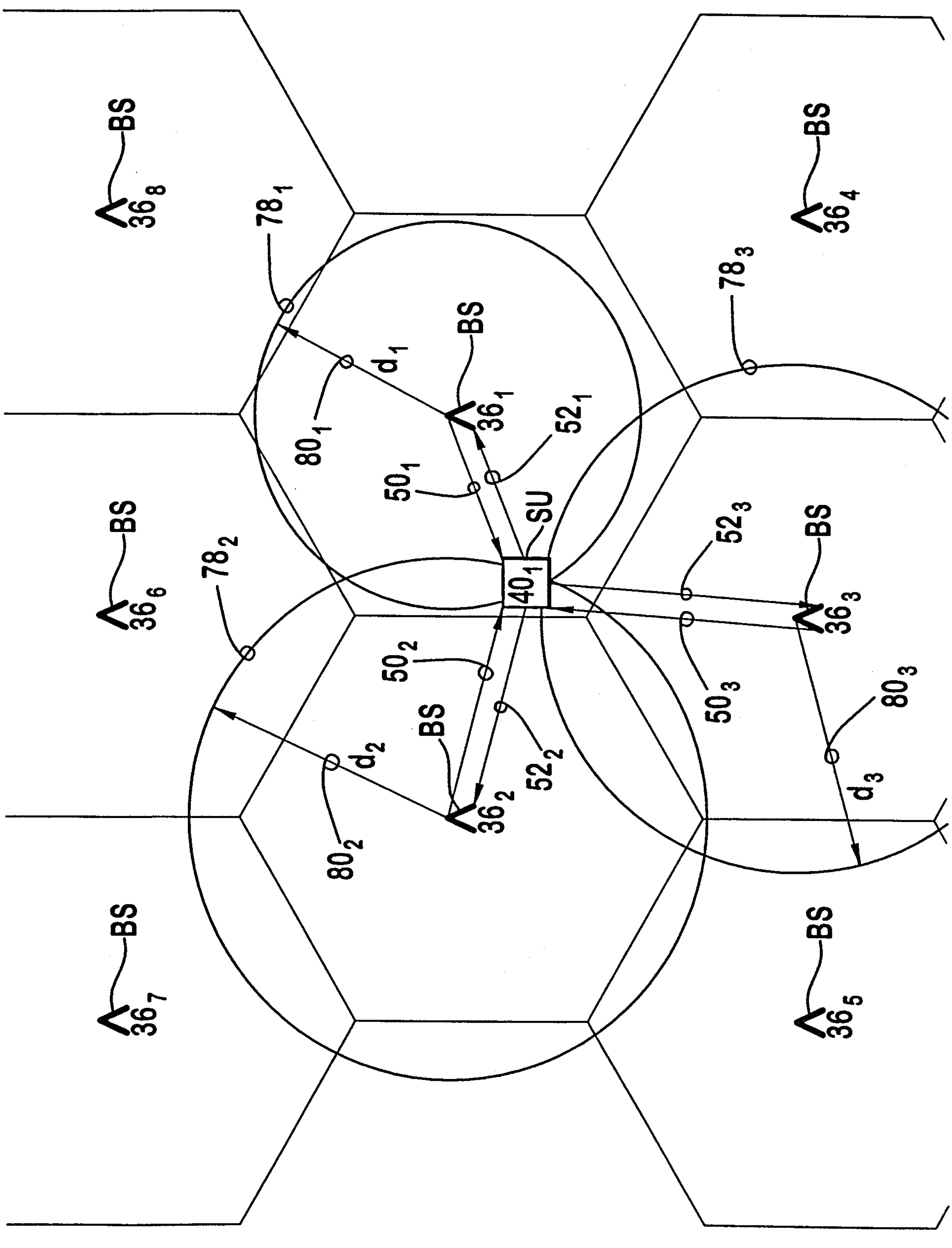
PRECINCT 74_2
PRECINCT 74_n
AMBULANCE DISPATCHER 76

