



(22) Date de dépôt/Filing Date: 1999/09/03

(41) Mise à la disp. pub./Open to Public Insp.: 2000/09/28

(62) Demande originale/Original Application: 2 489 816

(30) Priorité/Priority: 1999/03/22 (US09/274,081)

(51) Cl.Int./Int.Cl. *G01S 5/02* (2010.01),
H04B 1/69 (2011.01), *H04B 1/76* (2006.01),
H04B 7/08 (2006.01), *H04W 64/00* (2009.01)

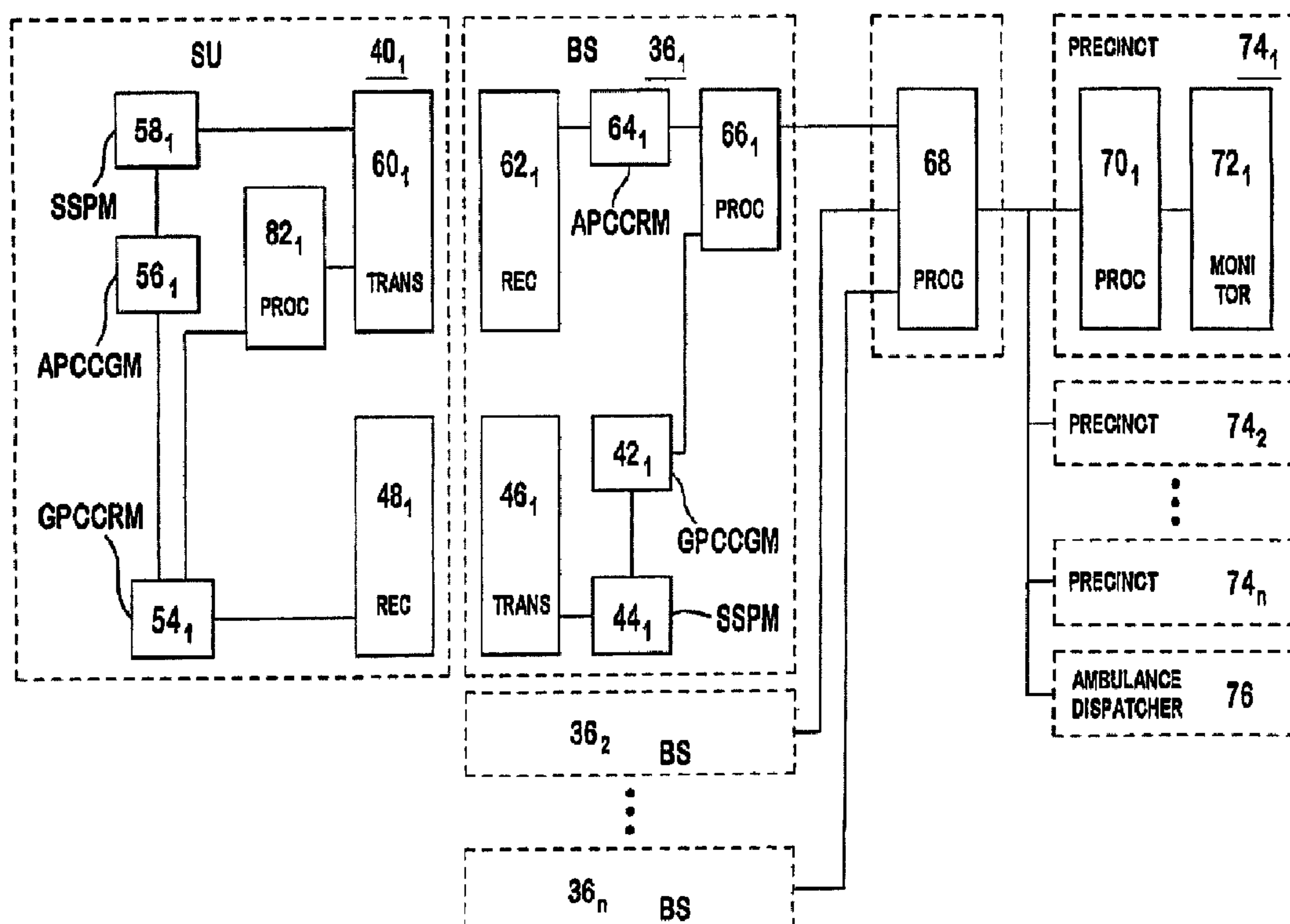
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(54) Titre : PROCÉDE ET SYSTÈME DE LOCALISATION D'UN ABONNÉ MOBILE DANS UN SYSTÈME DE
TELECOMMUNICATIONS AMDC

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



(57) Abrégé/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 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.



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 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.

TITLE OF THE INVENTION

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

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This application is a divisional of Canadian patent application Serial No. 2,489,816, which in turn is a divisional of Canadian patent application Serial No. 2,367,572 filed internationally on September 3, 1999 and entered nationally on September 21, 2001.

10

BACKGROUND OF THE INVENTION

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.

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Description of the Prior Art

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Wireless systems capable of locating a subscriber are presently known in the art. One wireless technique uses the global positioning system (GPS).

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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.

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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

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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.

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.

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.

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.

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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.

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.

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.

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

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

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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
5 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.

According to an embodiment of the present disclosure there is
10 provided a method of determining geographical location of a subscriber unit. The method comprises transmitting a first spread spectrum signal; receiving a second spread spectrum signal using a plurality of antennas, the second spread spectrum signal time synchronized with the first spread spectrum signal, each of the antennas separated by a known distance; making a
15 distance determination based on in part a timing difference between the second spread spectrum signal and the first spread spectrum signal; comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas; determining an angle of the second spread spectrum signal using the known
20 distance between the antennas and the phase difference; determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal,
25 wherein the determined first received component is used to make the distance determination.

According to an embodiment of the present disclosure there is provided a base station comprising: a plurality of antennas, each of the antennas separated by a known distance; means for transmitting a first
30 spread spectrum signal; means for receiving a second spread spectrum signal using the plurality of antennas, the second spread spectrum signal

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time synchronized with the first spread spectrum signal; means for making a distance determination based on in part a timing difference between the second spread spectrum signal and the first spread spectrum signal; means for comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas; means for determining an angle of the second spread spectrum signal using the known distance between the antennas and the phase difference; means for determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and means for analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal, wherein the determined first received component is used to make the distance determination.

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.

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

5 **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.

10 **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.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

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

20 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
25 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.

30 In a typical CDMA system, base stations send global pilot signals to all subscriber units within their communicating range to synchronize

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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 **36₁, 36₂ ... 36_n**. Each base station **36₁, 36₂ ... 36_n** is in wireless communication with a plurality of subscriber units **40₁, 40₂ ... 40_n**, which may be fixed or mobile. Each subscriber unit **40₁, 40₂ ... 40_n** communicates with either the closest base station **36₁** or the base station **36₁** which provides the strongest communication signal. Each base station **36₁, 36₂ ... 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) **34₁, 34₂ ... 34_n**. Each NIU is in communication with a plurality of radio carrier stations (RCS) **38₁, 38₂ ... 38_n** or base stations **36₁, 36₂ ... 36_n**. Each (RCS) **38₁, 38₂ ... 38_n** or base station **36₁, 36₂ ... 36_n** communicates with a plurality of subscriber units **40₁, 40₂ ... 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 **36₁, 36₂ ... 36_n** generates a unique global pilot signal using a global pilot chip code generating means **42₁** and spread spectrum processing means **44₁**. The global pilot chip code generating means **42₁** 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 **40₁** by the base station's transmitter **46₁**.

A receiver **48₁** at a subscriber unit **40₁** receives available signals from a plurality of base stations **36₁, 36₂ ... 36_n**. As shown in **Figure 5**, the

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global pilot **50₁** travels from the base station **36₁** to the subscriber unit **40₁** and can be represented as:

$$\tau_1 = \frac{d_1}{c}$$

c

Equation (1)

- 5 The time the signal travels from the base station **36₁** to the subscriber unit **40₁**, τ_1 , equals the distance between the base station **36₁** and subscriber unit **40₁**, d_1 , divided by the speed of light, c .

Referring back to **Figure 4**, a global pilot chip code recovery means **54₁** within the subscriber unit **40₁** can receive global pilot chip code sequences from a plurality of base stations **36₁**, **36₂** ... **36_n**. The subscriber unit **40₁** generates a replica of a global pilot chip code sequence and synchronizes the generated replica's timing with the received global pilot **50₁**. The subscriber unit **40₁** also has a processor **82₁** to perform the many analysis functions of the subscriber unit **40₁**.

- 15 The subscriber unit **40₁** generates an assigned pilot signal **52₁** using assigned pilot chip code generating means **56₁** and spread spectrum processing means **58₁**. The assigned pilot chip code generating means **56₁** 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 **36₁**, **36₂** ... **36_n**. The spread spectrum processing means **58₁** generates the assigned pilot signal **52₁** by modulating the assigned pilot chip code sequence up to a desired center frequency. The assigned pilot signal **52₁** is transmitted to all base stations **36₁**, **36₂** ... **36_n** within range to receive the assigned pilot signal **52₁**.

