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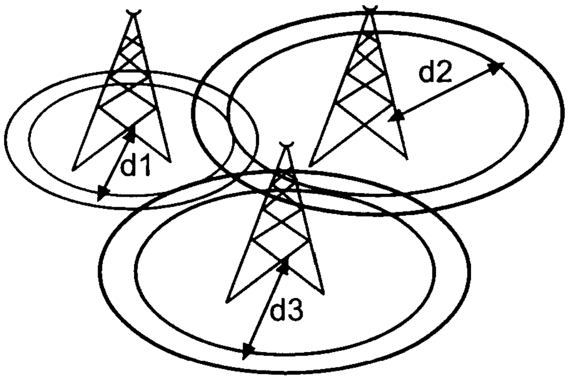

(57) Abstract: A device and a method to appoint the position of a mobile station in a mobile communication system including the steps to measure the signal strength of signals coming from base stations located in the neighbourhood and estimate the position (1) of the mobile station as a weighted sum of base station positions involving the use of the path loss L_i according to formula (I).

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{-\frac{L_i - A}{B}}}{\sum_{every\ i} 10^{-\frac{L_i - A}{B}}} \quad (\text{I})$$

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METHOD FOR POSITIONING OF MOBILE STATIONS

BACKGROUND

The present invention relates to a method for determining of the position of a mobile station in a mobile communications network.

FIELD OF INVENTION

The number of location based services continue to expand. Such services are based on the GSM standardised Cell Identity with Timing Advance technique, which gives position accuracy that depends among other things on the cell size, which can be very large. Some positioning services, such as emergency calls, demand high accuracy. The object of the present invention is to provide a method for improved accuracy.

The number of subscribers to second-generation systems that use digital transmission technology is increasing steadily. This depending on acceptable mobile phone prices, which make it possible for almost everyone in the Western World to buy a phone. Another reason for the increase is the acceptable prices for the calls. This trend is expected to continue in the future.

With the location of a mobile phone we mean the geographical position of the mobile. Mobile positioning in cellular networks provides several services such as information services, tracking services and positioning of emergency calls and stolen mobiles.

Current services are based on the known Cell Identity and Timing Advance method (Cell Id + TA), see below for detailed description. The disadvantage of this method is that the accuracy is directly dependent on the cell radius, which can be very large, especially in rural areas.

US Patent No. 5,732,354 (McDonald, A.O.) discloses a method and an apparatus for determining the location of a mobile telephone, where a mobile location module receives a list of signal strengths received by the mobile telephone from cell site antennas. The distance between the mobile telephone and the cell site antennas is calculated using an error component reducing technique and a term representing a propagation path slope. The reduced error distances are used to geometrically determine an estimate of the location area within the serving area of a mobile telephone system.

FR 2794313 (Lefebvre, B) discloses a geographic positioning system for mobile telephones involving measurements of transmission power levels in current and adjacent cells and use of co-ordinates of current and adjacent cells. The two cells with the highest power are selected and their base station co-ordinates are provided for calculation of mobile telephone position.

In CN 1284830 (Zhu Xiaodong) a mobile terminal self-positioning method is disclosed. The base stations broadcast a base station code, latitude and longitude and equivalent carrier emitting power of the present and adjacent base stations. Equivalent emitting power is calculated taking into account antenna gain and loss of synthesizer and feeder. The mobile terminal calculates distances to the base stations and determines its position according to received data and measured power and based on channel transmission model.

In CN 1255816 (Zhu Xiaodong) a similar method as in CN 1284830 is disclosed.

The purpose of the present invention is to provide a method with improved positioning accuracy. This because some services demand higher accuracy than the commonly used Cell Id + TA technique. An example of such services is emergency calls.

SUMMARY OF THE INVENTION

The invention comprises a method for determining the position of a mobile station based on signal strength measurements. Signal strength measurements are continuously performed within a GSM system as a means for facilitating the handover procedure between different base stations. Two times each second (still in the GSM case) the mobile station creates a measurement report, containing the measured signal strengths for signals coming from the base stations in those cells listed in a neighbouring cell list. These reports are subsequently sent to the base station controller (BSC), which is responsible for the handover procedure. This means that measurement values are available both inside the mobile station and in the network.

In an embodiment of the present invention the measured signal strengths, S_i, are employed to determine the coupling loss, L_i, taking into account the output power from the neighbouring base stations, P_i, as $L_i = P_i - S_i$, where the index character i denotes the different base stations. The position of each base station is known, and can be expressed in co-ordinates. We here denote these co-ordinates

$$\overline{R}_i = (X_i, Y_i)$$

The estimated position of the mobile station, $\overline{r}$, is now calculated using the weighting formula

$$\overline{r} = \frac{\sum_{every\ i} \overline{R}_i 10^{\frac{L_i - A}{B}}}{\sum_{every\ i} 10^{\frac{L_i - A}{B}}}$$

where A and B are algorithm parameters.

This method has a low complexity of calculation and low demand on information storage.

In another embodiment of the invention, especially devised to take care of the case when there is lack of information on base station output power, $\bar{r}$ is calculated using a modified formula:

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{\frac{A^1 - Si}{B}}}{\sum_{every\ i} 10^{\frac{A^1 - Si}{B}}}$$

where A^1 is another algorithm parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

Features, aspects and advantages of the present invention will become better understood with reference to the following description, appended claims and accompanying drawings, where:

Fig.1 shows an overview over the relations between the areas in GSM;

Fig. 2 shows the GSM structure;

Fig. 3 shows logical channels;

Fig. 4 shows control channels hierarchy;

Fig. 5 shows the traffic channels;

Fig. 6 shows different propagation phenomena;

Fig. 7 shows signal strength decreasing exponentially with the distance from the base station;

Fig. 8 shows MS position with CGI method for both omni and sector cell:

Fig. 9 shows the TA values;

Fig. 10 shows the MS possible position with CGI and TA for both omni and sector cells;

Fig. 11 shows the MPS structure;

Fig. 12 shows the triangulation of signal level;

Fig. 13 shows circle positioning;

Fig. 14 shows combination of strength and Cell ID with TA; and

Fig. 15 shows a MS position estimation unit according to an embodiment of the invention.

ABBREVIATIONS

AGCH	Access Grant Channel
A-GPS	Assisted GPS
AOA	Angle Of Arrival
AUC	Authentication Centre
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BSC	Base Station Controller
BSS	Base Station System
BTS	Base Transceiver Station
CCCH	Common Control Channel
CGI	Cell Global Identity
DCCH	Dedicated Control Channels
DCS	Digital Communication System
EIR	Equipment Identity Register
E-OTD	Enhanced-Observed Time Difference
FACCH	Fast Associated Control Channel
FCCH	Frequency Correction Channel
FDMA	Frequency Division Multiple Access
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GSM	Global System for Mobile communication
HLR	Home Location Register
LA	Location Area
LAI	Location Area Identity
LOS	Line Of Sight
MPC	Mobile Positioning Centre
MPS	Mobile Positioning System
MS	Mobile Station
MSC	Mobile services Switching Centre
NLOS	None Line Of Sight
OMC	Operations and Maintenance Centre
PCH	Paging Channel
PLMN	Public Land Mobile Network

RACH	Random Access Channel
SACCH	Slow Associated Control Channel
SCH	Synchronization channel
SDCCH	Stand alone Dedicated Control Channel
SIM	Subscriber Identity Module
SMS	Short Message Service
SS	Switching System
TA	Timing Advance
TCH	Traffic Channels
TDMA	Time Division Multiple Access
TOA	Time Of Arrival of the signal
UMTS	Universal Mobile Telecommunication System
VLR	Visitor Location Register
CDF	Cumulative Distribution Function

GENERAL DESCRIPTION

There are a number of position methods, which are standardised in GSM [1]. These are Cell Global Identity + Timing Advance (CGI + TA), Enhanced-Observed Time Difference (E-OTD), Assisted GPS (A-GPS) and Time Of Arrival of the signal (TOA). Several different methods are possible to use to estimate the positioning of a mobile station independent of the wireless system (e.g. UMTS, GSM and IS-95) that is used. The basic methods measure the Angle Of Arrival (AOA), TOA of the signal and the signal strength [2].