FIG. 6

FIG. 7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52₃
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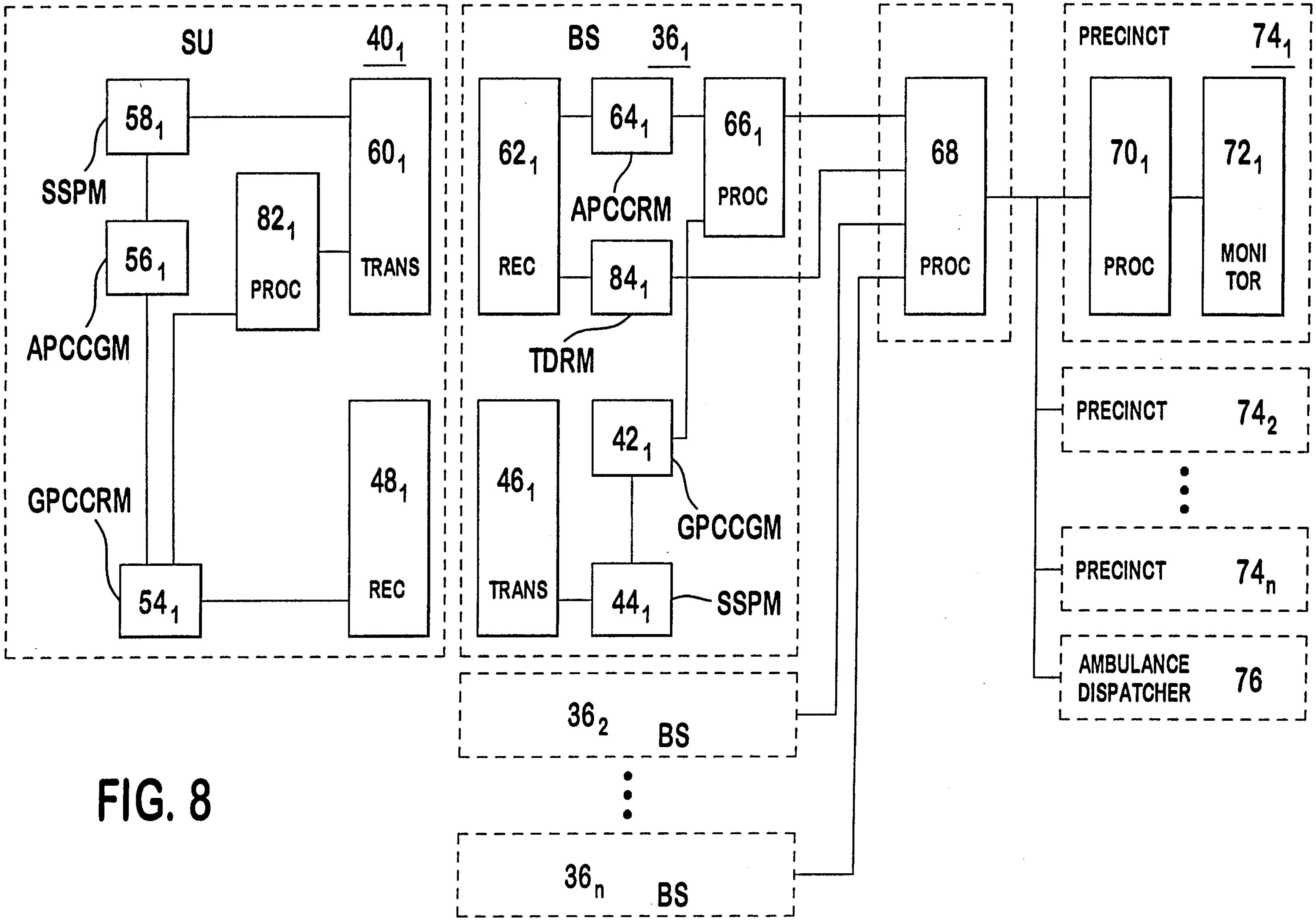
