PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01S 3/14, H04Q 7/38

A1

(11) International Publication Number: **WO 98/18018**

(43) International Publication Date: 30 April 1998 (30.04.98)

(21) International Application Number: PCT/CA97/00130

(22) International Filing Date: 26 February 1997 (26.02.97)

(30) Priority Data:
08/739,078 24 October 1996 (24.10.96) US

(71) Applicant: NORTHERN TELECOM LIMITED [CA/CA]; World Trade Center of Montreal, 8th floor, 380 St. Antoine Street West, Montreal, Quebec H2Y 3Y4 (CA).

(72) Inventors: ZHANG, Chang-Gang; 98 Stonebriar Drive, Nepean, Ontario K2G 5Y1 (US). TONG, Wen; Apartment 1106, 70 McEwen Street, Ottawa, Ontario K2B 5M3 (CA).

(74) Agent: HALEY, R., John; Northern Telecom Limited, Patent Dept., P.O. Box 3511, Station "C", Ottawa, Ontario K1Y 4H7 (CA).

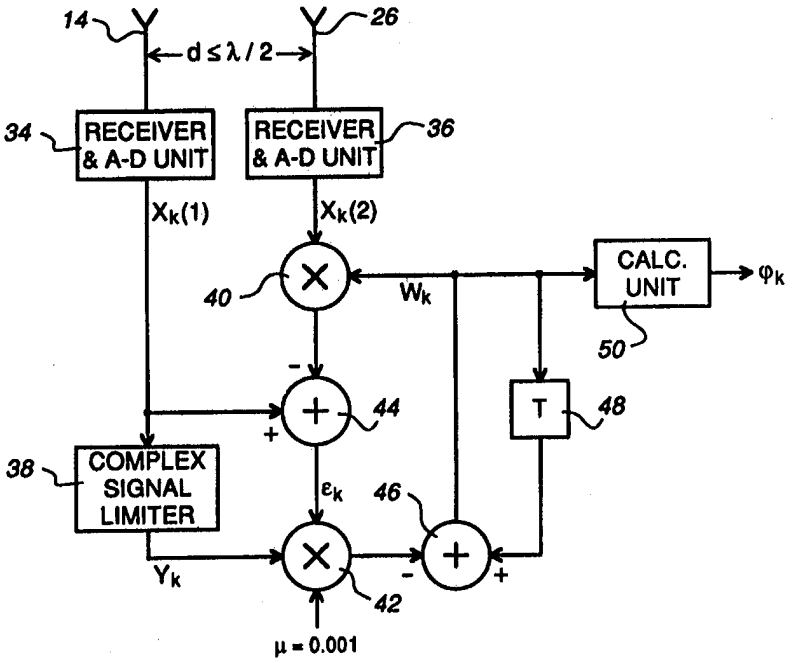
(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: DETERMINING DIRECTION OF A MOBILE TERMINAL IN A CELLULAR COMMUNICATION SYSTEM

(57) Abstract

A base station for a wireless communications system comprises two antennas (14, 26) spaced by a small distance (d) for receiving a signal from a mobile terminal, and two receivers (34, 36) coupled to the antennas for providing first and second received signals with a phase difference dependent upon a direction of the mobile terminal relative to the antennas. A nulling linear signal combiner (38–44) combines the received signals to determine the phase difference, and hence direction of the mobile terminal, using an adaptively adjusted complex weight W_k which is supplied via an arctangent function (50) to a d.c. tracking filter (50). The determined direction, and distance determined from signal strength information available in the base station, identify the location of the mobile terminal. The location is itself useful information, and can be monitored over time to determine velocity of the mobile terminal and/or can be used to identify candidate terminals for handoff from a macrocell to a microcell of the system.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

DETERMINING DIRECTION OF A MOBILE TERMINAL IN A CELLULAR COMMUNICATIONS SYSTEM

Technical Field and Industrial Application

This invention relates to determining the direction of a mobile terminal from a base station of a cellular radio communications system.

Background Art

Cellular radio communications systems are being used increasingly to provide communications with mobile terminals. To facilitate this increasing use, greater system capacity is required especially in high density locations with slow-moving mobile terminals. An attractive way of increasing system capacity is to provide microcells for the high density locations within larger cells of the system which are referred to as macrocells. Typically, a macrocell can have a high-power base station providing a coverage area within a radius of several kilometers from its antenna for mobile stations that can have high speeds, and a microcell within the macrocell can have a relatively low-power base station providing a coverage area within a radius of a few hundred meters from its antenna, for a high density of relatively slow-moving mobile terminals within the microcell. Communications channels allocated to the microcell can be re-used in other microcells within the macrocell, thereby enhancing the total system capacity.