- The base station **36₁** receives the assigned pilot signal **52₁** with the base station's receiver **62₁**. The received assigned pilot **52₁** travels the same distance d_1 as the global pilot signal **50₁** as shown in **Figure 5**. Accordingly, the received assigned pilot signal will be delayed by τ_1 with respect to the mobile unit **40₁** and by $2\tau_1$ with respect to the global pilot **50₁** generated at the base station **36₁**.

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Since the chip code sequence of the assigned pilot **52₁** received at the base station **36₁** will be delayed by **2τ₁** with respect to the chip code sequence of the global pilot signal **50₁** generated at the base station **36₁**, the round trip propagation delay, **2τ₁**, can be determined by comparing the timing of the two chip code sequences. Using the round trip propagation delay, **2τ₁**, the distance **d₁** between the base station **36₁** and subscriber unit **40₁** can be determined by:

$$d_1 = c \cdot \frac{2\tau_1}{2}$$

2**Equation (2)**

10 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 **d₁** 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 **40₁**.
 15 The only changes are implemented by software within the subscriber unit's processor **82₁** and the processors **66₁**, **66₂** ... **66_n**, **68**, **70₁**, **70₂** ... **70_n** located within the base station **36₁**, NIU **34₁** or Local Exchange **32₁**, Precincts **74₁**, **74₂** ... **74_n** and Ambulance Dispatcher **76**.

The subscriber unit **40₁** is sent a signal by a base station **36₁**
 20 indicating that a 911 call was initiated and to begin the subscriber location protocol. Upon receipt, the subscriber unit **40₁** will sequentially synchronize its transmission chip code sequence to at least three base stations' chip code sequences. To allow reception by the base stations **36₂**, **36₃** ... **36_n** outside of the subscriber unit's normal communicating range, these transmissions
 25 will be sent at a higher than normal power level temporarily over-riding any adaptive power control algorithms.

A processor **66₁** within each base station **36₁**, **36₂** ... **36_n** is coupled to the assigned pilot chip code recovery means **64₁** and the global pilot chip code generator **42₁**. The processor **66₁** compares the two chip code
 30 sequences to determine the round trip propagation delay **τ₁**, **τ₂** ... **τ_n** and the respective distance **d₁**, **d₂** ... **d_n** between the subscriber unit **40₁** and the

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respective base station **36₁, 36₂ ... 36_n**. Within either a NIU **34₁** or the local exchange **32**, a processor **68** receives the distances **d₁, d₂ ... d_n** from the processors **66₁, 66₂ ... 66_n** within all the base stations **36₁, 36₂ ... 36_n**. The processor **68** uses the distances **d₁, d₂ ... d_n** to determine the location
 5 of the subscriber unit **40₁** as follows.

By using the known longitude and latitude from three base stations **36₁, 36₂, 36₃** and distances **d₁, d₂, d₃**, the location of the subscriber unit **40₁** is determined. As shown in **Figure 7** by using the three distances **d₁, d₂, d₃**, three circles **78₁, 78₂, 78₃** with radii **80₁, 80₂, 80₃** are
 10 constructed. Each circle **78₁, 78₂, 78₃** is centered around a respective base station **36₁, 36₂, 36₃**. The intersection of the three circles **78₁, 78₂, 78₃** is at the location of the subscriber unit **40₁**.

Using the Cartesian coordinates, the longitude and latitude corresponding with each base station **36₁, 36₂ ... 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 **40₁**, using the distance formula the following equations result:

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

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

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

In practice due to small errors in calculating the distances **d₁, d₂, d₃**, **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
 25 increased accuracy, additional base stations **36₄, 36₅ ... 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 **74₁, 74₂ ... 74_n** and an ambulance dispatcher **76**. A processor **70₁** within each precinct **74₁, 74₂ ... 74_n** and the ambulance
 30 dispatcher **76** receives the location of all 911 calls originating in the system and displays the location on a conventional computer monitor **72₁**. The

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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 **36₁**, **36₂** ... **36_n** have their internal timing synchronized with each other and transmit their respective global pilot signals **52₁**, **52₂** ... **52_n** with time synchronized chip code sequences. The subscriber unit. **40₁** receives the global pilots **52₁**, **52₂** ... **52_n**. However, the received global pilots **52₁**, **52₂** ... **52_n** are not synchronized. The global pilot **52₁** from a first base station **36₁** will travel distance **d₁** and is delayed by **T₁**. The global pilot **52₂** from a second base station **36₂** travels distance **d₂** and is delayed by **T₂**. The subscriber unit **40₁** recovers each base station's global pilot chip code sequence with its global pilot chip code recovery means **54₁**. A processor **82₁** within the subscriber unit **40₁** is coupled to each global pilot chip code recovery means **54₁**, **54₂** ... **54_n**. The processor **82₁** compares the chip code sequences of each pair of pilot chip code sequences and calculates the time differences **Δt₁**, **Δt₂** ... **Δt_n** between the sequences as follows.

Within the subscriber unit **40₁**, the chip code sequences used by each base station **36₁**, **36₂** ... **36_n** are stored. After synchronizing with the first base station's pilot **36₁**, the processor **82₁** will store where within the sequence synchronization was obtained. This process is repeated for the other base stations **36₂**, **36₃** ... **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 **T₁**, **T₂**, ... **T_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:

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$$\Delta t_1 = T_2 - T_1 \quad \text{Equation (6)}$$

$$\Delta t_2 = T_3 - T_2 \quad \text{Equation (7)}$$

The time differences $\Delta t_1, \Delta t_2 \dots \Delta t_n$ are transmitted to at least one of the base stations **36₁**.

5 At least one base station **36₁** recovers the time difference data from the received signals using time difference recovery means **84₁**. The time difference data is sent with the distance data **d₁** through the communications system to a processor **68**. The processor 68 determines the location of the subscriber unit **40₁** using the time difference data $\Delta t_1,$
10 $\Delta t_2 \dots \Delta t_n$ and the distance data **d₁, d₂ ... d_n** as follows.

Using information from only two base stations **36₁, 36₂** as shown in **Figure 9**, the processor uses distances **d₁, d₂** to create two circles **78₁, 78₂**. Using the time difference, Δt_1 , a hyperbola **86₁** can be constructed as follows.

15 All the points along the hyperbola **86₁** receive the global pilot signals **52₁, 52₂** from the synchronized base stations **36₁, 36₂** 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 **d₁** in **Equation 1**. Using the distance formula and **X, Y** as the location of the subscriber unit
20 **40₁**, the following equation results:

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

By using **Equation 8** with **Equations 3** and **4** in a maximum likelihood estimation, the location of the subscriber unit **40₁** can be determined. The subscriber unit's location is subsequently sent to the
25 nearest police precinct **74₁, 74₂ ... 74_n** and ambulance dispatcher **76** in the cellular area.

For improved accuracy, additional base stations **36₁, 36₂ ... 36_n** are used. **Figure 10** shows the invention used with three base stations **36₁, 36₂, 36₃**. The distances **d₁, d₂, d₃** are used to create three circles **78₁, 78₂, 78₃**. Using time differences $\Delta t_1, \Delta t_2$, two intersecting hyperbolas **86₁, 86₂**
30 are constructed. With maximum likelihood estimation, the subscriber units'

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location calculated with two hyperbolas **86₁**, **86₂**, and three circles **78₁**, **78₂**, **78₃** yields greater accuracy.

As shown in **Figure 8**, the subscriber unit **40₁** is required to process each global pilot chip code sequence to determine the time differences **Δt_1** , **$\Delta t_2 \dots \Delta t_n$** . An alternate approach removes the processing from the subscriber unit **40₁**.

With reference to **Figure 6**, the mobile unit **40₁** will synchronize the assigned pilot to one of the base station's global pilot chip code sequences, such as the nearest base station **36₁** with a delay of **τ_1** . The assigned pilot **50₁** is transmitted to all base stations **36₁**, **36₂** ... **36_n**. The assigned pilot **50₁** 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 **36₁**, **36₂** ... **36_n** will send the delayed chip code sequence along with the calculated distance to a processor **68** located in a NIU **34₁** or local exchange **32**. The processor **68** will calculate the time differences **Δt_1** , **$\Delta t_2 \dots \Delta t_n$** 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** , **$\Delta t_2 \dots \Delta t_n$** . Accordingly, the subscriber unit **40₁** can be located using hyperbolas **86₁**, **86₂** as previously described.

Another embodiment shown in **Figures 11**, **12** and **13** uses a base station **36₁** with multiple antennas **88₁**, **88₂** ... **88_n**. Two of the antennas **88₁**, **88₂** lie along a centerline **92** at a known distance, **l** , apart as shown in **Figure 11**. Both antennas **88₁**, **88₂** receive the assigned pilot signal **90₁**, **90₂** from the subscriber unit **40₁**. However, the antenna **88₂** further away from the subscriber unit **40₁** receives the signal over a slightly longer distance **d_1'** and with a slight delay with respect to the nearer antenna **88₁**.

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 **96₁**, **96₂** ... **96_n** can determine the location of the subscriber unit **40₁** as follows.

