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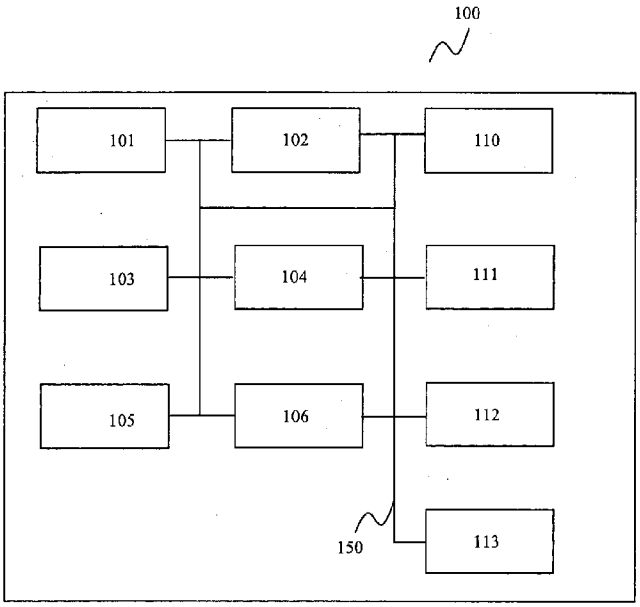
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(54) Title: A DEVICE FOR PERFORMING SIGNAL PROCESSING AND A SIGNAL PROCESSING METHOD FOR LOCALIZATION OF ANOTHER DEVICE

(57) Abstract: A device for performing signal processing and a signal processing method for the localization of another device based on the difference of time of arrival of multiple signals using a single ultra wide band base station.

FIG. 1



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A DEVICE FOR PERFORMING SIGNAL PROCESSING AND A SIGNAL PROCESSING METHOD FOR LOCALIZATION OF ANOTHER DEVICE

[0001] The present application claims the benefit of the Singapore patent application 201002195-4 (filed on 30 March 2010), the entire contents of which are incorporated herein by reference for all purposes.

Technical Field

[0002] Embodiments relate generally to devices for performing signal processing and signal processing methods. By way of example, embodiments relate to devices and methods for localization (i.e. positioning) using a single ultra wideband (UWB) base station.

Background

[0003] In the field of localization of a mobile device, multiple base stations setup may be used to obtain the localization information of the mobile device. However, several problems are encountered. That is, such system setup may involve placement of base stations and routing between base stations which may be troublesome, cumbersome and time-consuming. Sophisticated synchronization among the base stations may be also required. There is also a blocking or obstruction problem where a mobile device needs to be visible by at least three base stations for single two-dimensional location reading. In addition, more base stations also mean more maintenance.

[0004] There thus appears to be a need to provide a mono-station or single base station solution for the localization of a mobile device. To be able to locate an object using a single base station, finding angles of arrival utilizing sophisticated antenna arrays

is one of the most established way. However, this method generally requires complicated calculation and high cost antennas.

Summary of the Invention

[0005] Various embodiments provide a device for processing signal which solves at least partially the above mentioned problems.

[0006] In one embodiment, a device for performing signal processing is provided. The device may include a first antenna which is configured to, during a first predetermined time period, receive a first periodic signal with a first pulse repetition frequency. The device may further include a second antenna which is configured to, during the first predetermined time period, receive the first periodic signal. The device may further include a generator which is configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency. The device may further include a first multiplier which is configured to multiply the first periodic signal received by the first antenna and the second periodic signal to acquire a first output signal. The device may further include a second multiplier configured to multiply the first periodic signal received by the second antenna and the second periodic signal to acquire a second output signal. The device may further include a determining circuit which is configured to determine the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna based on the first output signal and the second output signal. The device may further include a third antenna which is configured to, during a second predetermined time period, receive the first periodic signal. The device may further include a fourth antenna which is configured to, during the second

predetermined time period, receive the first periodic signal. The first multiplier may be configured to multiply the first periodic signal received by the third antenna and the second periodic signal to acquire a third output signal. The second multiplier may be configured to multiply the first periodic signal received by the fourth antenna and the second periodic signal to acquire a fourth output signal. The determining circuit may be configured to determine the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna based on the third output signal and the fourth output signal.