Efficient operation of such a system is dependent upon effective handoffs from the macrocell to the microcells as a mobile terminal moves within the macrocell. Handoff of a rapidly moving mobile terminal to a microcell is undesired, but handoff of a slowly moving mobile terminal to a microcell is desirable as soon as the mobile terminal moves within a boundary of the microcell. Conventional handoff algorithms, especially for an AMPS (Advanced Mobile Phone Service) system, can not effectively handle this situation because of a large increase in false handoff triggering, messaging, and processing caused by being unable to detect handoff candidates efficiently. It is observed that handoff from the microcell back to the macrocell when the mobile terminal moves out of the microcell is also necessary but presents a much simpler problem that can be handled in known manner, for example on the basis of signal strength measurements.

It has been proposed to manage handoff from a macrocell to a microcell in various ways, including estimating velocity of a mobile terminal for example using its receiver's Doppler frequency in conjunction with level-crossing, zero-crossing, and covariance techniques. These proposals involve methods that tend to be unreliable because of high dependence on the propagation environment, so that efficient detection of microcell handoff candidates remains a substantial problem.

The present inventors have recognized that this problem is essentially a problem of determining the location of the mobile terminal. If the location of the mobile terminal can be reliably determined, then its velocity (change of location with time) can also be known,

and one or both of these parameters can be used in relation to known boundary parameters of the microcell to determine microcell handoff candidates.

The problem of determining the location of a mobile terminal is also significant for other reasons. For example, for telephone calls to emergency services (such as the 911 service), it is a typical requirement for the system to be able to identify the location of the calling party with a prescribed accuracy. Existing proposals for determining the location of a mobile terminal typically involve using measurements at three differently located base stations; this is relatively complex especially for a TDMA (Time Division Multiple Access) system which requires the use of GPS (Global Positioning System) to synchronize the stations, and tends to be unreliable in fading situations.

The present inventors have further recognized that the location of a mobile terminal can be determined from direction information representing a direction of the mobile terminal from a base station, together with distance information representing a distance of the mobile terminal from the base station. The distance information can be constituted primarily by the signal strength or RSSI (Received Signal Strength Indicator) information that is already monitored at the base station, optionally supplemented by secondary information that may be available, with averaging or smoothing in known manner to compensate for relatively rapid changes in signal strength due to fading, as distinct from distance changes which are relatively slow even for a rapidly moving mobile terminal.

Accordingly, an object of this invention is to provide a method of, and apparatus for, providing direction information representing a direction of a mobile terminal from a base station in a cellular radio communications system. Such direction information can then be used in combination with the distance information to determine the location of the mobile terminal, which can be useful in itself as discussed above, and/or in combination with one or more other parameters for various other purposes, in particular for handoff purposes between a macrocell and a microcell of the system.

Disclosure of the Invention

According to one aspect, this invention provides a method of determining a direction of a mobile terminal from a base station of a wireless communications system, comprising the steps of: receiving a signal from the terminal via two antennas of the base station, said two antennas being spaced by a predetermined distance to provide first and second received signals with a phase difference between them, the phase difference being dependent upon said direction of the mobile terminal relative to the antennas and upon said predetermined distance; and determining said direction from the phase difference between the first and second received signals.

The predetermined distance is preferably less than or equal to $\lambda/2$ where λ is the wavelength of the signal received by the two antennas. The step of determining said direction from the phase difference between the first and second received signals

preferably comprises the step of linearly combining the first and second received signals to produce a null combined signal.

The invention also provides a method of determining a location of a mobile terminal relative to a base station of a wireless communications system, comprising the steps of determining a direction of the mobile terminal from the base station by the method recited above, and determining a distance of the mobile terminal from the base station using a signal strength of the received signal.

Another aspect of the invention provides a base station for a wireless communications system comprising: two antennas spaced by a predetermined distance for receiving a signal from a mobile terminal of the system; two receivers coupled to the antennas for providing first and second received signals with a phase difference dependent upon a direction of the mobile terminal relative to the antennas and upon said predetermined distance; and a signal combiner for combining the first and second received signals to determine said phase difference.

The signal combiner preferably comprises a linear combiner arranged to produce a null combination of the first and second received signals. The first and second received signals provided by the receivers conveniently comprise complex signal samples, and the linear combiner is arranged to produce as said null combination differences between samples of the first received signal and products of samples of the second received signal and a complex weight which represents said phase difference.

The base station preferably includes apparatus for adaptively adjusting the complex weight for successive signal samples, said apparatus comprising a complex signal limiter arranged to amplitude limit samples of the first received signal, and a complex signal multiplier for multiplying amplitude limited samples of the first received signal by said null combination of the first and second received signals to produce an adaptive adjustment for the complex weight.