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PRECINCT
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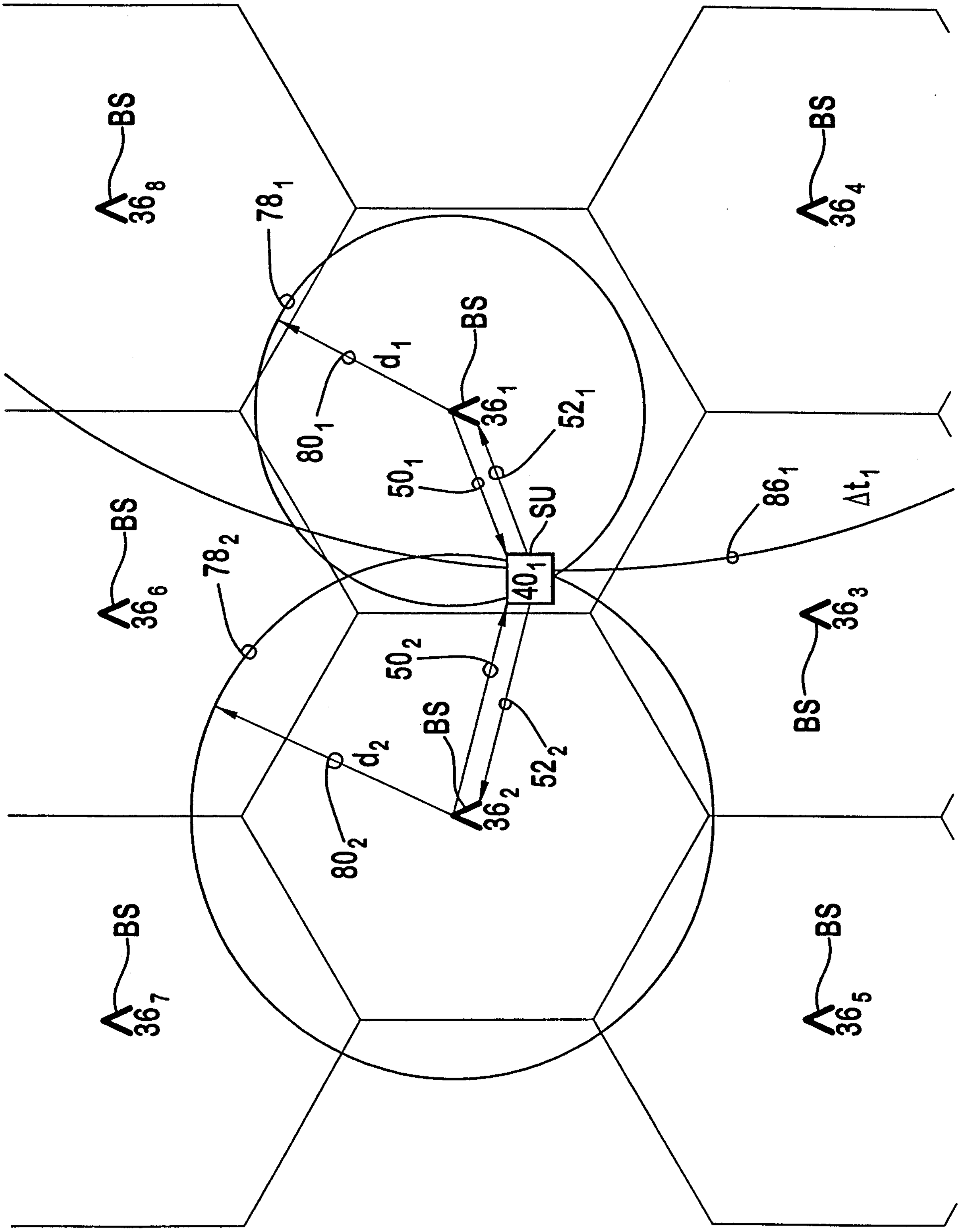
AMBULANCE DISPATCHER
76