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As shown in **Figure 12**, the subscriber unit **40₁** is located at distance **d_1** at angle α from the centerline **92** of the antennas **88₁**, **88₂**. As seen at the scale of **Figure 12** both received assigned pilot signals **90₁**, **90₂** appear to be coincident. However, as shown in **Figure 11**, the received assigned pilot signals **90₁**, **90₂** are slightly separated. The received assigned pilot signal **90₁** returning to the first antenna **88₁** travels a distance **d_1** . The received assigned pilot signal **90₂** returning to the second antenna **88₂** 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 **88₁**, **88₂** and the subscriber unit **40₁** are much larger than the distance **l** between the antennae **88₁**, **88₂** both received assigned pilot signals **90₁**, **90₂** follow approximately parallel paths. By constructing a right triangle using a point **94** which is distance **d_1** from the subscriber unit **40₁** as shown in **Figure 11**, the angle α can be determined by the following geometric relationship:

$$\alpha = \cos^{-1} (m/l). \quad \text{Equation (9)}$$

The distance **m** can be determined by using the carrier phase difference, ϕ , between the two received signals **90₁**, **90₂** as follows:

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

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:

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

The processor **68** also compares the chip code sequences of the global pilot generating means **42₁** with the recovered assigned pilot chip code sequence to determine the distance **d_1** as shown in **Figure 6**. Using both the angle α and distance **d_1** , the processor **66₁** locates the subscriber unit **40₁** using simple geometry. There are many techniques well known to those skilled in the art to eliminate the ambiguity between locations above

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and below the antennas **88₁**, **88₂**. One such technique is using antennas employing sectorization. Subsequently, the subscriber unit's location is sent to the precincts **74₁**, **74₂** ... **74_n** and ambulance dispatcher **76**. Additional antennas may be used to improve on the accuracy of the system.

5 An alternate embodiment uses more than one base station **36₁**, **36₂** ... **36_n**. A processor **68** located within either a NIU **34₁** or the local exchange **32** collects distance and angle information from more than one base station **36₁**, **36₂** ... **36_n** as well as the time differences **Δt_1** , **Δt_2** ... **Δt_n** , between the base stations **36₁**, **36₂** ... **36_n**. Using the maximum likelihood
10 estimation technique, the processor **68** determines a more accurate location of the subscriber unit **40₁**.

 A fourth embodiment corrects for multipath. **Figure 14** illustrates multipath. A signal such as a global pilot signal is transmitted from a base station **36₁**. The signal follows a multitude of paths **98₁**, **98₂** ... **98_n** between
15 the base station **36₁** and subscriber unit **40₁**.

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 **98₁**, **98₂** ... **98_n**. The impulse response
20 **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 **40₁** synchronizes with the line of sight multipath component **98₁** traveling distance **d_1** . However, if the subscriber unit
25 synchronizes with a non-line of sight multipath component **98₁**, **98₂** ... **98_n**, the distance calculation will be in error due to the delay **MD₁** as shown in **Figure 15**. **Figure 16** is a system correcting for errors resulting from multipath. The global pilot **50₁** is sent from the base station **36₁** to subscriber unit **40₁**. The subscriber unit **40₁** collects all of the multipath
30 components using a multipath receiver **102₁** such as disclosed in U.S. Patent

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No. 5,796,776, Lomp et al. A processor **82₁** within the subscriber unit **40₁** analyzes the impulse response **100** of the received global pilot signal **50₁**.

Since the line of sight multipath component **98₁** travels the shortest distance **d₁**, the first received component **98₁** is the line of sight component.

5 If the line of sight component is not received, the first received component **98₁** will be the closest and, accordingly, the best available estimate for the line of sight component. The processor **82₁** compares the chip code sequence of the first received component **98₁** with the chip code sequence used to synchronize the assigned pilot chip code sequence. This comparison
10 determines the delay due to multipath, **MD₁**. The multipath delay, **MD₁**, is transmitted to the base station **36₁**.

A processor **66₁** and multipath receiver **104₁** within the base station **36₁** perform the same analysis on the received assigned pilot signal. As a result, the multipath delay, **MD₂**, of the assigned pilot signal is determined.
15 Additionally, multipath delay recovery means **106₁** recovers the transmitted global pilot signal's multipath delay **MD₁** for use by the processor **66₁**. The processor **66₁** compares the generated global pilot chip code sequence to the recovered assigned pilot chip code sequence to determine the round trip propagation delay **2T₁**. To correct for multipath, the processor **66₁** subtracts
20 both the global pilot signal's multipath delay **MD₁** and the assigned pilot signals multipath delay **MD₂** from the calculated round trip propagation delay, **2T₁**. The corrected round trip propagation delay is used to determine the subscriber unit's location in one of the techniques as previously described.

25 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
30 the teachings herein.

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CLAIMS:

1. A method of determining geographical location of a subscriber unit, the method comprising:

transmitting a first spread spectrum signal;

receiving a second spread spectrum signal using a plurality of antennas, the second spread spectrum signal time synchronized with the first spread spectrum signal, each of the antennas separated by a known distance;

making a distance determination based on in part a timing difference between the second spread spectrum signal and the first spread spectrum signal;

comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas;

determining an angle of the second spread spectrum signal using the known distance between the antennas and the phase difference;

determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and

analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal, wherein the determined first received component is used to make the distance determination.

2. The method of claim 1 wherein the first spread spectrum signal is a pilot signal.

3. A base station comprising:

a plurality of antennas, each of the antennas separated by a known distance;

means for transmitting a first spread spectrum signal;

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means for receiving a second spread spectrum signal using the plurality of antennas, the second spread spectrum signal time synchronized with the first spread spectrum signal;

means for making a distance determination based on in part a timing difference between the second spread spectrum signal and the first spread spectrum signal;

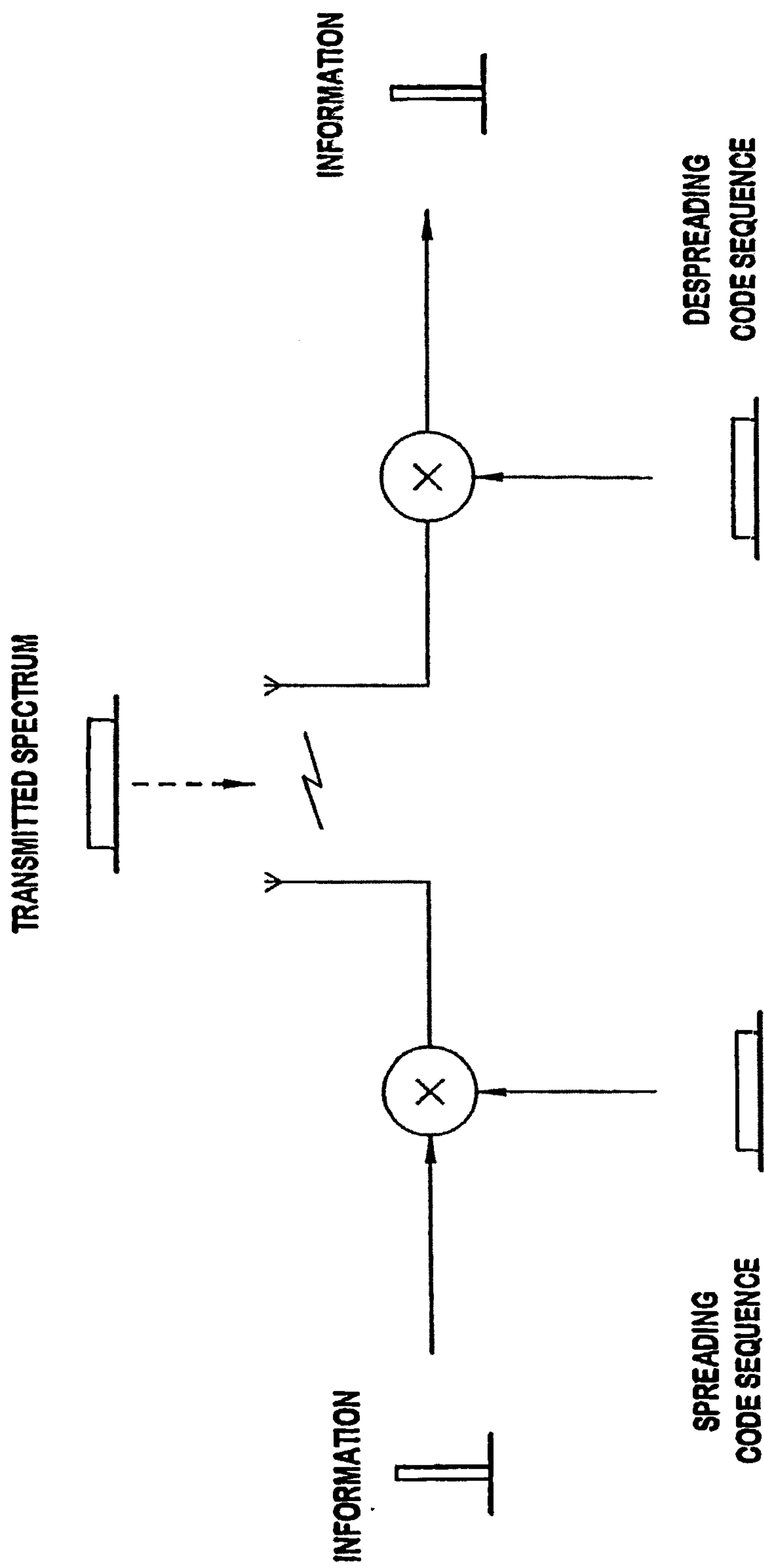
means for comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas;

means for determining an angle of the second spread spectrum signal using the known distance between the antennas and the phase difference;

means for determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and

means for analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal, wherein the determined first received component is used to make the distance determination.