Brief Description of the Drawings

The invention will be further understood from the following description with reference to the accompanying drawings, in which:

Fig. 1 is an illustration showing movement of a mobile terminal within a coverage area of a cellular communications system including a microcell;

Fig. 2 illustrates principles of a dual antenna arrangement for determining direction of a mobile terminal; and

Fig. 3 schematically illustrates a block diagram of an arrangement for producing direction information.

Mode(s) of Carrying Out the Invention

Referring to Fig. 1, the plane of the drawing represents the coverage area of a macrocell 10 of a cellular radio communications system, for example an AMPS or GSM (Global System for Mobile Communications) or other TDMA system, having a base station (BS) 12 connected to an antenna 14 at a predetermined physical location. The base station 12 is also connected to an intelligent cellular peripheral or ICP (not shown); the base station 12 and ICP are arranged and operate in known manner to provide communications with mobile terminals within the macrocell 10.

In order to increase the capacity of the communications system, within the macrocell 10 at least one microcell 16 is provided in known manner, with its own base station (not shown) connected to the ICP and an antenna 18 located at a predetermined position for example in a location of high traffic density. The microcell 16 has a relatively small coverage area within a boundary 20; for illustrative purposes and simplicity in Fig. 1 this boundary is represented as a circle, but in practice it can be both indistinct and of an arbitrary shape. Communications with mobile terminals within the boundary 20 can be via the base station 12 of the macrocell or via the base station of the microcell 16. The microcell 16 uses for its communications frequency channels that are allocated to it by the ICP and are not used by the macrocell 10, although they generally will also be re-used by other microcells (not shown) to achieve the increased system capacity.

Two arrowed lines 22 and 24 (shown as straight lines for convenience) represent arbitrary paths of mobile terminals within the macrocell 10, each path passing into and out of the coverage area of the microcell 16 at points marked A and B respectively for the line 22 and C and D respectively for the line 24.

The line 22 is a solid line representing a mobile terminal moving relatively rapidly. Although this path passes through the coverage area of the microcell 16, handoff of communications with this mobile terminal from the macrocell 10 to the microcell 16 in response to the mobile terminal moving to within the boundary 20 at the point A, and consequent handoff back to the macrocell 10 in response to the mobile terminal moving back outside the boundary 20 at the point B, is desirably avoided because of the relatively high speed, and consequent short time within the microcell 16, of the mobile terminal.

The line 24 is a dashed line representing a mobile terminal moving relatively slowly. It is desirable for communications with this mobile terminal to be handed off from the macrocell 10 to the microcell 16 in response to this mobile terminal moving to within the boundary 20 at the point C, with a consequent handoff back to the macrocell 10 in response to the mobile terminal moving back outside the boundary 20 at the point D. The latter handoff back to the macrocell 10 is relatively easily accomplished in known manner in dependence upon the RSSI of the signal communicated with the base station of the microcell 16. However, as discussed in the background of the invention, determining

mobile terminal candidates for handoff to the microcell 16 as at the point C presents a significant practical problem in view of the numbers of mobile terminals that may be present to be monitored within the macrocell 10, and their arbitrary positions, speeds, and directions of movement.

In accordance with this invention, the base station 12 and its antenna 14 are supplemented with an auxiliary antenna 26 and a related receiver and processing functions as described below to enable determination of the direction of a mobile terminal from the antennas. Although the following description refers only to a dual antenna arrangement, it can be appreciated that the same principles can be extended to an antenna array comprising more than two antennas.

Referring to Fig. 2, dots represent the physical positions, in a horizontal plane represented by the plane of the diagram, of the antennas 14 and 26. As shown in Fig. 2, the antennas 14 and 26 are spaced apart by a distance d along a line 28. In order to provide an unambiguous determination of direction, the distance d is selected to be less than or equal to half the wavelength λ of the radio frequency communications signal, i.e. $d \leq \lambda/2$ (for example, d is up to about 19 cm. for a frequency of 800 MHz), but larger separations d can be used if directional ambiguities are resolved in other ways, for example by limiting the polar response of the antennas, using other auxiliary antennas with different spacings or orientations, and using other parameters available at the base station 12.