FIG. 8

FIG. 9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BS
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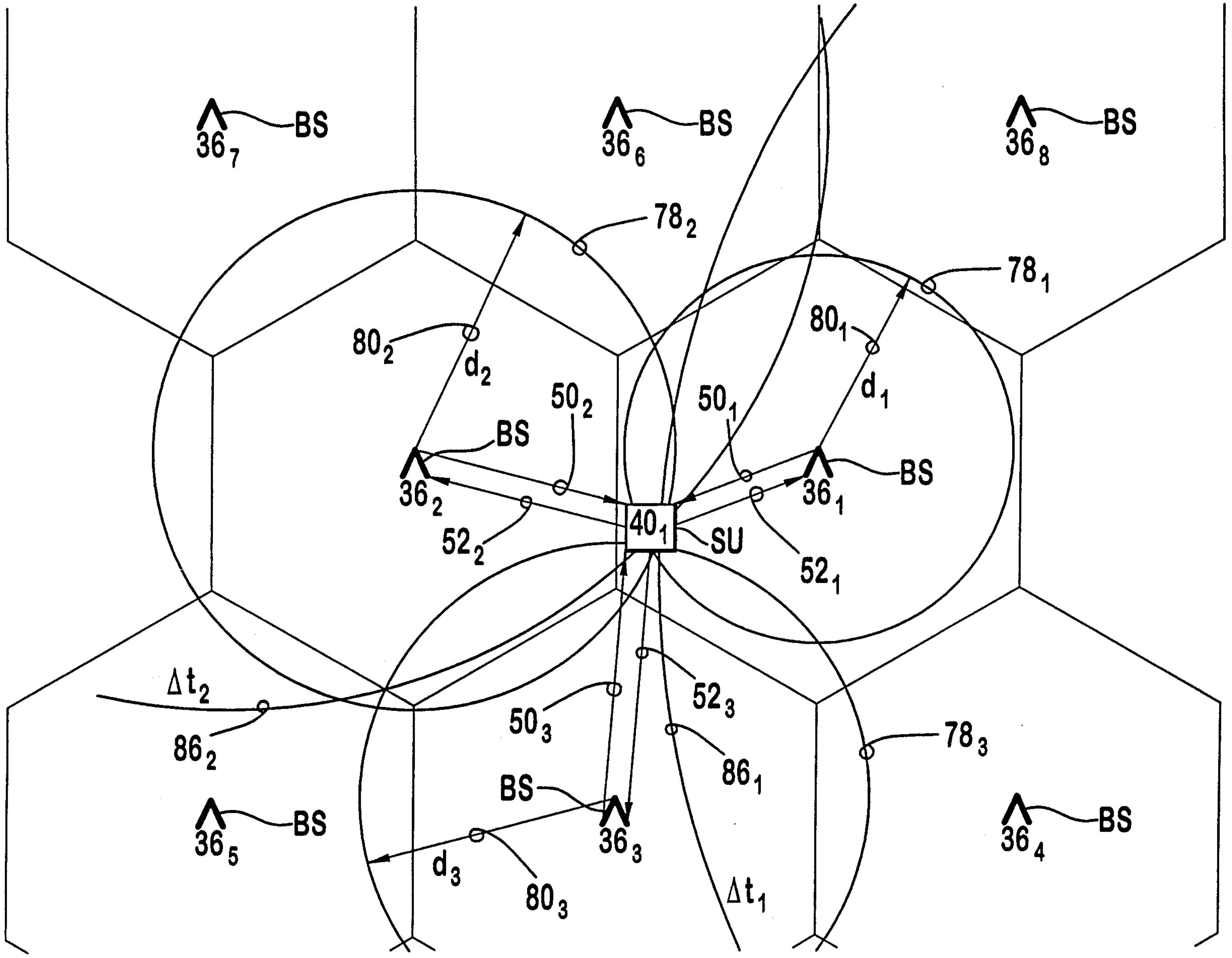
BS
36_5