The E-OTD and the A-GPS methods have an accuracy of the order 50-150 meter and 3-150 meter respective. A disadvantage is that they are expensive to implement, which makes it advantageous to investigate signal strength positioning techniques.

Global System for Mobile Communication (GSM)

There are two existing wireless location systems, GPS and positioning in the GSM-network. This chapter provides a brief description of the GSM network [4]. The GPS system omitted, if there is interest see [5][6].

GSM, the Global system for Mobile Communications, was developed as a European digital mobile phone standard. It was first deployed in 1992 and it became one of the fastest growing and most demanding telecommunications applications ever. In the 900 MHz band (GSM 900) there are services operating in at least 140 countries across all continents. GSM have later also been available at 1800 MHz in Europe, Australia and Asia; this standard is referred to as Digital Communication System (DCS 1800) or GSM 1800. USA uses GSM 1900.

GSM differs from the first generation wireless systems in that it uses digital technology, narrowband time division multiple access transmission methods (TDMA) and advanced handover algorithms between radio cells in the network. Those allow significantly better frequency usage then in analogue cellular systems and increase the number of subscribers that can be served.

The GSM Structure

The GSM network needs a certain structure in order to route incoming calls to the correct exchange and to the called subscriber. The network is divided into several areas. Every operator has each "PLMN Service Area" (Public Land Mobile Network). This area has a number different "MSC Service Area" (Mobile services Switching Centre). An MSC Service Area represents the geographical part of the network that is covered by one MSC. Each MSC Service Area is divided into several Location Areas, which then can have a lot of cells [7]. A cell is a radio coverage area of a BTS. The network identifies the cell by the Cell Global Identity (CGI).

The GSM networks are very complex communications systems; hence to understand positioning in GSM it is necessary to first take a look at the system structure. GSM is basically divided into the Switching System (SS) and the Base Station System (BSS). Each of these contains a lot of functional units, which are implemented in various equipments (hardware).

The SS includes the following units:

MSC Mobile services Switching Centre

The MSC controls calls to and from other telephony and data communication systems.

A MSC serves a number of Base Station Controllers.

VLR Visitor Location Register

The VLR is a database containing relevant information about all mobiles currently located in a serving MSC area. If a mobile roams into a new MSC area, the VLR connected to that MSC would request data about the mobile from the HLR. Thus the HLR will be informed in which MSC area the mobile stay.

HLR Home Location Register

HLR is one of the most important databases; it contains subscriber information such as supplementary services and authentications parameters. HLR also contains information about the location of the mobile, i.e. in which MSC area the mobile stay in.

AUC Authentication Centre

AUC provides the HLR with different sets of parameters to complete the authentication of a mobile station. AUC is related to the HLR.

EIR Equipment Identity Register

The EIR is an option that is up to the network operator to make use of. It includes all the serial numbers of certain mobile equipment; this prevents a stolen or non-type-approved mobile being used.

The BSS includes the following units:

BTS Base Transceiver Station

The BTS is the mobile's interface to the network. A BTS is usually located in the centre of a cell.

BSC Base Station Controller

The BSC monitors and controls several BTS; it controls such functions as handover and power control.

MS Mobile Station

There are a lot of various MS; vehicle installed or hand-held. The MS has two different parts, the physical equipment and the subscription (Subscriber Identity Module SIM). The SIM is a smart card with a computer and memory chip that is installed in a plastic card. Without SIM, the MS cannot get access to the GSM network, except for emergency calls. Only the SIM cards contain the identity and personalized information.

OMC Operations and Maintenance Centre

The OMC is connected to all equipment in the SS and to the BSS. It handles error messages coming from the GSM-network and controls the traffic load of the BSC and the BTS.

The Frequencies

In GSM the mobile station and the BTS transmits in different frequency bands. GSM 900 uses two 25 MHz blocks and DCS 1800 uses two 75 MHz of the radio frequency spectrum. The two blocks are called the uplink (signal transfer from mobile station to base station) and downlink (signal transfer from base station to mobile station). The mobile station transmits in the 890-915 and 1710-1785 MHz, and the base station in the 935-960 and 1805-1880 MHz. Every operator get a certain part of frequency spectrum, which are divided in several frequency channels. This is called Frequency Division Multiple Access (FDMA). The FDMA frequency channels are then divided on eight TDMA slots. One timeslot of a TDMA-frame on one carrier is called a physical channel. The mobile station transmits and receivers in the same time slot. This means that eight subscribers (calls) can take place on the same carrier.

To be able to send the digital wireless information, then the information has to be modulated on an analogue carrier wave first. The chosen modulation method for GSM is called GMSK (Gaussian Minimum Shift Keying).

GSM is a very complex communications system, which have to transmit a great variety of information between the mobile station and the BTS. Depending on the kind of information that will be transmitted, it is often referred to different logical channels, i.e. different types of information are sent on the physical channels in a certain order. These logical channels are mapped on to the physical channels. There are two groups of the logical channels; the control channels and the traffic channels.

The Control Channels

Searching for a BTS to communicate with is the first thing a MS does after switching on. This can be done by scanning the whole frequency band, or, apply a list, which include the allocated BCCH-carriers) for the operator. There is a lot of control channels, which are used from the time MS switches on until change of BTS during a call is performed. Depending on their tasks, there are four different classes of control channels. These control channels are arranged below in a chronological order.

Broadcast channels, BCH

FCCH Frequency Correction Channel

A sinus wave signal is sent on the FCCH. This have two purposes; to make sure that this is the BCCH-carrier and to enable the MS to synchronise to the frequency.

SCH Synchronization channel
This channel is used to make sure that the chosen BTS is a GSM-BTS. The MS receives the Base Station Identity Code, BSIC, and also information on the TDMA frame number in this cell.

BCCH Broadcast Control Channel
The last information the MS must receive is general information regarding the cell. This is done on the BCCH. It contains the Location Area Identity, LAI, maximum output power and the BCCH-carriers for the neighbouring cells.

Common Control Channels, CCCH

PCH Paging Channel
The MS will listen to the PCH within certain time to see if the network wants to get in contact with the MS. This to check if there is an incoming call or a Short Message Service, SMS.

RACH Random Access Channel

If the PCH has been paged, then the MS answers on the RACH. The RACH can also be used when the MS wants to get in contact with the network.

AGCH Access Grant Channel

The network use AGCH to assign SDCCH (see below) to MS.

Dedicated Control Channels, DCCH

SDCCH Stand alone Dedicated Control Channel

This channel is used due to a call set up or sending SMS.