Because of the close spacing of the antennas 14 and 26 relative to the distance of these antennas from a mobile terminal, a signal, represented by an arrow 30, received from a mobile terminal having an arbitrary direction at an angle Θ from a normal 29 to the line 28, has a substantially planar wavefront at the antennas. The resulting received signal is correlated for the two antennas 14 and 26 and differs between the two antennas only by a phase difference φ which is equal to $(2\pi d/\lambda)\sin\Theta$ and hence directly represents the angle Θ. Consequently, determining this phase difference enables a determination of the direction Θ, within a range from 0° to ±90°, of the mobile terminal from the base station antennas. As the arrangement is symmetrical about the line 28, this does not determine which side of the line 28 the mobile terminal is on; this can be determined for example by arranging the antennas, e.g. with reflectors, so that they are responsive to signals on only one side of the line 28, or using another auxiliary antenna spaced from the antenna 14 in a direction perpendicular to the line 28, or in any other desired manner.

As described further below, the angle Θ is determined by an adaptive process in which the signals received from the mobile terminal via the two antennas 14 and 26 are combined in a manner which substantially nulls the combined received signal, so that as represented in Fig. 2 a spatial response of the combined antennas, shown in conventional

manner by a curve 32, is rotated to orient its null in the direction Θ of the mobile terminal. This enables the angle Θ to be determined with substantial precision.

A receiver arrangement in which this determination is made is illustrated in block diagram form in Fig. 3. The arrangement includes the antenna 14 and a conventional receiver and A-D (analog to digital conversion) unit 34 which in known manner produces digital complex signal samples (i.e. complex numbers) $X_k(1)$ of a signal received via the antenna 14, where k is an integer identifying the sample and the suffix (1) refers to the first antenna 14. In a similar manner, a second receiver and A-D unit 36, the same as the unit 34, receives signals from the auxiliary antenna 26, spaced from the antenna 14 by the distance $d \leq \lambda/2$ as described above, and produces digital complex signal samples $X_k(2)$ of the received signal, the suffix (2) referring to the second antenna 26.

The remainder of the arrangement shown in Fig. 3 comprises units for processing these complex signal samples $X_k(1)$ and $X_k(2)$ as described below. The functions of these units, and the A-D conversion functions of the units 34 and 36, can all conveniently be implemented by functions of a digital signal processor. These remaining units in the arrangement of Fig. 3 comprise a complex signal limiter 38, complex signal multipliers 40 and 42, complex signal adders 44 and 46 each having one additive (+) input and one subtractive (-) input, a complex signal delay unit 48 providing a delay by one sampling period T, and a calculation unit 50.

The complex signal samples $X_k(1)$ are supplied to the additive input of the adder 44 and to an input of the complex signal limiter 38, which for each sample k produces a limited complex signal sample Y_k in accordance with the equation:

$$Y_k = \frac{X_k(1)}{|X_k(1)|} = \frac{X_k(1)}{\left(X_k(1)\, X_k^*(1)\right)^{0.5}} \qquad (1)$$

where $X_k^*(1)$ is the complex conjugate of $X_k(1)$. The value of each limited complex signal sample Y_k can be calculated in known manner for the respective sample $X_k(1)$, but much more desirably is determined using a look-up table in the manner described and claimed in W. Tong et al. United States patent application No. 08/545,182 filed October 19, 1995 entitled "Complex Signal Limiting", the entire disclosure of which is hereby incorporated herein by reference.

The multiplier 40 is supplied with the current signal sample $X_k(2)$ and an adaptive complex weight W_k that is produced at the output of the adder 46, and produces their complex product. This product is supplied to the subtractive input of the adder 44, in which it is subtracted from the respective sample $X_k(1)$ to produce a combined signal sample ε_k in accordance with the equation:

$$\varepsilon_k = X_k(1) - W_k\, X_k(2) \qquad (2)$$

The multiplier 40 and adder 44 thus constitute a linear combiner. The complex weight W_k is adaptively produced in order to minimize the energy of the linear combiner output signal ε_k, thereby performing the nulling of the combined received signal as described above. To this end, the complex weight W_{k+1} to be used for the subsequent sample k+1 is determined from the weight W_k for the current sample k, the limited complex signal sample Y_k, and the combined signal sample ε_k in accordance with the equation:

$$W_{k+1} = W_k - \mu \varepsilon_k Y_k \qquad (3)$$

where μ is a real step size constant, desirably having a small size and for example being equal to 0.001 as indicated in Fig. 3.

The constant μ, the limited complex signal sample Y_k, and the combined signal sample ε_k are supplied to inputs of the multiplier 42, which produces the product of these parameters and supplies this to the subtractive input of the adder 46. The output of the adder 42 constitutes the weight W_k that is supplied to the multiplier 40 as described above, and is also supplied to the calculation unit 50 and to the delay unit 48, whose output is supplied to the additive input of the adder 46. The units 42, 46, and 48 thus implement equation (3) above.