4. The base station of claim 3 wherein the first spread spectrum signal is a pilot signal.



PRIOR ART

FIG. 1

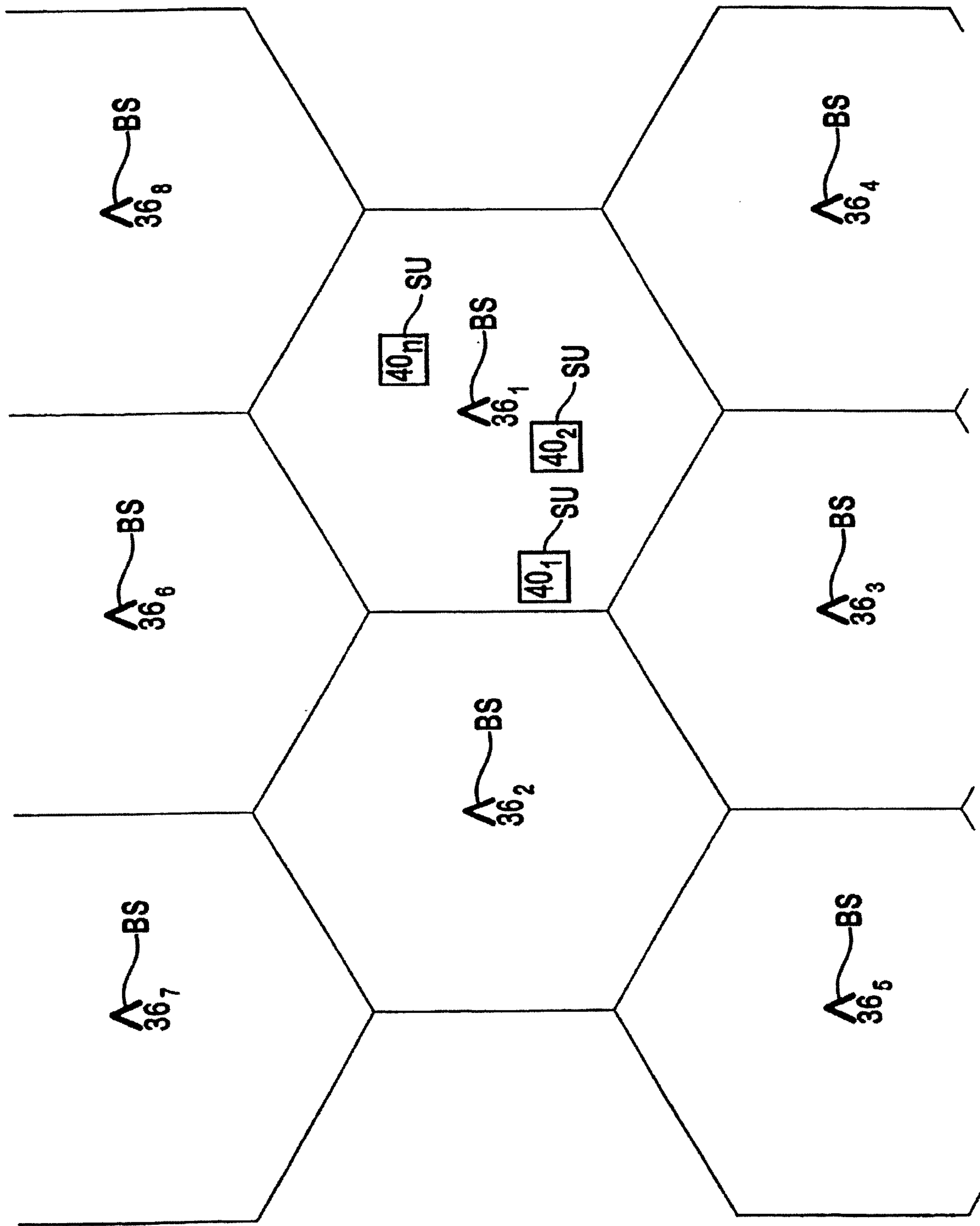
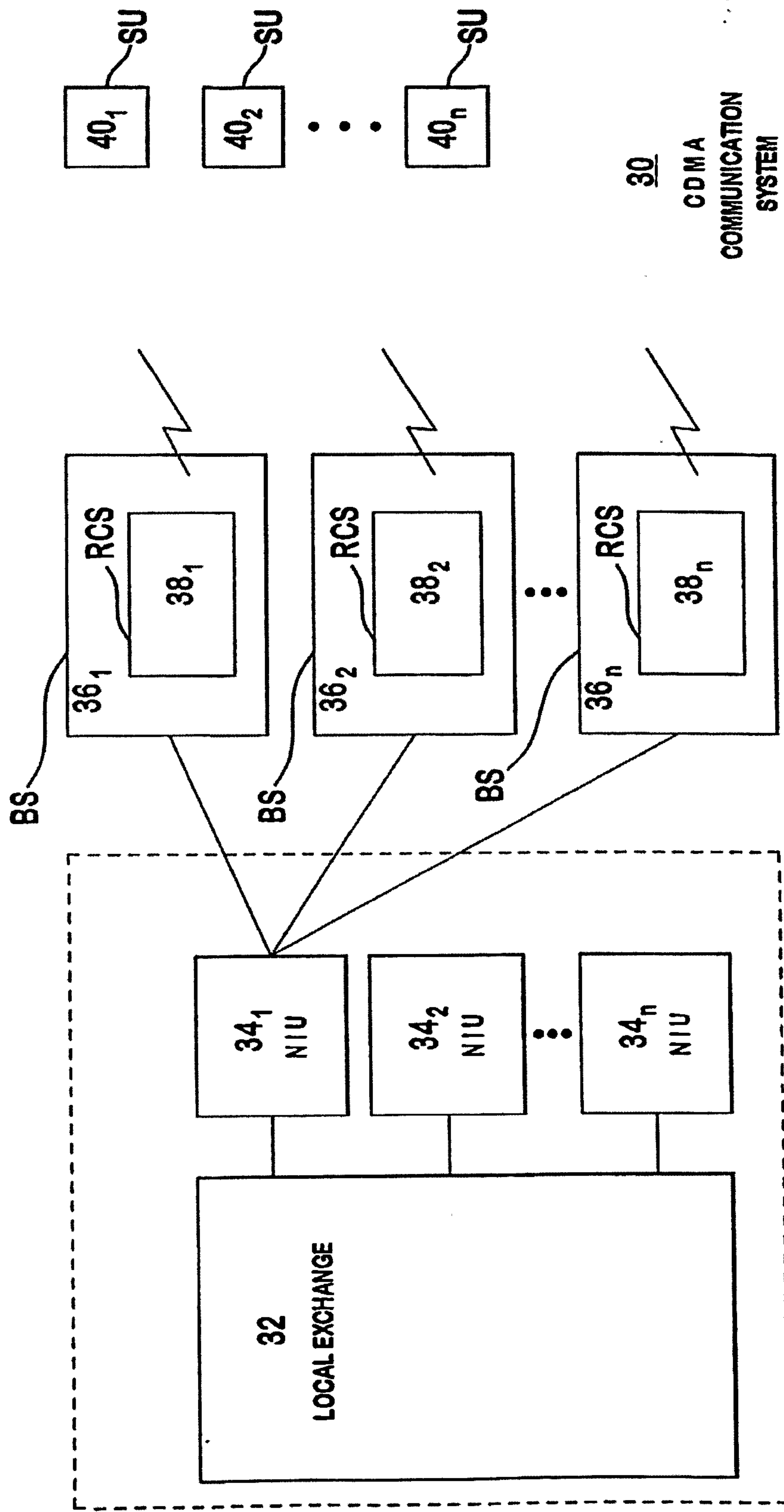