FIG. 10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Δt_2
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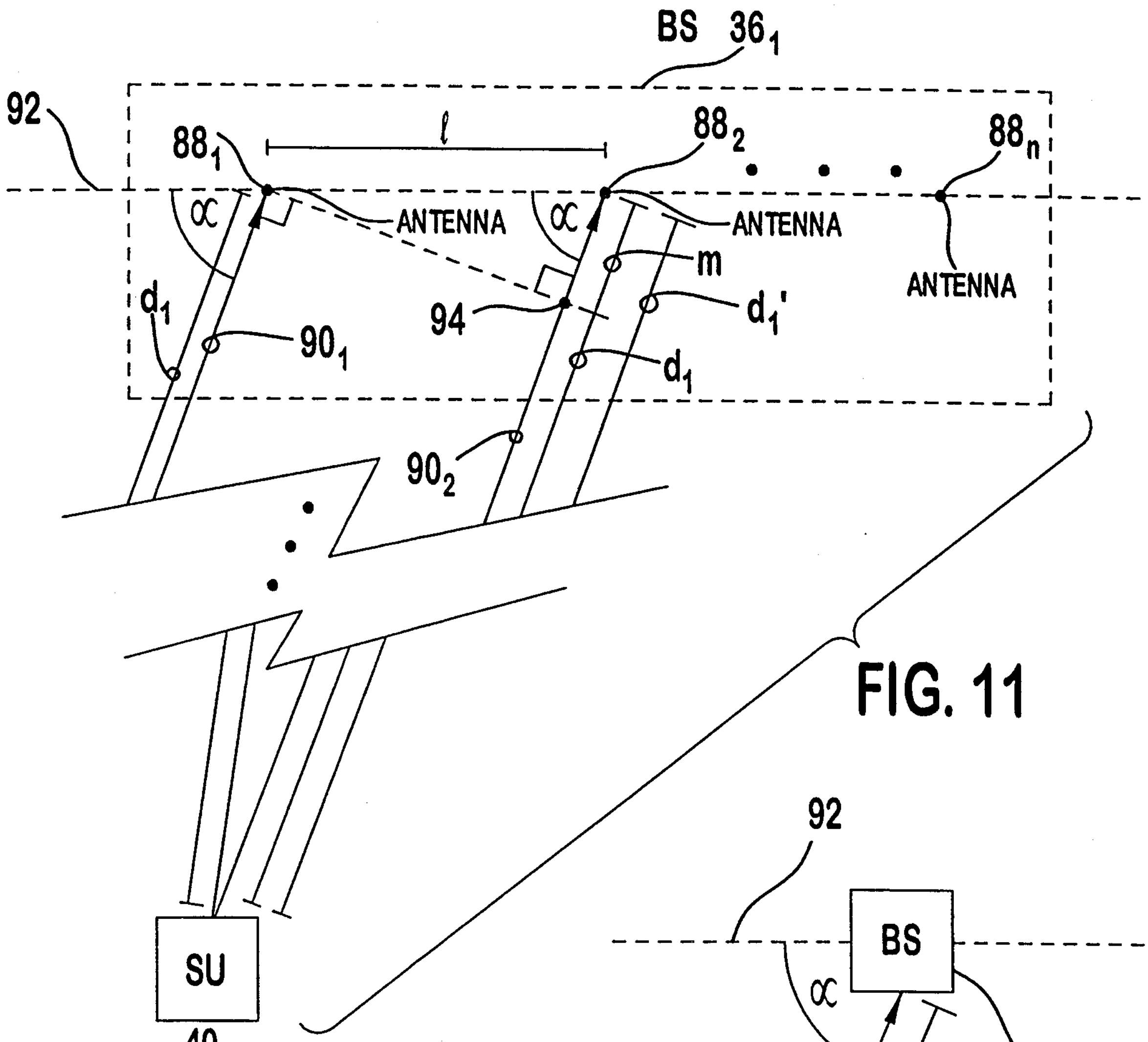
80_3
Δt_1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d_1'
90_1
d_1
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SU
40_1