As indicated above, each signal sample $X_k(2)$ differs from the signal sample $X_k(1)$ only by the phase difference φ, so that:

$$X_k(2) = X_k(1) \exp\{j\varphi\} = X_k(1) \exp\left\{j\frac{2\pi d}{\lambda}\sin\Theta\right\} \qquad (4)$$

Consequently, it can be shown that, when the complex weight W_k has been adaptively adjusted to null or minimize the energy $\|\varepsilon_k\|^2$ of the combiner output signal ε_k in the manner described above, then:

$$W_k = -\exp\{j\varphi\} = -\exp\left\{j\frac{2\pi d}{\lambda}\sin\Theta\right\} \qquad (5)$$

Thus the adaptively adjusted complex weight W_k provides a determination of the phase difference φ and hence of the direction Θ (the distance d and the wavelength λ both being known). Accordingly, the calculation unit 50 is supplied with the complex weight W_k and produces the corresponding phase difference φ as described below, the direction Θ thereby being determined for example from a look-up table stored in memory.

The calculation unit 50 includes an atan (arctangent) function which determines an instantaneous phase angle θ_k from the complex weight W_k. This instantaneous phase angle is subject to noise due to fading (which is correlated for the antennas 14 and 26) over a wide dynamic range of the received signals. However, variation of the direction of a mobile terminal due to its movement is much slower than the speed of signal fading, so that averaging of the instantaneous phase angle θ_k can be performed to provide a reliable resulting phase difference φ. To this end, the calculation unit 50 also includes a d.c. tracking filter which produces the resulting phase difference φ from the instantaneous

phase angle θ_k using an intermediate parameter ϕ_k. These functions of the calculation unit 50 for example implement the following equations (6) to (8):

$$\theta_k = -\,a\tan\left(\frac{\mathrm{Imag}(W_k)}{\mathrm{Real}(W_k)}\right) \tag{6}$$

$$\phi_k = \theta_k - \theta_{k-1} + 0.999\,\phi_{k-1} \tag{7}$$

$$\varphi = \theta_k - \phi_k \tag{8}$$

The small step size μ discussed above enables mis-adjustments of the least mean square adaptive algorithm to be minimized, but results in a relatively slow adaptation of the complex weight W_k. The effects of this can be reduced by selecting an appropriate initial complex weight for the adaptive algorithm, dependent upon coarse information of the direction of the mobile terminal. Such coarse information can already be available at the base station 12, for example from sectorization and microcell deployment information.

Although in the above description it is assumed that there is perfect correlation between the antennas, in practice this will not be the case, and the two antennas 14 and 26 and receivers 34 and 36 will not have identical phase characteristics. This can be compensated for by calibration, with pre-correction of the determination of direction, on implementation of the communications system using mobile terminals with known directions from the antennas.

Simulation results have shown that the arrangement and procedure described above can provide an accurate determination of the direction Θ in an AMPS or TDMA cellular communications system in the presence of flat (frequency independent) fading, and also in the presence of multi-path fading and/or weak co-channel interference, these being reduced by the complex signal limiter 38 which also serves to compensate for the dynamic range of the received signal samples $X_k(1)$.

Information as to the direction Θ of a mobile terminal from the base station antennas 14 and 26, determined in the manner described above, can be used in conjunction with information as to the distance of the mobile terminal from the base station antennas to identify the location of the mobile terminal. Distance information can be derived directly from parameters already monitored at the base station 12, in particular the RSSI. In this case as above, on implementation of the communications system mobile terminals with known locations can be used to determine a correlation between mobile terminal locations and the direction Θ and RSSI representing distance. Other parameters can be used for determining distance information instead of, or more desirably in addition to, RSSI.

The determination at the base station 12 of the location of a mobile terminal in this manner provides information that is useful in itself, for example for identifying the location of a mobile terminal in a sufficiently precise manner to satisfy the requirements of

emergency services (e.g. 911 service). In addition, monitoring the location of a mobile terminal over time provides information as to the velocity of the mobile terminal, and this information may also be useful for a variety of purposes.

However, the location and, preferably, velocity of a mobile terminal constitute information that is particularly useful in determining handoff from the macrocell 10 to the microcell 16 as described above with reference to Fig. 1. To this end, the base station 12 establishes a table of direction and RSSI (distance) information which corresponds to the coverage area of each microcell 16, with which the direction and RSSI information determined as described above for individual mobile terminals is compared to determine candidates for handoff from the macrocell 10 to the respective microcell 16. This can be done for all of the mobile terminals in turn. Handoff can then be effected in known manner for appropriate ones of the handoff candidates, for example also in dependence upon the velocity information to distinguish between relatively fast and slow mobile terminals as discussed above with reference to Fig. 1. Particular details of the handoff process can vary to suit particular circumstances, and such details follow generally known principles so that they need not be further described here. It is observed that the handoff process can be facilitated by including fuzzy logic processes if desired.