SACCH Slow Associated Control Channel

Within certain time intervals the BTS sends information about the transmitting power and the timing advance the MS shall use. The MS sends measurements concerning received signal strength and quality on own and neighbouring base station. This information is sent on the SACCH.

FACCH Fast Associated Control Channel

When a handover between the BTSs must be performed the FACCH is used. FACCH steals a 20 ms segment of speech to exchange signalling information.

Traffic Channels, TCH

There are two types of traffic channels; full rate and half rate as can be seen in fig. 5. Full rate and half rate are two different methods of speech coding. Full rate is the usual one. One full rate TCH take one physical channel, while two half rate TCHs can share one physical channel.

Propagation models

The radio signal becomes attenuated on its way between the transmitting and the receiving antennas. The loss the signal strength suffers is called the *path loss*, denoted L_{path}. It depends among other things on the distance between the base station and the mobile station which calculates by using path loss models. The distance will then be used solving mobile station position, see chapter 5.

The received power P_r from the base station can be used to calculate the path loss between the base station and the mobile station if we know the output power P_t, the receivers antenna gain G_r and the transmitting antenna gain G_t. The output power may be expressed as

$$P_r = P_t \frac{G_t G_r}{L_{path}} \qquad (1)$$

or expressed in dB

$$(P_r)_{dB} = P_t + G_t + G_r - L_{path} \quad (2)$$

which gives the path loss

$$(L_{path})_{dB} = P_t - P_r + G_t + G_r \quad (3)$$

There are a lot of wave propagation models that can be used to calculate the path loss. The simplest one is free space propagation. This model is based on direct wave between the base station (BS) and the mobile station (MS) (as can be seen from fig. 6). That means that the propagation is on the line-of-sight (LOS) path between transmitter and receiver.

The problem is that the radio wave is influenced by the ground, different obstacles on the ground, change in weather and the various shapes of man-made structures. These phenomena cause Non-line-of-sight (NLOS) and affect the radio wave propagation with: reflection, penetration, diffraction and scattering (view fig. 6). All theses different waves received at the mobile station result in a multipath fading, also called fast fading. It is in other words the man-made structures as houses and buildings or natural obstacles such as forests surrounding the mobile which cause the fast fading [8].

The terrain configuration and the man-made environment that is located between the receiver and the transmitter cause the shadow fading. Terrain configurations can be mountain area, hilly terrain, open area or flat terrain.

There are, in other words, three factors that affect the signal strength; path loss, shadow fading and fast fading (view fig. 7).

The propagation loss model is generally a sum of the path loss model L_i and the shadow fading loss Z_i. The fast fading has been taken care of the mobile station. It does not affect the propagation model.

$$L_{Tot,i} = L_{path,i} + Z_i \qquad (4)$$

These mechanisms have to be described by approximations in the practical prediction of propagation in different environments.

The shadow fading loss can be a random variable that follows a certain distribution with one standard deviation of σ. It is generally not possible to know the exact standard deviation and the distribution of the environment.

Hata-Model, Cost 231-Hata Model and Cost 231 Walfisch-Ikegami Model are three different and more complicated path loss models that can be used in the GSM network. These models have different advantages and disadvantages depending on the environment they will be used in. The path loss can generally be expressed as

$$(L_{path})_{dB} = K_1 + K_2 \log d \qquad (5)$$

where K_1 and K_2 are model parameters which depends on frequency, mobile station and base station antenna heights. These parameters vary for the different path loss models.

Positioning technique in cellular networks

There is different positioning technique, which can be used to calculate the location of a terminal. At least one operator currently uses (2002) the model Cell Id and TA in this network. A more detailed description of these models and techniques follow below.

Cell Global Identity (CGI)

Cell Global Identity, which is also called Cell Id, is one of the simplest and cheapest forms of terminal positioning. This method is based on the knowledge of the "highest" received power at the terminal, which gives the BTS/cell the terminal is connected to at the moment (serving cell). By using the serving cell position the approximate position of the terminal can be calculated [10]. The accuracy depends on the cell size and if the cell has an omni-directional BTS antenna or if it has a directional antenna. When the position is based on the CGI the position estimate for omni and sector cells looks like this. The radius of a cell may vary from around 100 meters to 35 km. The Cell Id positioning method can be network-based or terminal-based.

Timing Advance (TA)

Every frequency on the GSM system is divided in time slots, which allocates the users. The MS can be found at different distances from the BTS within a single cell. Depending on the distance to the base station the mobile have to send the burst in advance to arrive in the right time slot on the BTS. This phenomenon is called Timing Advance [4]. The Base Station will send a TA value between 0 and 63, which tells the MS how many bit-times ahead of synchronisation time it have to transmit its burst (see fig. 9).

In other words the TA is used to compensate transmission of the time slots in relation to the distance between the MS and the BS. Each TA step corresponds to 1.85 µs, which is equal to 0.5 bits. That gives accuracy of 550 meters for TA = 0 and the user be on the distance 0-550 from the BS, TA = 1 means that the user is 550-1100 meters away from the BS and so on for other TA values.

When the position is based on the TA value the accuracy for omni and sector cells is illustrated in fig. 10.

Figure 10 shows that the TA value makes the position area smaller compared with the Cell Id model. The maximal distance between the MS and the BS is about 35km; in that case the TA is equal to 63.

Signal Strength (SS)

There are many ways in which position can be derived from the measurement of the signals [10]. Those methods use a known mathematical model which describe the path loss attenuation with distance. The MS lies on a circle centred at the BTSs. The location of the MS can be calculated by using multiple BTSs. This methods accuracy depends thus on the distance between the BTS and the MS, on the environment where the user is at the moment and also on the weather. In other words the signal strength becomes weaker for example on account of attenuation in the walls, reflection in the buildings and precipitation.

In the GSM system each mobile station measures and reports signal strength from up to six neighbouring base stations (the six base stations with the strongest signal strength). The present invention uses this information to improve the position accuracy of the mobile terminal.

Mobile Positioning System (MPS)
On the market there exist a number of GSM positioning solutions, e.g. the MPS (Mobile Positioning System) from Ericsson. The MPS is prepared to handle both GPS and the GSM solutions of positioning. But in the present situation the MPS use only CGI+TA technique. The MPS structure is illustrated in fig. 11.

There is a positioning gateway in the MPS, which is called Mobile Positioning Centre (MPC). The MPC acts as a gateway with the positioning procedure including the positioning applications on one side and the network signalling on the other. The MPC communicate with the GSM-network and the Internet. The communication between the MPC and the Internet occurs by means of http-inquiries. It performs also the calculation of the position. Depending on the different indicators in the system, the MPC decides if a MS should be positioned or not and also which positioning procedure (co-ordinate system) should be used. The MPC, which is a logical concept, is implemented as a stand alone node and is a part of the network. The PLMN operator owns it.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS
The present invention discloses a method for calculating the position of the mobile terminal using the transmitted/received

signal strength. Preferred embodiments include triangulation of the signals; another preferred embodiment includes linear combination of site positions. These embodiments require different input parameters and yield different position accuracy.

The mobile station location can be determined as the unique intersection point of three circles; this method is mentioned as triangulation of signal strength (see fig 12). It receives therefore at least three signal levels from three different base stations for calculating the position. The base stations are located at the centre of the circles with the radius d_i which is the distance from the mobile station to base station i.