[0007] In one embodiment, a signal processing method is provided. The method may include during a first predetermined time period, receiving a first periodic signal with a first pulse repetition frequency using a first antenna. The method may further include during the first predetermined time period, receiving the first periodic signal using a second antenna. The method may further include generating a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency. The method may further include multiplying the first periodic signal received by the first antenna and the second periodic signal to acquire a first output signal. The method may further include multiplying the first periodic signal received by the second antenna and the second periodic signal to acquire a second output signal. The method may further include determining the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna based on the first output signal and the second output signal. The method may further include during a second predetermined time period, receiving the first periodic signal using a third antenna. The method may further include during the second

predetermined time period, receiving the first periodic signal using the fourth antenna. The method may further include multiplying the first periodic signal received by the third antenna and the second periodic signal to acquire a third output signal. The method may further include multiplying the first periodic signal received by the fourth antenna and the second periodic signal to acquire a fourth output signal. The method may further include determining the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna based on the third output signal and the fourth output signal.

[0008] It should be noted that the embodiments described in the dependent claims of the independent device claim are analogously valid for the corresponding method claim where applicable, and vice versa.

Brief Description of the Drawings

[0009] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

FIG. 1 shows a device for performing signal processing in one embodiment;

FIG. 2 (a) illustrates a circuit diagram of a circuit which may be configured to apply time expansion technique in one exemplary embodiment;

FIG. 2 (b) illustrates, in terms of the time expansion technique and with reference to FIG. 2 (a), the waveforms of the received first periodic signal, the second periodic

signal, the output signal from the mixer sampler, and the time expanded signal, respectively;

FIG. 3 shows the antenna arrangement according to one exemplary embodiment;

FIG. 4 shows a signal processing method in one embodiment;

FIG. 5 illustrates the mechanism of determining the time difference of arrival (TDOA) in a direction X according to one exemplary embodiment;

FIG. 6 illustrates the switching circuitry of a device for performing signal processing according to one exemplary embodiment;

FIG. 7 (a) illustrates the localization of a mobile device by a base station;

FIG. 7 (b) illustrates the working mechanism to carry out two-way ranging in one exemplary embodiment;

FIG. 8 illustrates a frame structure generated by a device for performing signal processing in one exemplary embodiment;

FIG. 9 illustrates the circuit diagram of a mobile device in one exemplary embodiment;

FIG. 10 illustrates the circuit diagram of a device for performing signal processing in one exemplary embodiment;

FIG. 11 (a) illustrates the tested ranging error in a horizontal direction; and

FIG. 11 (b) illustrates the tested ranging error in a vertical direction.

Description

[0010] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those

skilled in the art to practice the invention. In this regard, directional terminology, such as "top", "bottom", "front", "back", "leading", "trailing", etc, is used with reference to the orientation of the Figure(s) being described. Because components of embodiments can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments. The following detailed description therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

[0011] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration". Any embodiment or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs.

[0012] The device as described herein may include a memory which is for example used in the processing carried out by the device. A memory used in the embodiments may be a volatile memory, for example a DRAM (Dynamic Random Access Memory) or a non-volatile memory, for example a PROM (Programmable Read Only Memory), an EPROM (Erasable PROM), EEPROM (Electrically Erasable PROM), or a flash memory, e.g., a floating gate memory, a charge trapping memory, an MRAM (Magnetoresistive Random Access Memory) or a PCRAM (Phase Change Random Access Memory).

[0013] In an embodiment, a "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing

software stored in a memory, firmware, or any combination thereof. Thus, in an embodiment, a "circuit" may be a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "circuit" may also be a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit" in accordance with an alternative embodiment.