FIG. 2

FIG. 3



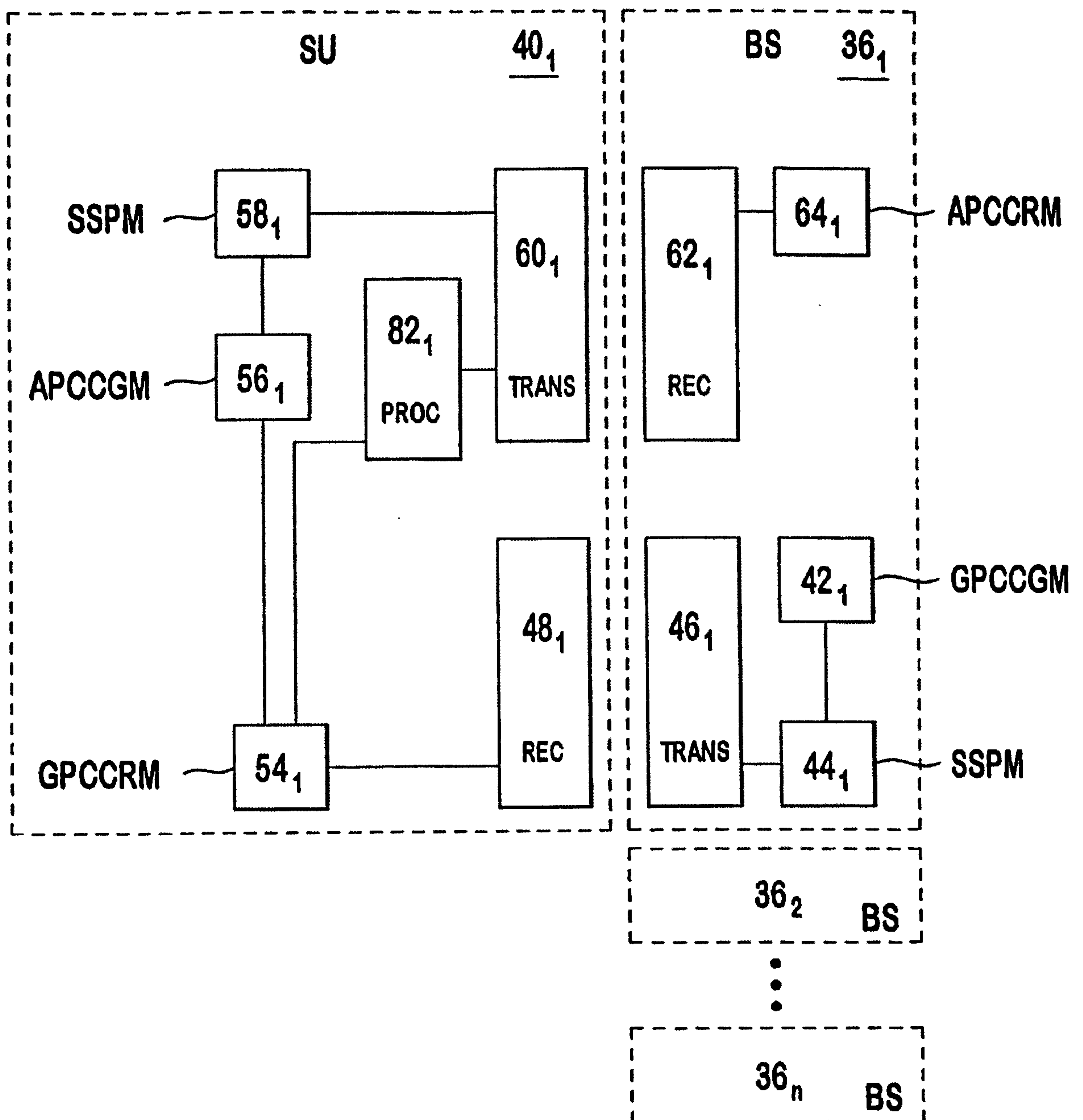
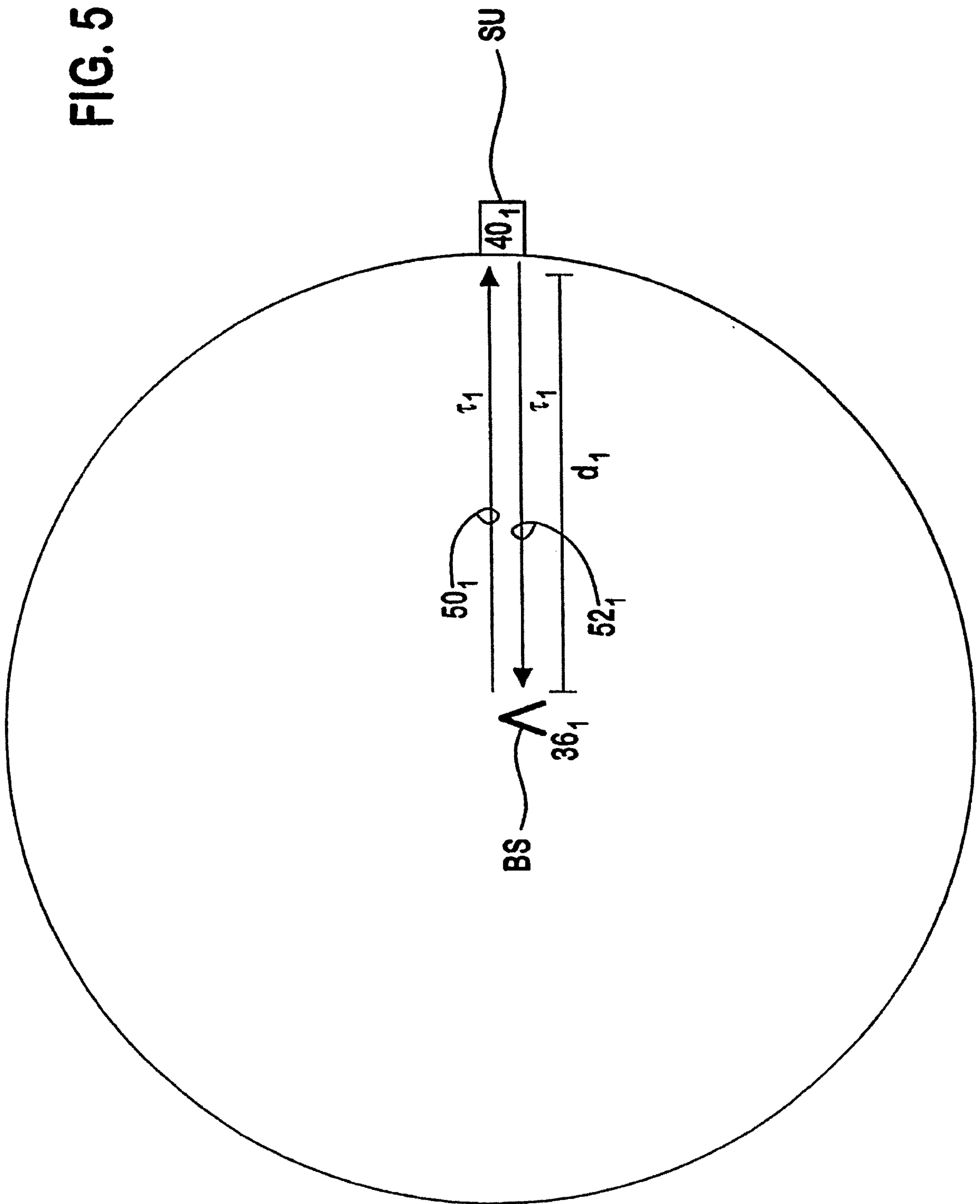