From equation (5) d_i can be expressed as

$$d_i = 10^{\frac{L_i - K_1}{K_2}} \qquad (15)$$

The location calculation of the mobile station is done by finding the unique intersection point of the three circles that are centred on the BTSs. The equation for a circle is

$$(x_i - x)^2 + (y_i - y)^2 = d_i^{\,2}, \qquad (16)$$

where: (x , y) is the location of the mobile station in meter;
(x_i , y_i) is the location of the base station i in meter;
i is the base station number, i = 1, 2 and 3.

Fig. 13 shows the mobile station can be on two different places when two base stations are used, the third one solves the ambiguity. Thus by combining three circle equations (see equation 16) from three base stations 1, 2 and 3 yields these equations

$$(x_1 - x_2)\,x + (y_1 - y_2)\,y = (d_2^{\,2} - d_1^{\,2} + x_1^{\,2} - x_2^{\,2} + y_1^{\,2} - y_2^{\,2})\,\frac{1}{2} = f_{12}$$
$$(x_1 - x_3)\,x + (y_1 - y_3)\,y = (d_3^{\,2} - d_1^{\,2} + x_1^{\,2} - x_3^{\,2} + y_1^{\,2} - y_3^{\,2})\,\frac{1}{2} = f_{13} \qquad (17a,17b)$$

These two equations have two unknown quantities x and y which are the mobile station position. The equations are easily solved, either by multiplication of for example 17a by $1/(x_1 - x_2)$ and 17b with $1/(x_1 - x_3)$ and subtracting the resulting equations; this solves y, an analog technique solves x. The problem with this method is it overlooks the shadow fading. The shadow fading affects the signal strength and creates a deviation in the actual intersection point between the three considered base stations.

More than three signal strength measurements between base station and mobile can often be available and used. A more detailed description follows in the next sections.

If we have the signal strength measurements from N different base stations then a total of

$$\binom{N}{3} = \frac{N!}{(N-3)!*3!} \qquad (18)$$

different versions of equation number 17, which yields $\binom{N}{3}$ solutions, is obtained. That is the case if none of the three cells are co-sited, in other case equation number 17 cannot be solved.

In the case of N available signal strength measurements all the information can be taken into account for obtaining the position of the mobile station. This can be done in different ways. One way is by calculating a median value of the $\binom{N}{3}$ solutions that are solved by means of the previous method. We denote the solutions from the triangulation method $x_{group\ i}$

and y $_{group\ i}$ where *i* is the number of the solution. These solutions can be expressed in a matrix as

$$(\vec{x}_{groupi}, \vec{y}_{groupi}) = \begin{pmatrix} x_{group1} & y_{group1} \\ x_{group2} & y_{group2} \\ \vdots & \vdots \\ & \end{pmatrix} \tag{19}$$

To get the mobile station position we calculate the median value

$$(x, y) = median(\vec{x}_{groupi}, \vec{y}_{groupi}) \tag{20}$$

which gives the middle value if the number of $(\vec{x}_{groupi}, \vec{y}_{groupi})$ is odd and if it's even then the mean of the two middle values are calculated.

Other solutions that use the N available signals will be described in the following chapters.

In the case of using N signal strength measurements equation number 17a can be written as a matrix equation with all the N cases [12]. The matrix equation will be

$$A\vec{r} = \vec{f} \tag{21}$$

where $\vec{r}$ is the mobile position and is a 2 x 1 vector. The matrixes A and $\vec{f}$ are written as

$$A = \begin{pmatrix} (x_1 - x_2) & (y_1 - y_2) \\ (x_1 - x_3) & (y_1 - y_3) \\ \vdots & \vdots \\ (x_{N-1} - x_N) & (y_{N-1} - y_N) \end{pmatrix}, \quad \vec{f} = \begin{pmatrix} f_{12} \\ f_{13} \\ \vdots \\ f_{(N-1)N} \end{pmatrix} \tag{22}$$

The A matrix will have $\binom{N}{2}$ rows and thus there is $\binom{N}{2}$ ways to chose a pair from N base stations [12]. The least square sense solution of the mobile position is yielded by solving the expression

$$A^T A\vec{r} = A^T \vec{f} \tag{23}$$

By weighting each row in A and f with a weight factor w the error of the solution in equation 23 can decrease. The weight factor depends on the path loss L_i. The larger path loss (larger d_i) the minor weight. This will lead to larger deviations and shift the solution closer to the strongest signal strength BTS. The weight factors that are formed are

$$\vec{w} = \begin{pmatrix} 10^{-\frac{L_1+L_2}{20}} \\ 10^{-\frac{L_1+L_3}{20}} \\ \vdots \\ 10^{-\frac{L_{N-1}+L_N}{20}} \end{pmatrix} \tag{24}$$

In order to obtain the mobile position equation 23 is solved with the matrix A and f given by

$$A = \begin{pmatrix} w_{12}(x_1 - x_2) & w_{12}(y_1 - y_2) \\ w_{13}(x_1 - x_3) & w_{13}(y_1 - y_3) \\ \vdots & \vdots \\ w_{(N-1)N}(x_{N-1} - x_N) & w_{(N-1)N}(y_{N-1} - y_N) \end{pmatrix}, \quad \vec{f} = \begin{pmatrix} w_{12} f_{12} \\ w_{13} f_{13} \\ \vdots \\ w_{(N-1)N} f_{(N-1)N} \end{pmatrix} \tag{15}$$

Since the strongest signal strength the mobile station receives is often, but not always, from the closest base stations; the weighted sum of base station position is a good estimate of the mobile position.

In a particularly advantageous embodiment of mobile station position $\bar{r}$ is estimated according to the formula

$$\vec{r} = \frac{1}{N} \sum_{i=1}^{N} W_i \vec{R}_i, \tag{26}$$

where $\overrightarrow{R_i}$ is the position of base station number i. Each weight factor W_i is calculated according to the following expression:

$$w_i = \frac{10^{-\frac{L_i}{K_2}}}{\sum_{j=1}^{N} 10^{-\frac{L_j}{K_2}}} \tag{27}$$

where W_i is equal to the quotient between two terms; the numerator is equal to 10 to the power of the quotient between minus the path loss for signals from base station i and the model parameter K_2. K_2 depends on frequency, mobile station and base station antenna heights as described before.

The denominator is calculated as the sum over N neighbouring base stations of ten to the power of the quotient between minus the path loss for signals from base station i and the model parameter K_2.

The weight factor is a kind of a normalized distance weighting,

$$\frac{1}{d_i} \bigg/ \sum_{i=1}^{N} \frac{1}{d_i}.$$

In another embodiment of the invention a combination of one of the mentioned methods and the Cell Id + TA technique used. The accuracy for such an embodiment will be the common area between the Cell Id with TA and the signal strength method [13]. Fig. 14 illustrates the common area in the combination.

Fig. 15 shows a mobile station position estimation unit 1500, comprising a processor 1501 and a memory 1502. The estimation unit 1500 receives input data 1503 containing BTS signal strength data together with BTS position data and algorithm parameter data. Algorithm parameter data can also, or alternatively, be permanently stored in the memory 1502. The memory 1502 also contains computer program instructions that instruct the processor to use the input information 1503 to calculate an estimated mobile station position by the use of one or more of the above described algorithms.