[0014] FIG. 1 illustrates a device 100 for performing signal processing in one embodiment. The device 100 may be a radio communication device, for example. The device 100 may also be a base station which is able to determine the 2-dimensional or 3-dimensional location of a mobile device, for example.

[0015] It is noted that when the device 100 as described is a base station which is configured to find the location of another mobile device, the base station 100 itself may also be mobile device, in which case the mobile base station 100 may be configured to find the location of another mobile or stationary device relative to the current position of the mobile base station 100. An example application in this scenario may involve putting a mobile device on one vehicle A and a base station on another vehicle B, to track the position of the former vehicle A with respect to the latter vehicle B.

[0016] The device 100 may include a first antenna 101, a second antenna 102, a third antenna 103, and a fourth antenna 104. The device 100 may further include a generator 110, a first multiplier 111, a second multiplier 112, and a determining circuit 113. The

first antenna 101, the second antenna 102, the third antenna 103, the fourth antenna 104, the generator 110, the first multiplier 111, the second multiplier 112, and the determining circuit 113 may may be coupled with each other, e.g. via an electrical connection 150 such as e.g. a cable or a computer bus or via any other suitable electrical connection to exchange electrical signals.

[0017] In one embodiment, the first antenna 101 may be configured to, during a first predetermined time period, receive a first periodic signal with a first pulse repetition frequency. In one embodiment, the second antenna 102 may be configured to, during the first predetermined time period, receive the first periodic signal. In one embodiment, the generator 110 may be configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency. In one embodiment, the first multiplier 111 may be configured to multiply the first periodic signal received by the first antenna 101 and the second periodic signal to acquire a first output signal. In one embodiment, the second multiplier 112 may be configured to multiply the first periodic signal received by the second antenna 102 and the second periodic signal to acquire a second output signal. In one embodiment, the determining circuit 113 may be configured to determine the time difference between the arrival time of the first periodic signal at the first antenna 101 and the arrival time of the first periodic signal at the second antenna 102 based on the first output signal and the second output signal. In one embodiment, the third antenna 103 may be configured to, during a second predetermined time period, receive the first periodic signal. In one embodiment, the fourth antenna 104 may be configured to, during the second predetermined time period, receive the first periodic signal. In one embodiment, the first multiplier 111 may be

configured to multiply the first periodic signal received by the third antenna 103 and the second periodic signal to acquire a third output signal. In one embodiment, the second multiplier 112 may be configured to multiply the first periodic signal received by the fourth antenna 104 and the second periodic signal to acquire a fourth output signal. In one embodiment, the determining circuit 104 may be configured to determine the time difference between the arrival time of the first periodic signal at the third antenna 103 and the arrival time of the first periodic signal at the fourth antenna 104 based on the third output signal and the fourth output signal.

[0018] In one embodiment, in other words, the device 100 may be provided in a base station or may be a base station. The device 100 may be configured to determine the two or three dimensional location of a mobile device A by processing a first periodic signal transmitted by the mobile device A. The first periodic signal may for example be an ultra wideband (UWB) signal. The first antenna 101 and the second antenna 102 may be spaced apart in a first direction, and the third antenna 103 and the fourth antenna 104 may be spaced apart in a second direction, for example. The device 100 may be configured to determine the difference between the arrival time of the first periodic signal at the first antenna 101 and at the second antenna 102 in the first direction, and the difference between the arrival time of the first periodic signal at the third antenna 103 and at the fourth antenna 104 in the second direction, respectively. The difference of the arrival time of the first periodic signal at two different antennas may be referred to as the time difference of arrival (TDOA) in this context. The determined TDOA in the first direction and the determined TDOA in the second direction may be used in the further determination of the two or three dimensional location of the mobile device A.

[0019] Generally speaking, using TDOA to calculate location requires the antennas to be spaced very far apart since the further the antennas are, the smaller the final positioning (x, y, z) error will be, given any error in the TDOA information. In a single base station system which uses only one single base station (BS) to determine the two or three dimensional location of a mobile device, the antennas separation is generally small, which means that a small error in TDOA may cost huge error in the final calculated position.