FIG. 11

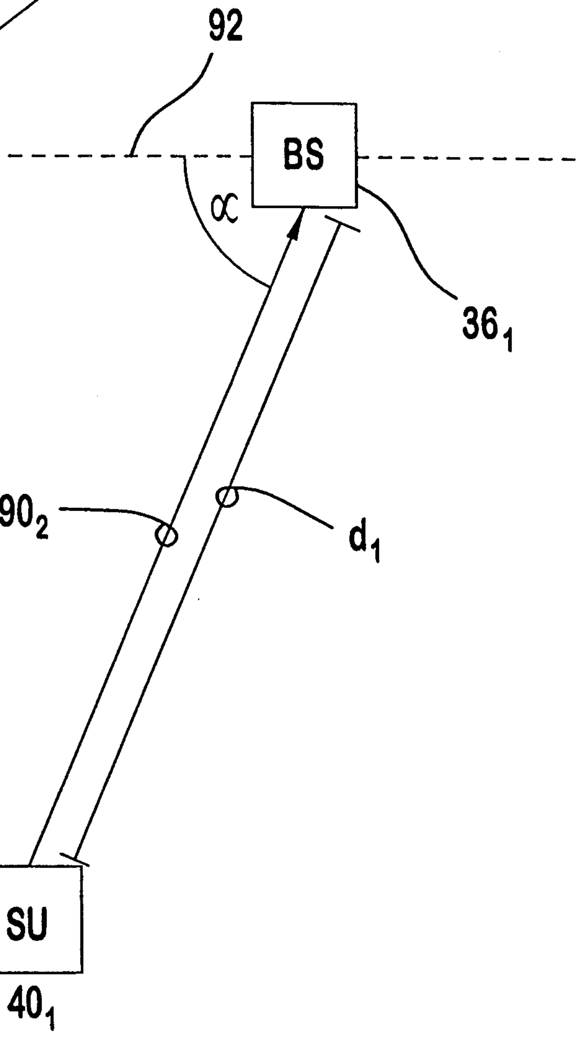
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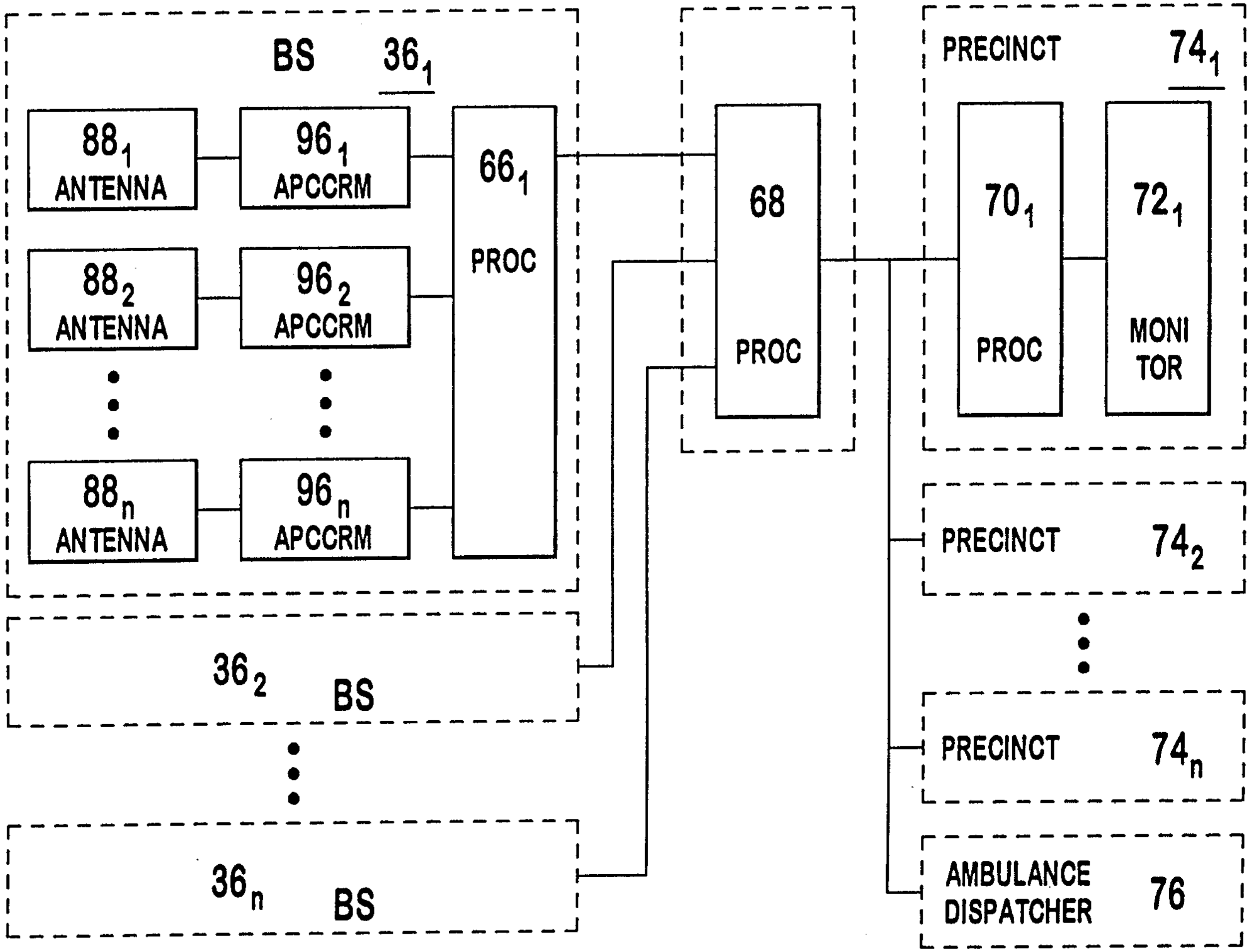
FIG. 12