FIG. 4

FIG. 5



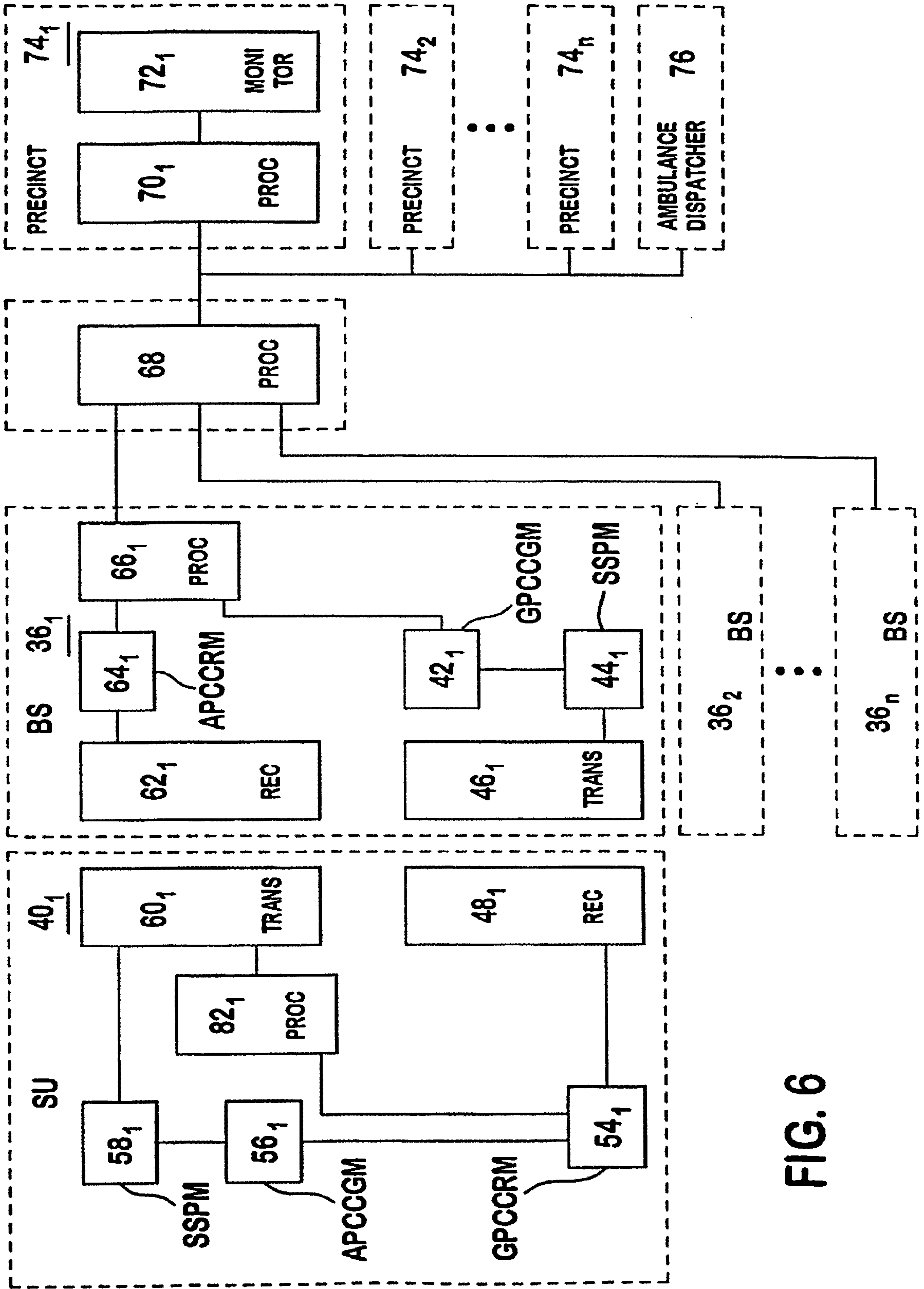


FIG. 6

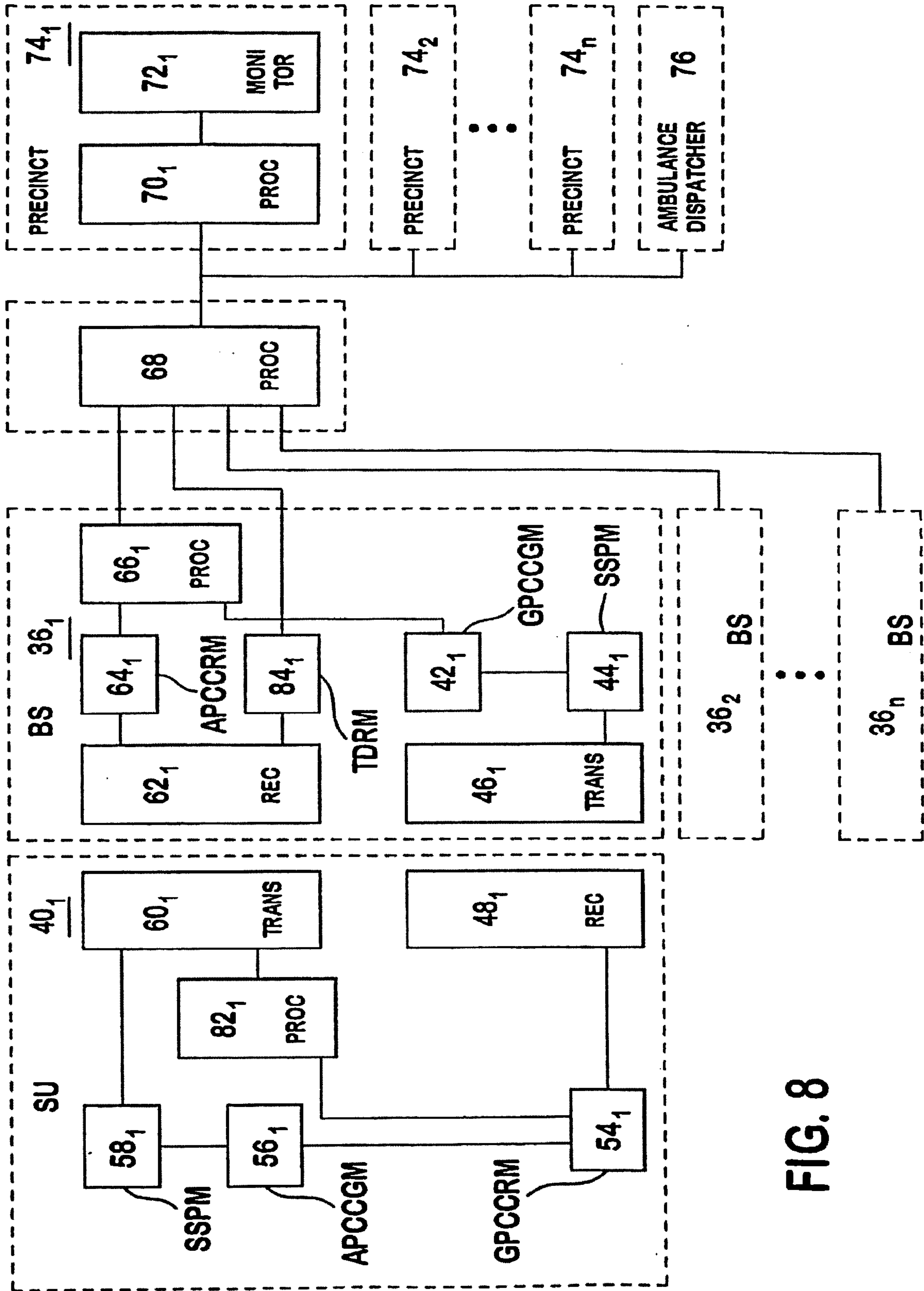