PATENT CLAIMS

1. A method to appoint the position of a mobile station in a mobile communication system with a plurality of base stations, located at known positions, said mobile station having means to measure the signal strength of signals transmitted from at least three base stations, including the following steps:
   - measuring of signal strength,
   - making data regarding the location of the base station accessible,
   - calculation, for a number of base stations in the neighbourhood of a mobile station, a standardized weight factor depending on the signal strength for each base station, where each weight factor for the equation, corresponding to the signal strength measurements for a first and a second base station, is calculated as ten (10) raised to an expression of power containing path loss figures,
   - multiplication, for each base station, of its base station position data with belonging weight factor, under creation of a set of products for each base station corresponding to position coordinates,
   - calculation of, by summing up said products, the position of the mobile station.

2. A method as claimed in patent claim 1, further including the steps:
   - calculation of linear combination weight factors,
   - calculation of the position of the mobile station as a weighted sum by use of said linear combination weight factors for the positions of N base stations.

3. A method as claimed in patent claim 2, further including the steps:
- calculation of each said linear combination weight factor W_i as a ratio between a dividend and a denominator,
- calculation of said dividend as ten (10) raised to the minus ratio of the path loss i divided by a system specific term,
- calculation of said denominator as the sum of N terms,
- calculation of each of said N terms as ten (10) raised to minus the path loss i divided by said system specific term.

4. A method as claimed in patent claim 2, where said expression contains the sum of two path losses divided by minus twenty.

5. A method as claimed in patent claim 1, where the position $\bar{r}$ of the mobile station is calculated according to the formula

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{-\frac{L_i - A}{B}}}{\sum_{every\ i} 10^{-\frac{L_i - A}{B}}} \quad \text{where}$$

$\overrightarrow{R_i}$ = (X_i, Y_i), that is, the vector of the base station position

A = a first algorithm parameter

B = a second algorithm parameter

A and B can be obtained from the Hata, Cost 231-Hata, or Cost 231 Walfisch - Ikegami-models.

L_i = path loss for base station i

6. A method as claimed in patent claim 1, where the position of the mobile station is calculated according to the formula

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{-\frac{A^1 - S_i}{B}}}{\sum_{every\ i} 10^{-\frac{A^1 - S_i}{B}}}$$ where

$\overrightarrow{R_i}$ = the position (X_i, Y_i) of the base station as has been described above

A^1 = a third algorithm parameter

B = the second algorithm parameter

A^1 and B can be obtained from the Hata, Cost 231-Hata, or Cost 231 Wälfisch - Ikegami-models.

S_1 = the measured signal strength for signals from base station i.

7. A mobile station position estimation unit to appoint the position of a mobile station in a mobile communication system with a number of base stations located at known positions and with means to measure the signal strength from at least three base stations in the neighborhood of the mobile station, at which said unit includes device to receive information about the signal strength of signals received by the mobile station from in the neighbourhood located base stations; device to receive information regarding the position of in the neighbourhood located base station; means to calculate an estimated position of said mobile station as a weighted sum of the positions of in the neighbourhood located base stations; device to bring an estimated position back to a base station, and device to receive information regarding the output power of said in the neighbourhood located base

station, c h a r a c t e r i z e d in that said unit also includes device to receive information regarding antenna amplification.

8. A unit as claimed in patent claim 7, c h a r a c t e r i z e d in that said means to calculate an estimated position includes a process unit and a memory unit, and in that said memory unit stores computer program instructions, said program instructions being able to instruct said processor unit to perform calculations to estimate the position of the mobile station according to a predefined set of formulas.

9. A unit as claimed in patent claim 8, c h a r a c t e r i z e d in that said program instructions instruct the processor to calculate said, weighted sum according to the formula

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{-\frac{L_i - A}{B}}}{\sum_{every\ i} 10^{-\frac{L_i - A}{B}}}$$

10. A unit as claimed in patent claim 8, c h a r a c t e r i z e d in that said program instructions instruct the processor to calculate said, weighted sum according to the formula

$$\bar{r} = \frac{\sum_{every\ i} \bar{R}_i 10^{-\frac{A^{1} - Si}{B}}}{\sum_{every\ i} 10^{-\frac{A^{1} - Si}{B}}}$$

11. A unit as claimed in patent claim 8, c h a r a c t e r i z e d in that said set of formulas agrees with

$$\vec{r} = \frac{1}{N}\sum_{i=1}^{N} W_i \vec{R}_i,$$

$$w_i = \frac{10^{-\frac{L_i}{K_2}}}{\sum_{j=1}^{N} 10^{-\frac{L_j}{K_2}}}$$

12. A mobile station in a mobile communication system, c h a r a c t e r i z e d in that said station includes a mobile station position estimation unit according to patent claim 7.

13. A base station in a mobile communication system, c h a r a c t e r i z e d in that said base system includes a mobile station position estimation unit according to patent claim 7.

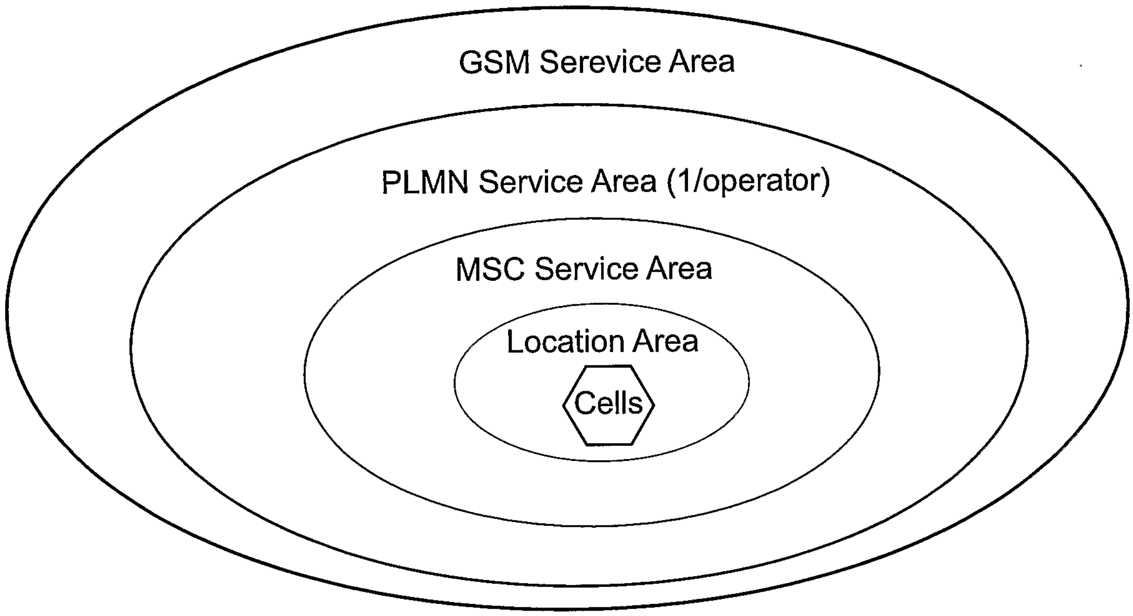
GSM Serevice Area
PLMN Service Area (1/operator)
MSC Service Area
Location Area
Cells