BS
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68 PROC
PRECINCT
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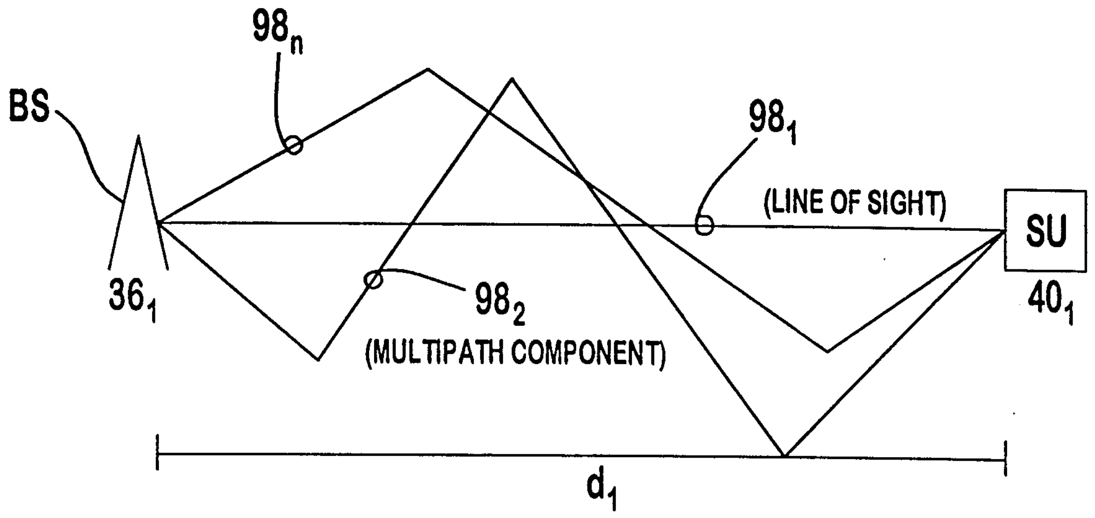
PRECINCT 74_2
PRECINCT 74_n
AMBULANCE DISPATCHER 76

FIG. 13

FIG. 14


BS
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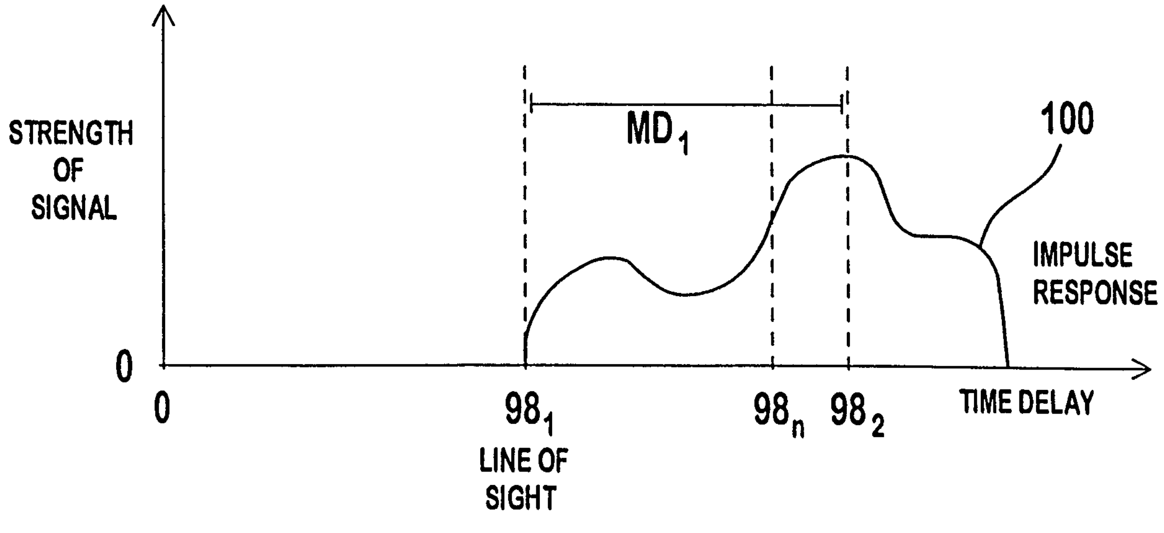
(LINE OF SIGHT)
SU
36_1
98_2
(MULTIPATH COMPONENT)
40_1
d_1

FIG. 15


STRENGTH OF SIGNAL
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TIME DELAY