FIG. 8

FIG. 9

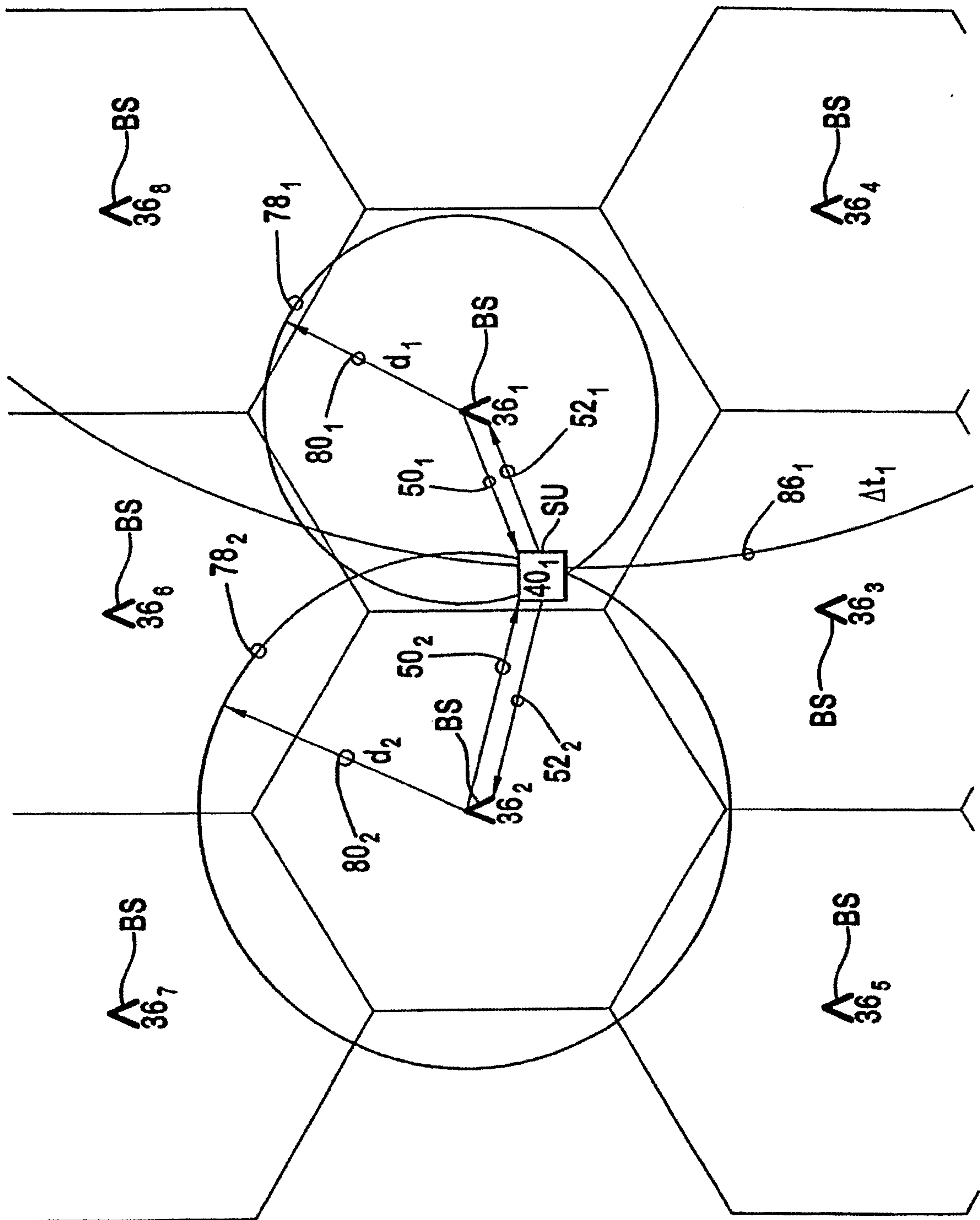
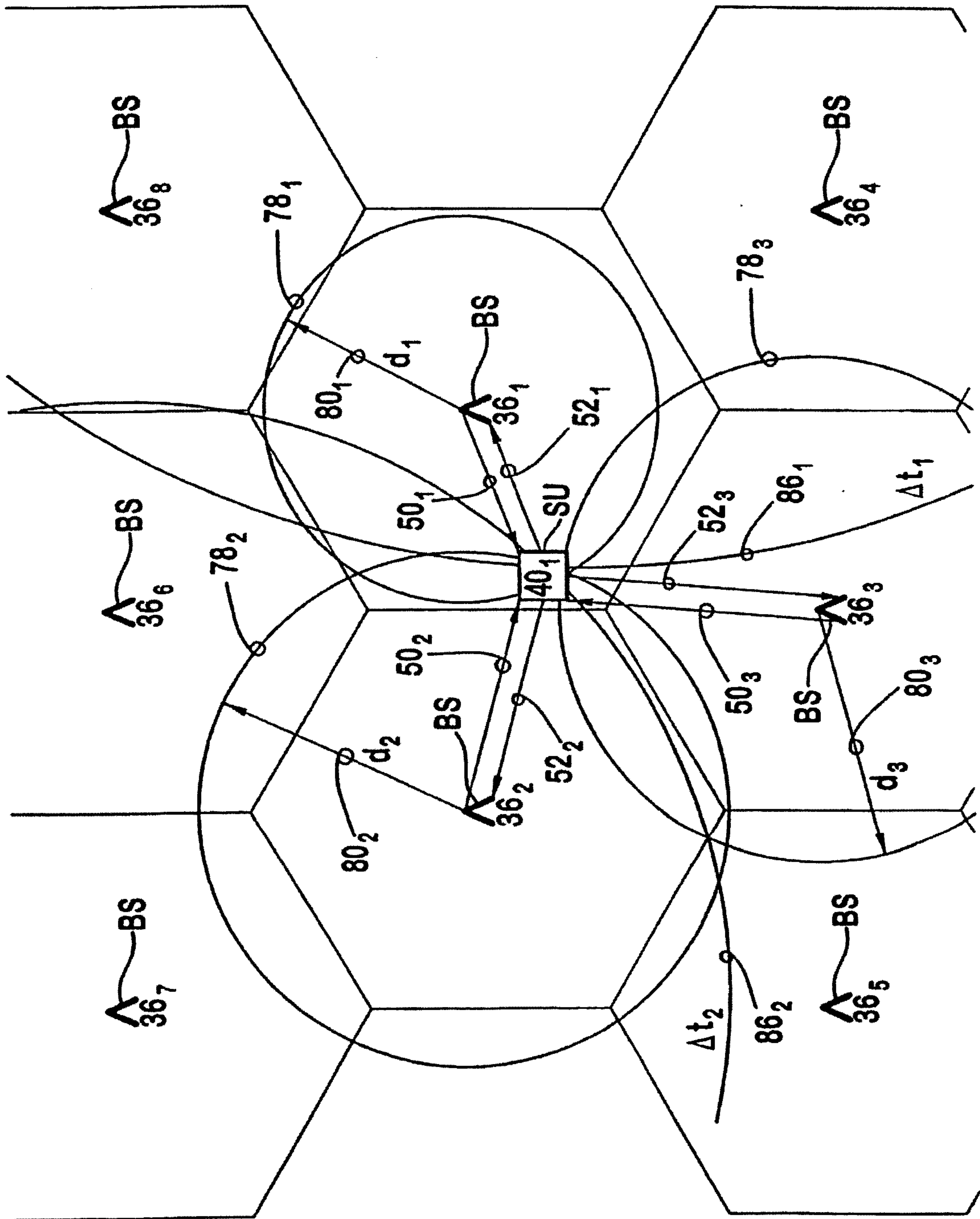