Fig 1

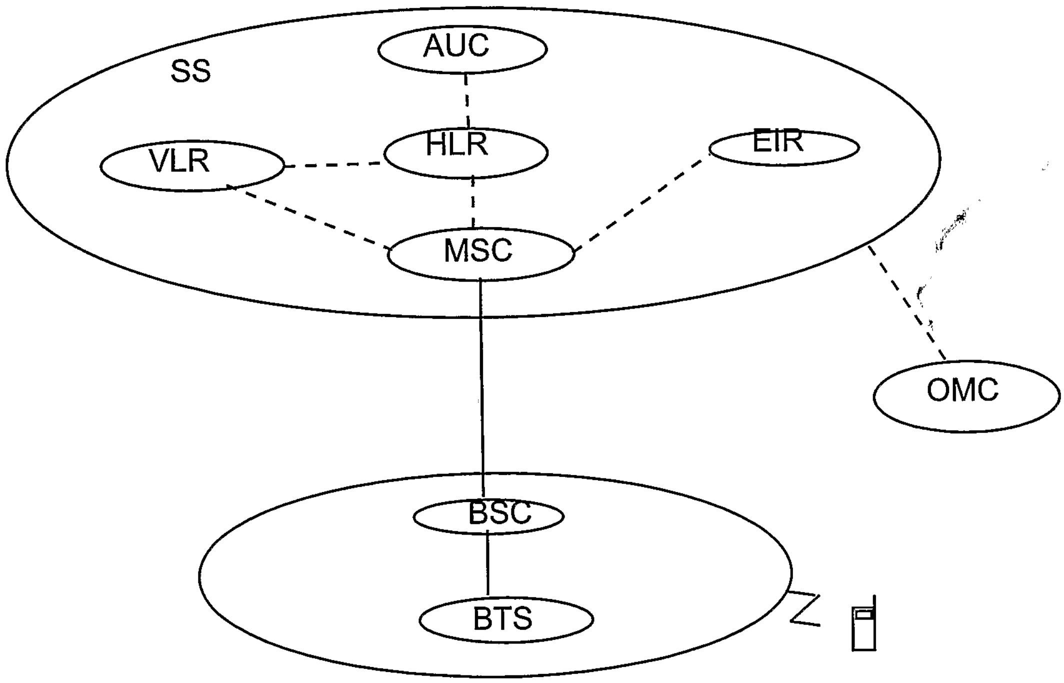
AUC
SS
VLR
HLR
EIR
MSC
OMC
BSC
BTS

Fig 2

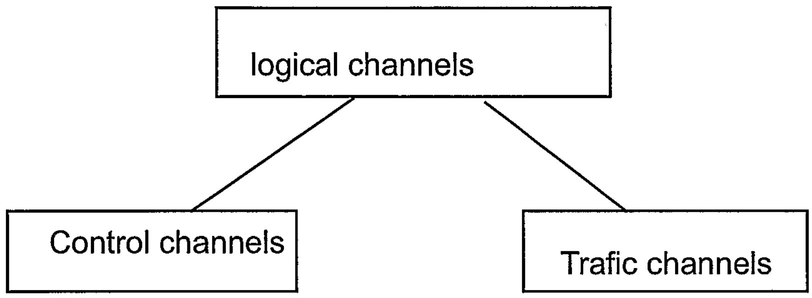

Fig 3

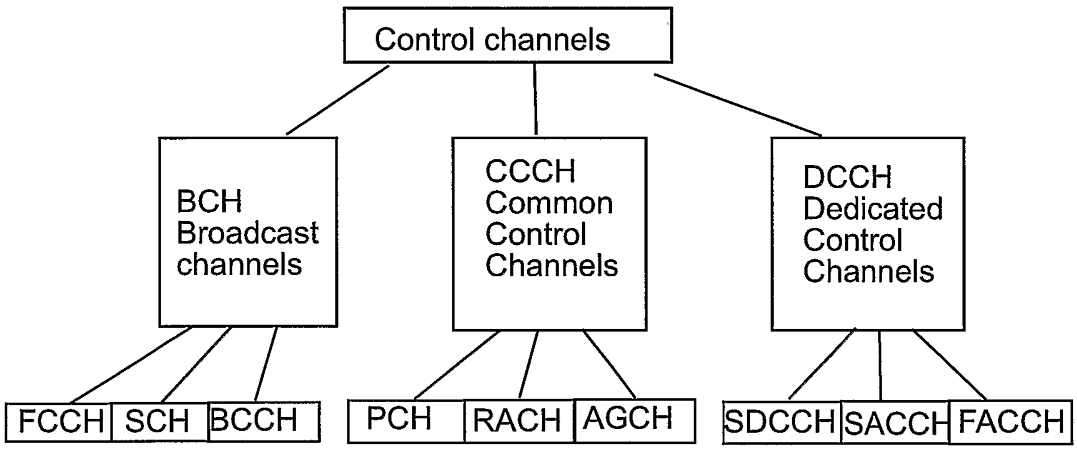

Fig 4

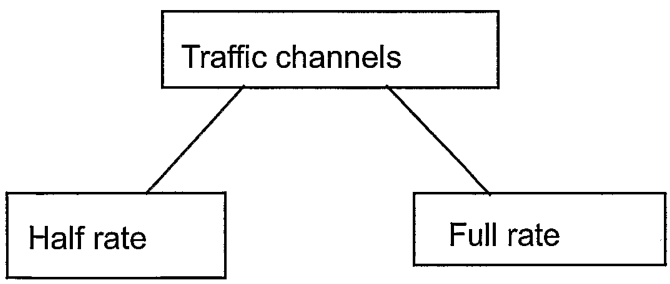

Fig 5

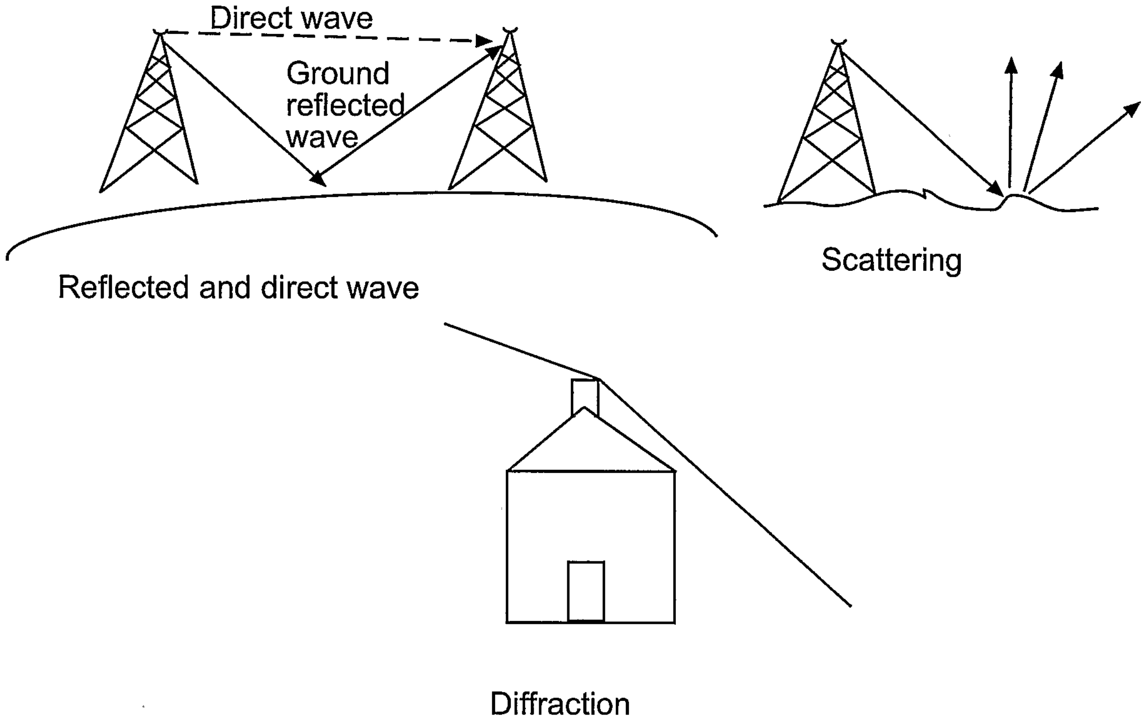
Direct wave
Ground reflected wave
Reflected and direct wave
Scattering
Diffraction