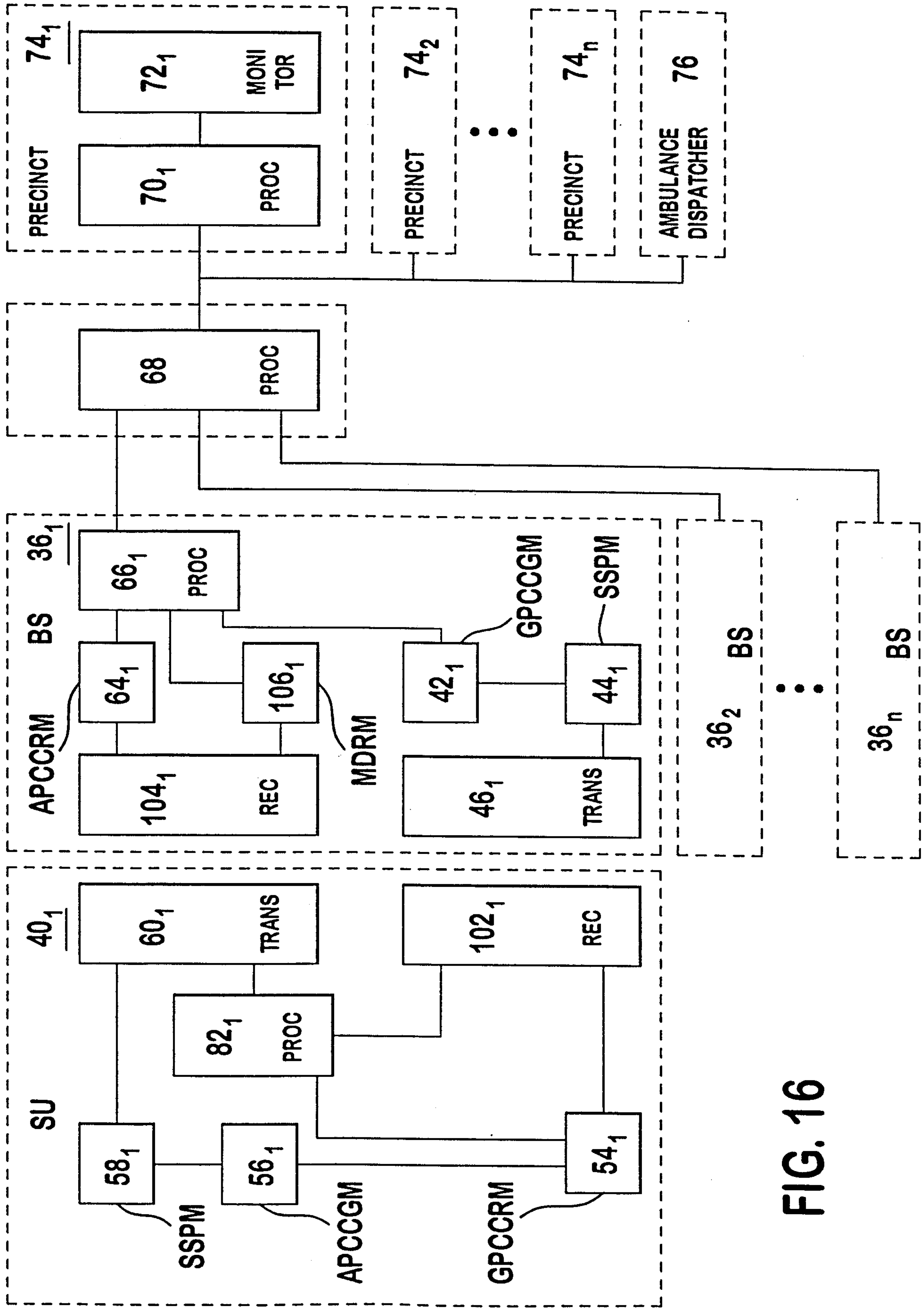
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FIG. 16

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/20257

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04Q G01S H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 736 964 A (BUFORD KEVIN ANDREW ET AL) 7 April 1998 (1998-04-07)	1-4,6,7, 11-15, 19,20
Y	column 3, line 6 -column 12, line 51 claims	5,8,9, 16-18

X	EP 0 865 223 A (NIPPON TELEGRAPH & TELEPHONE) 16 September 1998 (1998-09-16) column 6, line 14 -column 15, line 26 claims	1,2,6, 11-14,19

X	US 5 506 864 A (SCHILLING DONALD L) 9 April 1996 (1996-04-09) the whole document	1,6,11, 12,19

	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search 22 December 1999	Date of mailing of the international search report 14/01/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Roberti, V

1

Intern ..onal Application No
PCT/US 99/20257

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 600 706 A (FEUERSTEIN MARTIN J ET AL) 4 February 1997 (1997-02-04) column 11, line 23 -column 12, line 65 column 15, line 11 -column 17, line 37 ---	8,9,17,18
Y	WO 98 18018 A (NORTHERN TELECOM LTD) 30 April 1998 (1998-04-30) the whole document ---	5,16
A	WO 97 47148 A (QUALCOMM INC) 11 December 1997 (1997-12-11) the whole document -----	1-20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/20257

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP 10505723 T	02-06-1998
		PL 318057 A	12-05-1997
		SE 9604432 A	07-03-1997
		WO 9635958 A	14-11-1996
EP 0865223 A	16-09-1998	JP 10322752 A	04-12-1998
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