FIG. 10



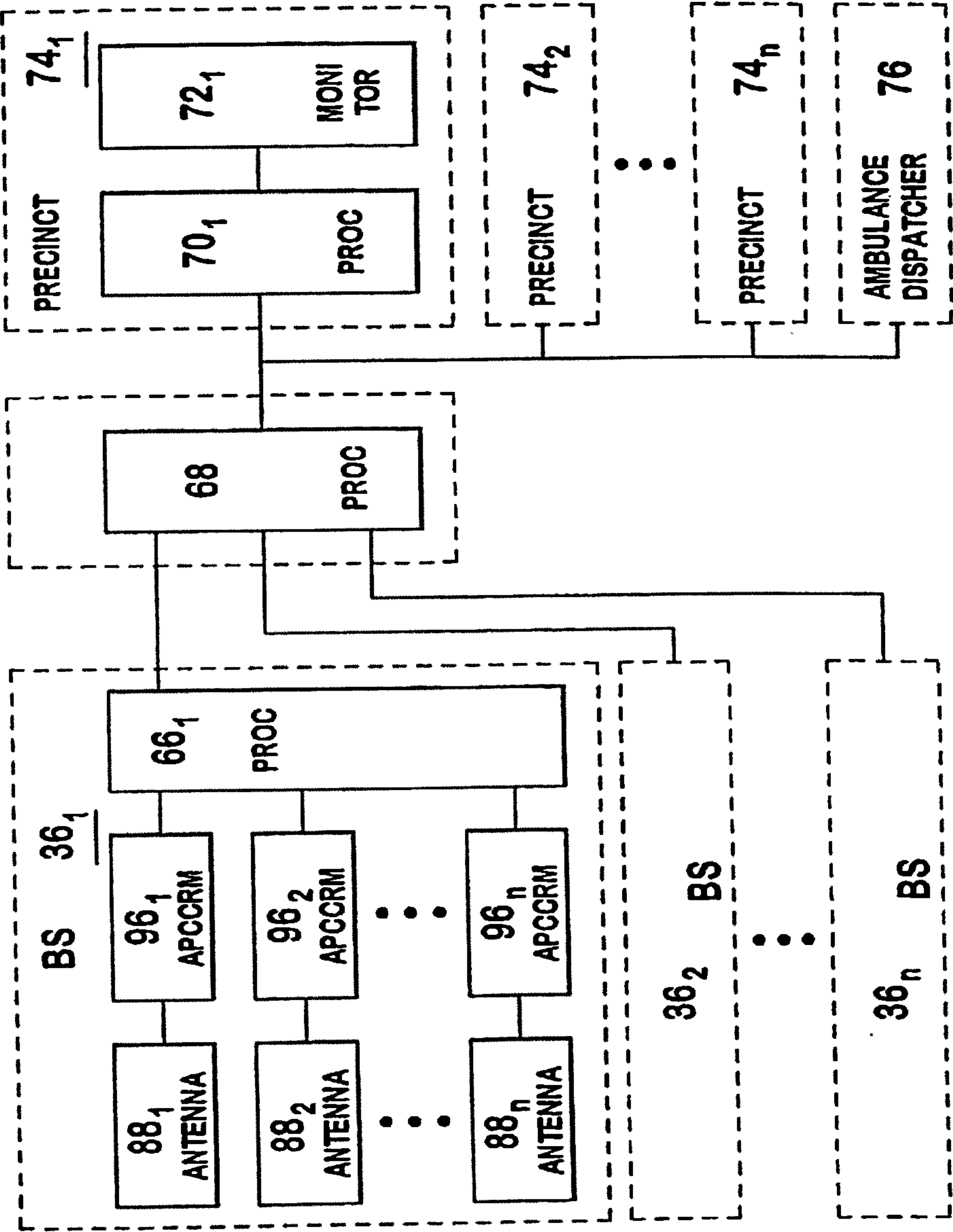


FIG. 13

FIG. 14

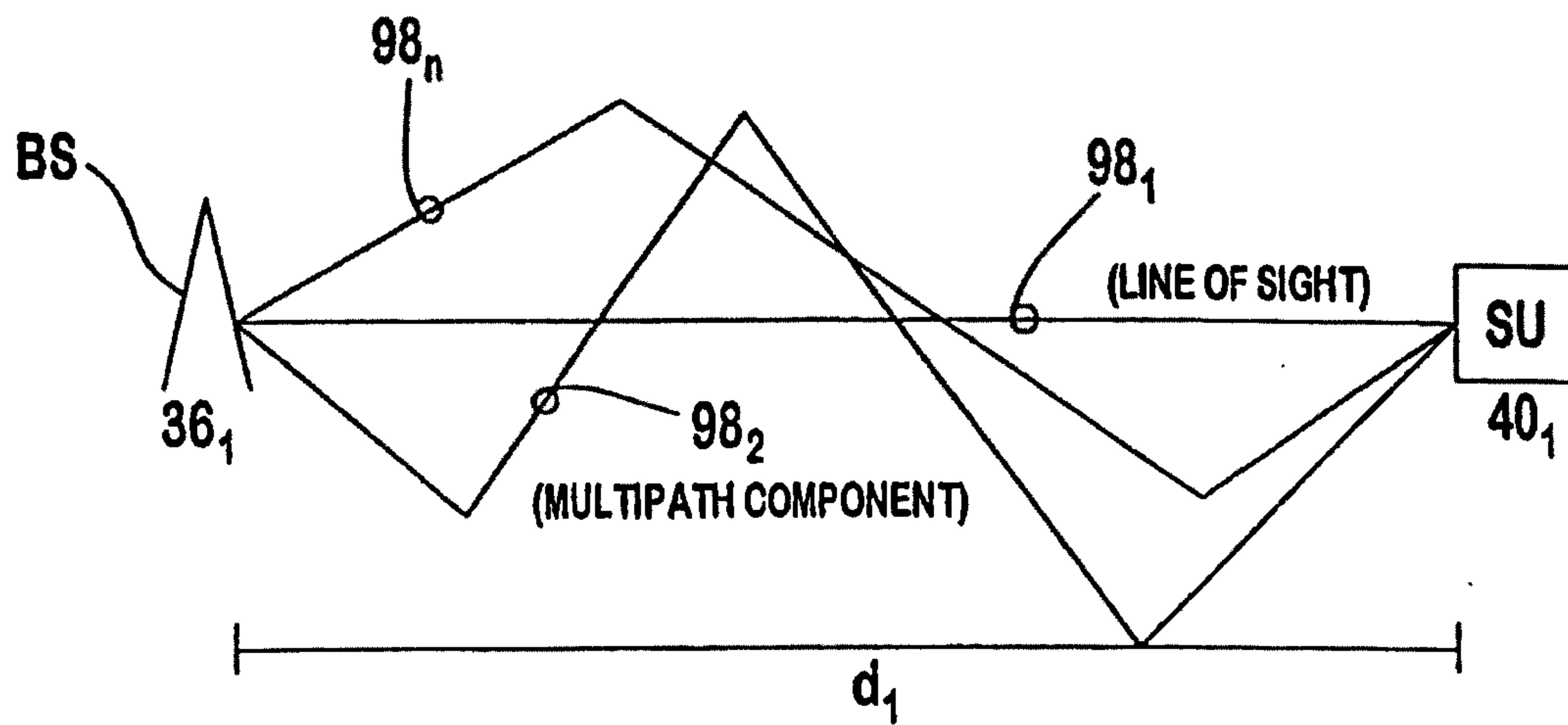
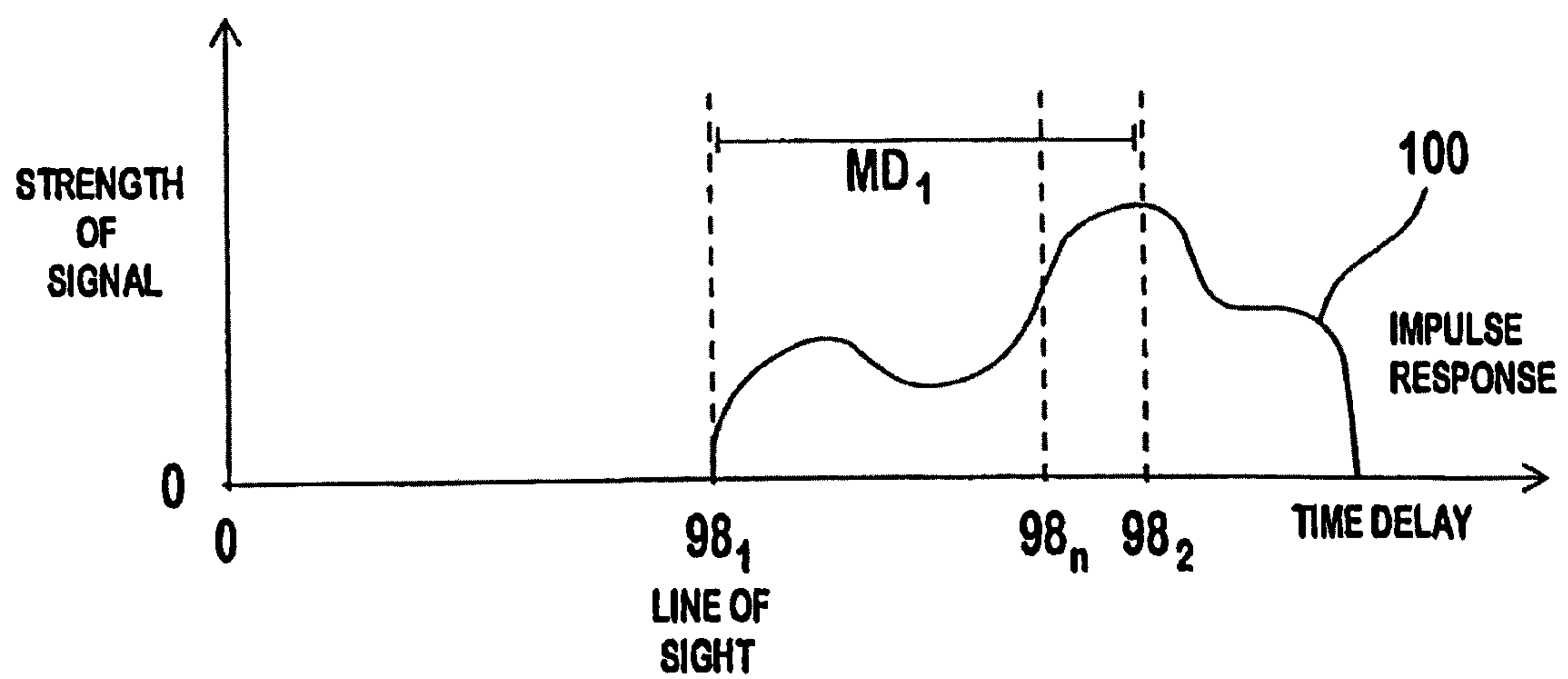


FIG. 15



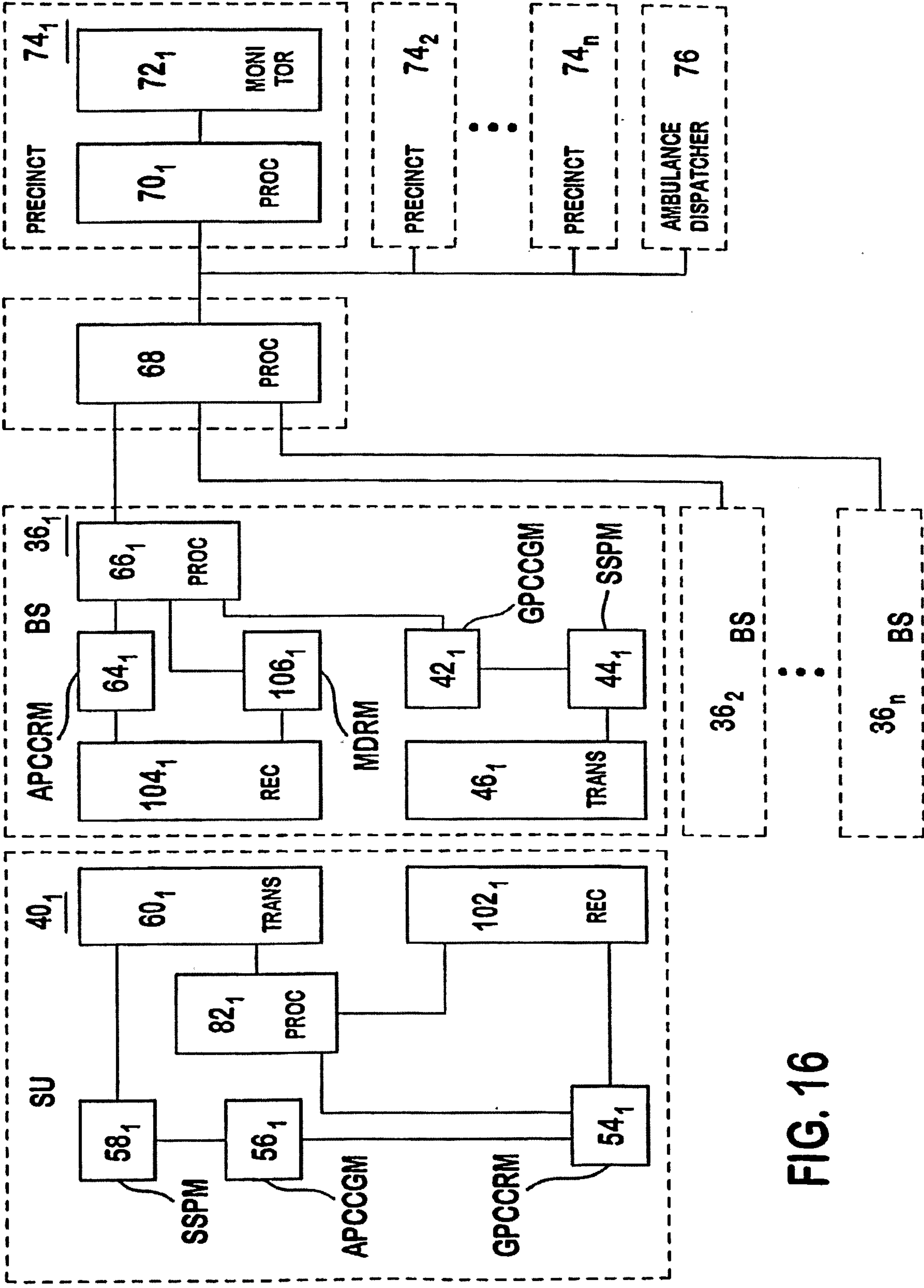


FIG. 16