Fig 6

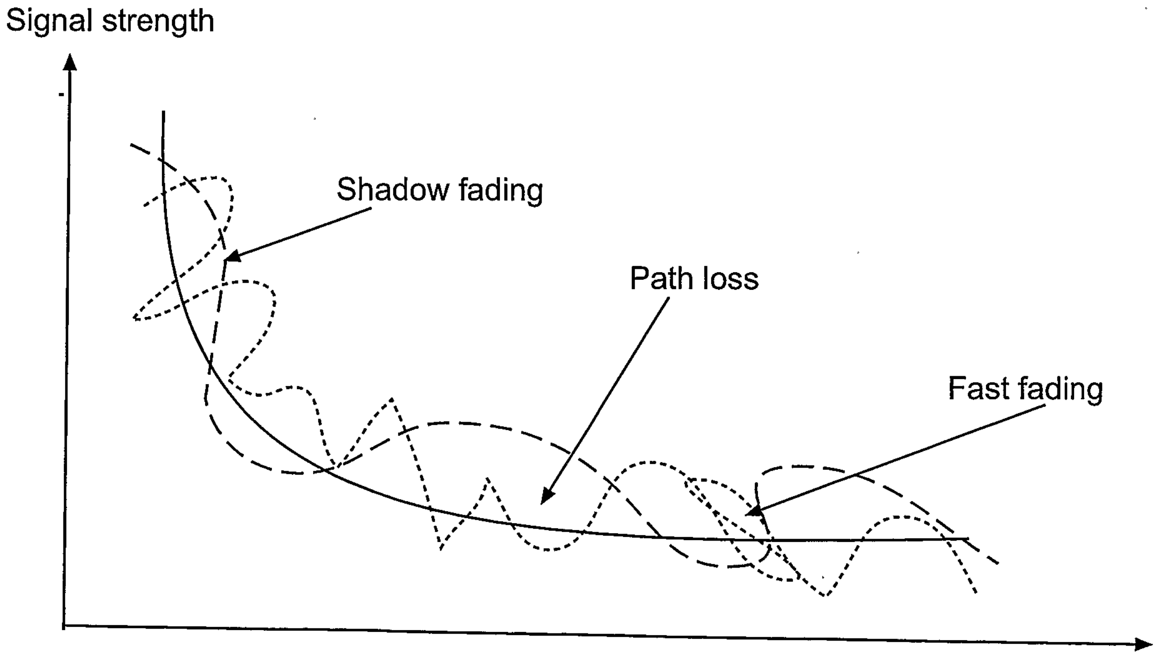
Signal strength
Shadow fading
Path loss
Fast fading