It is observed that the handoff procedure using direction and distance information as described above has the advantage of not requiring the provision of a locate receiver function within the microcell 16.

As already indicated, although the detailed description above relates to a dual antenna arrangement, the arrangement can be extended to include more than two antennas and associated receivers, for example to enhance the determination of the direction Θ or to resolve ambiguities in this determination. In addition, the received signals can be processed in other ways to provide for the determination of the direction Θ. For example, a multiple (e.g. 4) antenna array can be used with signals received via the multiple antennas being processed in a (e.g. 4 by 4) correlation matrix to determine eigen vectors and hence a peak corresponding to the direction Θ to be determined using the same principles as used in sonar applications. This provides an accurate determination of direction but involves the disadvantages of being relatively complex, expensive, and subject to problems in fading situations (which are typical for cellular communications systems and are not an issue for sonar applications). In contrast, the simplicity and effectiveness in fading situations of the signal processing described above is particularly advantageous, while the arrangement provides a practically sufficient accuracy in its determination of direction and hence location of the mobile terminal.

Thus although a specific form of the invention has been described in detail, it can be appreciated that these and numerous other modifications, variations, and adaptations may be made without departing from the scope of the invention as defined in the claims.

WHAT IS CLAIMED IS:

1. A method of determining a direction of a mobile terminal from a base station of a wireless communications system, comprising the steps of:

receiving a signal from the terminal via two antennas of the base station, said two antennas being spaced by a predetermined distance to provide first and second received signals with a phase difference between them, the phase difference being dependent upon said direction of the mobile terminal relative to the antennas and upon said predetermined distance; and

determining said direction from the phase difference between the first and second received signals.

2. A method as claimed in claim 1 wherein said predetermined distance is less than or equal to $\lambda/2$ where λ is the wavelength of the signal received by the two antennas.

3. A method as claimed in claim 1 or 2 wherein the step of determining said direction from the phase difference between the first and second received signals comprises the step of linearly combining the first and second received signals to produce a null combined signal.

4. A method as claimed in claim 3 wherein the first and second received signals comprise complex signal samples and the step of linearly combining the first and second received signals comprises producing, as said null combined signal, differences between samples of the first received signal and products of samples of the second received signal and a complex weight which represents said phase difference.

5. A method as claimed in claim 4 and comprising the step of adaptively adjusting the complex weight for successive signal samples by amplitude limiting complex signal samples of the first received signal and multiplying the amplitude limited samples of the first received signal by said null combined signal to produce an adaptive adjustment for the complex weight.

6. A method as claimed in claim 4 or 5 and including the step of providing an instantaneous phase angle from an arctangent function of the complex weight.

7. A method as claimed in claim 6 and including the step of d.c. tracking the instantaneous phase angle to produce said phase difference.

8. A method of determining a location of a mobile terminal relative to a base station of a wireless communications system, comprising the steps of determining a direction of the mobile terminal from the base station by the method of any of claims 1 to 7, and determining a distance of the mobile terminal from the base station using a signal strength of the received signal.

9. A base station for a wireless communications system comprising:

two antennas spaced by a predetermined distance for receiving a signal from a mobile terminal of the system;

two receivers coupled to the antennas for providing first and second received signals with a phase difference dependent upon a direction of the mobile terminal relative to the antennas and upon said predetermined distance; and

a signal combiner for combining the first and second received signals to determine said phase difference.

10. A base station as claimed in claim 9 wherein said predetermined distance is less than or equal to $\lambda/2$ where λ is the wavelength of the signal received by the two antennas.

11. A base station as claimed in claim 9 or 10 wherein the signal combiner comprises a linear combiner arranged to produce a null combination of the first and second received signals.

12. A base station as claimed in claim 11 wherein the first and second received signals provided by the receivers comprise complex signal samples, and the linear combiner is arranged to produce as said null combination differences between samples of the first received signal and products of samples of the second received signal and a complex weight which represents said phase difference.

13. A base station as claimed in claim 12 and including apparatus for adaptively adjusting the complex weight for successive signal samples, said apparatus comprising a complex signal limiter arranged to amplitude limit samples of the first received signal, and a complex signal multiplier for multiplying amplitude limited samples of the first received signal by said null combination of the first and second received signals to produce an adaptive adjustment for the complex weight.

14. A base station as claimed in claim 12 or 13 and including an arctangent function for providing an instantaneous phase angle from the complex weight.