Fig 7

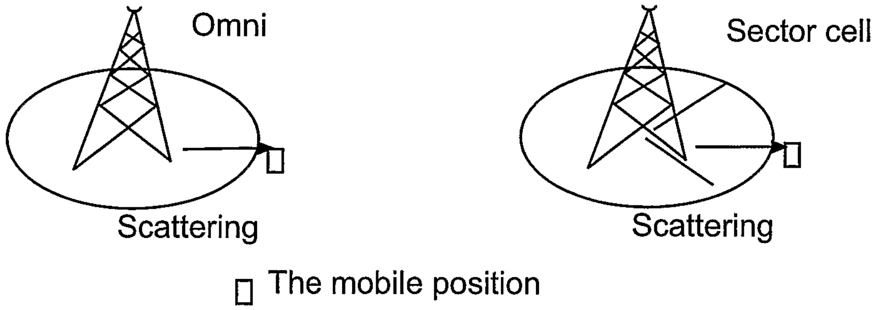

Fig 8

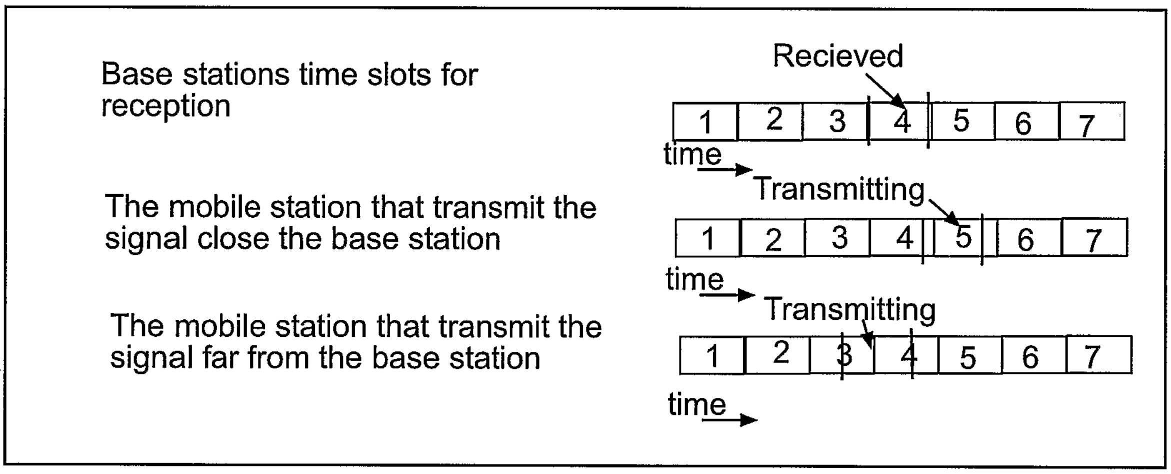

Fig 9

Fig 10

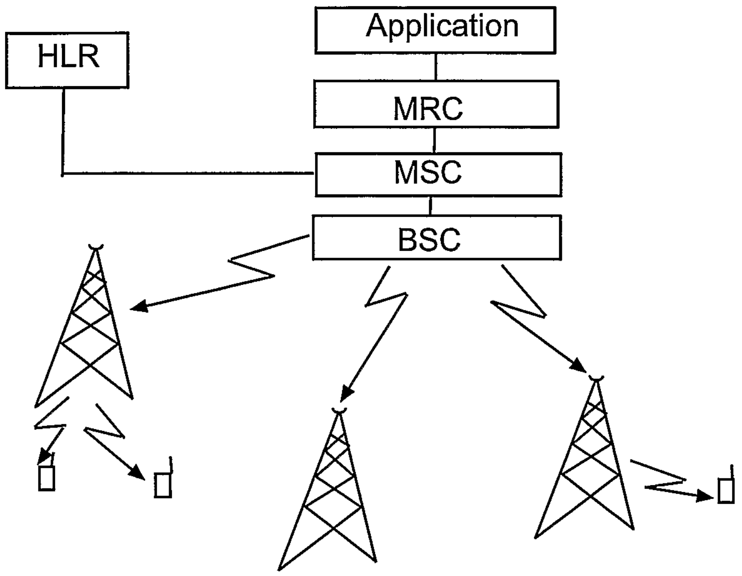

fIG 11

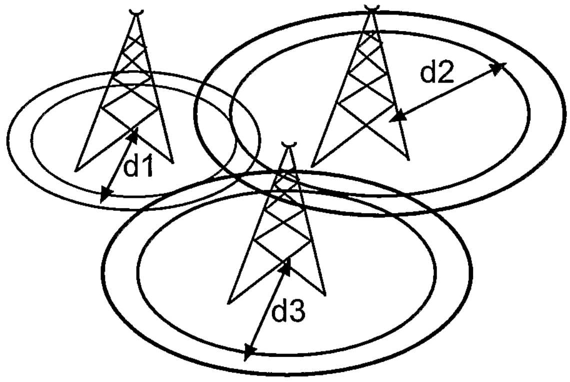

Fig 12

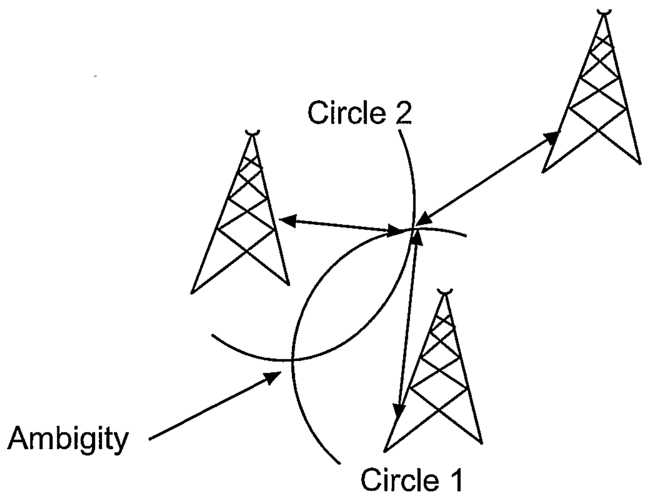

Fig 13

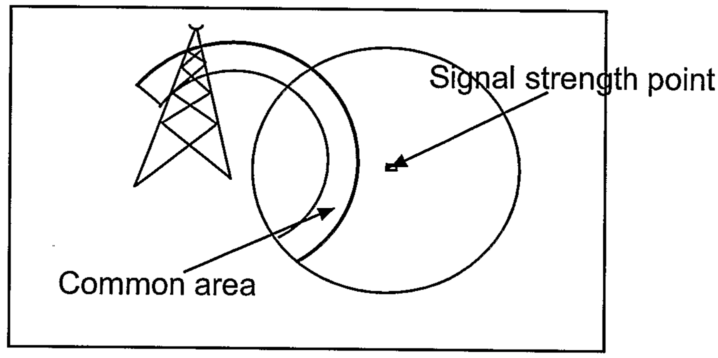
Signal strength point
Common area

Fig 14

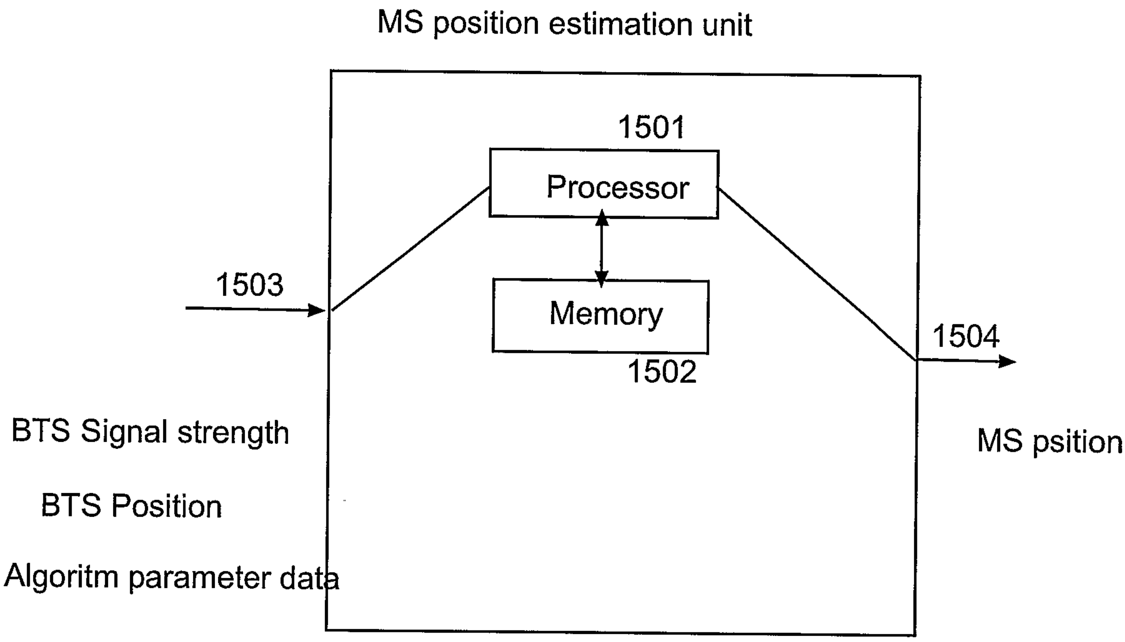
MS position estimation unit
1501
Processor
Memory
1502
1503
1504
BTS Signal strength
BTS Position
Algoritm parameter data
MS psition

Fig 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 03/00246

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01S 5/14, H04Q 7/38
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)

IPC7: G01S, H04Q

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 0124559 A1 (OY RADIOLINJA AB), 5 April 2001 (05.04.01), page 6, line 7 - line 8; page 19 - page 21	7-8
A		1-6,9-13
	--	
Y	WO 0105184 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)), 18 January 2001 (18.01.01), page 7, line 13 - page 11, line 2, claim 11	7-8
A		1-6,9-13
	--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family 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 application or patent 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	Date of mailing of the international search report
2 May 2003	19 -05- 2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Lars Lundström /LR Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Int( )nal application No.
PCT/SE 03/00246

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 6263208 B1 (CHANG, K.K. ET AL), 17 July 2001 (17.07.01), column 5, line 10 - line 37	7-8
A		1-6,9-13
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A	WO 9931921 A1 (ERICSSON INC), 24 June 1999 (24.06.99), page 5, line 1 - line 16; page 9, line 7 - line 11, figure 5	1-13
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A	US 6266534 B1 (RAITH, A.K. ET AL), 24 July 2001 (24.07.01), column 8, line 34 - line 52	1-13
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A	EP 1030531 A1 (LUCENT TECHNOLOGIES INC), 23 August 2000 (23.08.00)	1-13
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 03/00246

Patent document cited in search report			Publication date	Patent family member(s)			Publication date
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				FI	992094	A	30/03/01
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				CN	1360807	T	24/07/02
				EP	1197114	A	17/04/02
				US	6282427	B	28/08/01
US	6263208	B1	17/07/01	NONE			
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				GB	0016202	D	00/00/00
				GB	2348579	A,B	04/10/00
				US	6029070	A	22/02/00
US	6266534	B1	24/07/01	AU	742151	B	20/12/01
				AU	6954898	A	13/11/98
				BR	9808954	A	01/08/00
				CN	1261436	T	26/07/00
				EP	0977999	A	09/02/00
				JP	2001523337	T	20/11/01
				NZ	500344	A	30/11/01
				TW	456121	B	00/00/00
				US	6040800	A	21/03/00
				WO	9848578	A	29/10/98
EP	1030531	A1	23/08/00	AU	1527800	A	24/08/00
				BR	0000341	A	19/12/00
				JP	2000244968	A	08/09/00