15. A base station as claimed in claim 14 and including a d.c. tracking filter for producing said phase difference from the instantaneous phase angle.

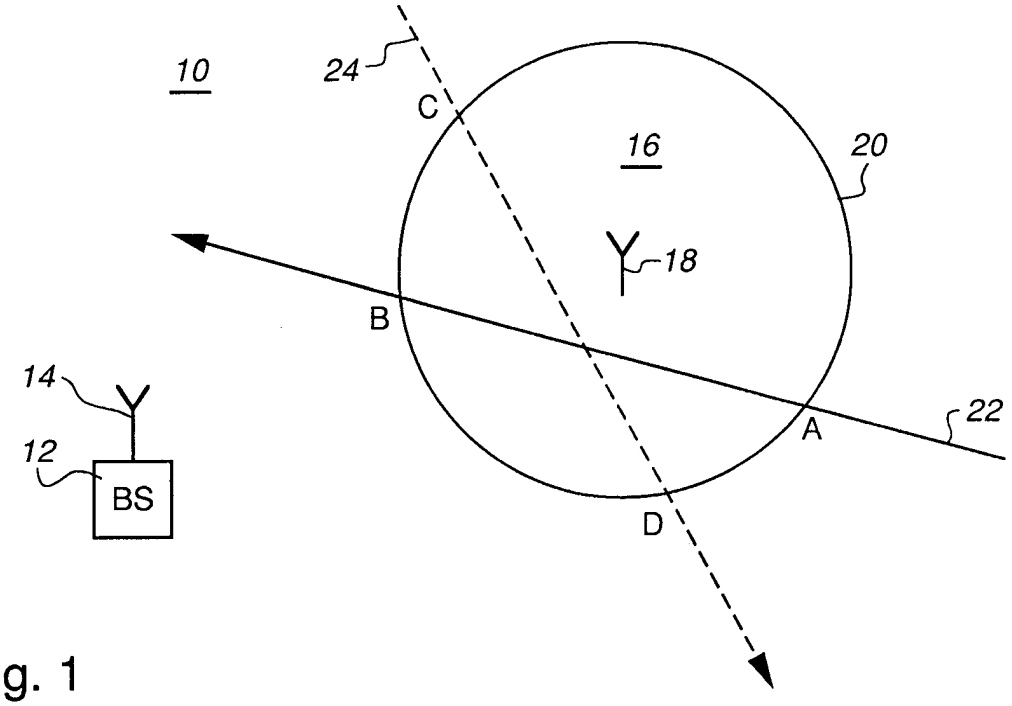


Fig. 1

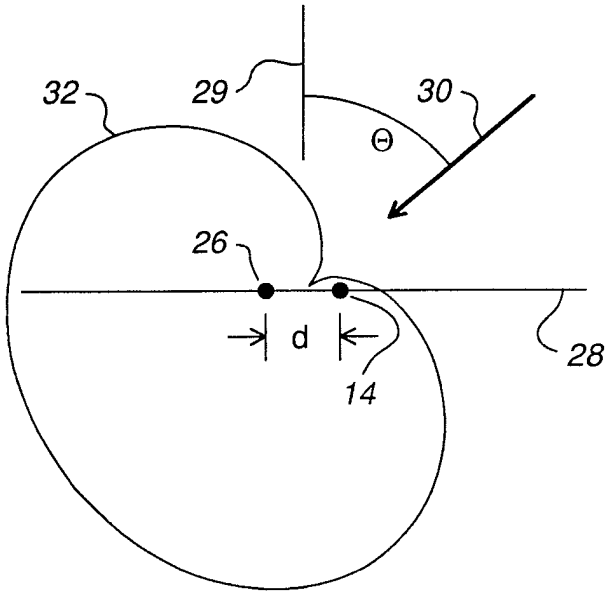


Fig. 2

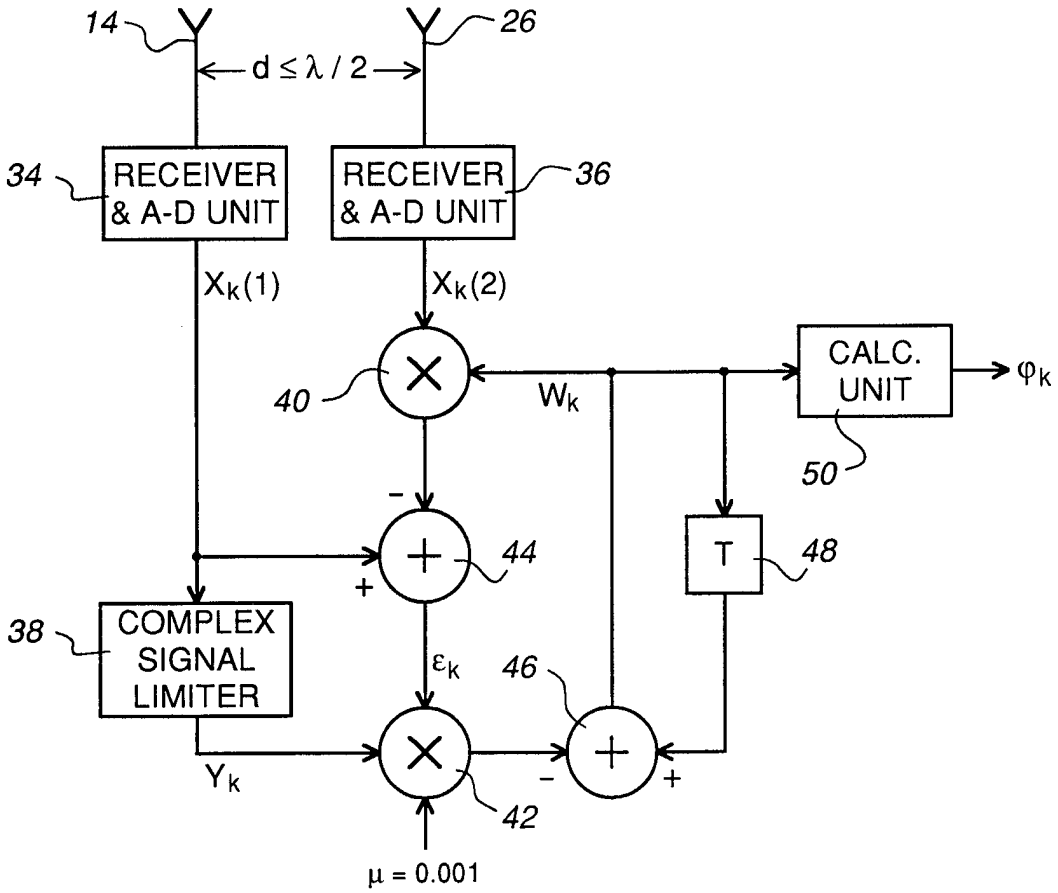

14
26
d ≤ λ / 2
34
RECEIVER & A-D UNIT
RECEIVER & A-D UNIT
36
Xk(1)
Xk(2)
40
Wk
CALC. UNIT
φk
50
-
+
44
T
48
38
COMPLEX SIGNAL LIMITER
εk
46
Yk
-
+
42
μ = 0.001

Fig. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 97/00130

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01S3/14 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 6 G01S H04Q

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.
Y	FR 2 284 887 A (MARCONI CO LTD) 9 April 1976 see page 3, line 5 - page 5, line 6; figure 1	1,2,8,9
Y	WO 88 01061 A (VENTANA SCIENCES INC) 11 February 1988 see page 3, line 11 - line 21; figure 1	1,2,8,9
Y	WO 96 14588 A (MULOC INC) 17 May 1996 see page 9, line 18 - page 11, line 4; figure 3	1,2,8,9
A	US 5 497 161 A (TSUI DAVID C) 5 March 1996 see column 4, line 53 - column 5, line 10	2

-/--

[X] Further documents are listed in the continuation of box C.

[X] 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

1

Date of the actual completion of the international search
24 June 1997

Date of mailing of the international search report
15.07.97

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
Breusing, J

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 97/00130

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 689 178 A (ANT NACHRICHTENTECH) 27 December 1995 see claim 2	4,12
A,P	EP 0 756 430 A (AT & T IPM CORP) 29 January 1997 see page 4, line 12 - line 36; figures 2-4	1
A	WO 92 02105 A (BRITISH TELECOMM) 6 February 1992 see page 3, line 6 - page 4, line 38	

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 97/00130

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR 2284887 A	09-04-76	GB 1475289 A	01-06-77
WO 8801061 A	11-02-88	US 4728959 A	01-03-88
WO 9614588 A	17-05-96	AU 4199596 A	31-05-96
US 5497161 A	05-03-96	NONE	
EP 0689178 A	27-12-95	DE 4421573 A	11-01-96
EP 0756430 A	29-01-97	NONE	
WO 9202105 A	06-02-92	AU 8230191 A	18-02-92
		CA 2087842 A,C	26-01-92
		EP 0540611 A	12-05-93
		GB 2263608 A,B	28-07-93
		HK 133396 A	02-08-96
		JP 6501347 T	10-02-94
		US 5394158 A	28-02-95