[0020] One way to reduce TDOA error is via increasing the sampling rate at the receiver side (e.g. the BS). With 1 GHz sampling rate in a field programmable gate array (FPGA), the timing resolution is 1 ns, which is equivalent to a 30 cm resolution for calculating the distance traveled by the signals used for the localization. In this context, the timing resolution may refer to the minimum time between two consecutive sampling points. With a 10 GHz sampling rate, the resolution in terms of localization can be improved to 3 cm. However, the cost goes up exponentially with higher sampling rate devices, and more importantly, the sampling rate required may even be too fast and not be achievable through commercially available devices .

[0021] In one embodiment, a technique called time expansion technique may be applied by the device 100. Briefly, according to the time expansion technique, a received signal consisting of repetitive waveforms may be expanded in time domain without changing the overall shape of the waveforms before the received signal is sampled by an analogue-to-digital circuit (ADC) for further processing. For example, assuming a received signal is expanded in the time domain by 10000 times at a receiver side before sampling by the ADC, the equivalent timing resolution would be about 10000 times

higher compared with the timing resolution obtained when the signal is sampled at the same sampling rate but without time expansion. In other words, for example, when an ADC sampling rate of 50 MHz is used, if the timing resolution without time expansion is 20 ns, with 10000 times time expansion of the received periodic signal, an equivalent timing resolution of 2 ps can be obtained. For an application such as localization, for example, the improvement in the timing resolution allows for a proportional improvement by the localization system, to resolve the distance traversed by a signal from a transmitter or in other words, it leads to an equivalent improvement in the ranging resolution. Assuming that the signal is traveling at the speed of light in free space of 300,000 km per sec or 0.3 m per ns. So when the timing resolution improves from 20 ns to 2 ps, the ranging resolution improves from (20 ns × 0.3 m/ns) = 6 m to (0.002 ns × 0.3 m/ns) = 0.0006 m .

[0022] In order to expand the received signal, i.e. the first periodic signal, in the time domain, in one embodiment, a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency of the first periodic signal may be generated by the generator 110. The second periodic signal may include a plurality of pulses, for example. The received first periodic signal may then be sampled by the second periodic signal in order to obtain a time expanded signal corresponding to the first periodic signal. The sampling of the first periodic signal by the second periodic signal may be achieved by a multiplier which is configured to perform a multiplication operation of the two input signals into the multiplier. Both the first periodic signal and the second periodic signal may be input into the multiplier, and such a multiplier may be configured to output an output signal which includes a plurality of pulses. The pulses

output from the multiplier may have an envelope which has the shape of the input first periodic signal but has been expanded in the time domain. The output of the multiplier may be connected to the input of a filter, e.g. an active filter, which may be configured to output the envelope of the input signal into the filter. The output signal from the filter may be referred to as the time expanded signal of the first periodic signal. The time expanded signal of the first periodic signal may then be sampled, e.g. by a ADC, for further processing. By sampling the time expanded signal of the first periodic signal instead of sampling the first periodic signal itself, the timing resolution may be increased and the TDOA error may be reduced. The waveforms of the first periodic signal, the second periodic signal, the output of the multiplier and the output of the filter is illustrated in FIG. 2 (b) according to an exemplary embodiment.

[0023] In an illustration example, the mobile device A may transmit the first periodic signal with a first pulse repetition frequency (PRF) of for example 20 MHz, and the device 100 may be configured to determine the TDOA in the first direction using the first antennas 101 and the second antenna 102, and to determine the TDOA in the second direction using the third antenna 103 and the fourth antenna 104. The generator 110 may be configured to generate the second periodic signal with a second pulse repetition frequency (PRF) of for example19.998 MHz. Accordingly, a 20M/(20M-19.998M) = 10,000 times expansion factor may be achieved by the device 100. With this time expansion and 20 MHz ADC sampling rate, the equivalent timing resolution of the TDOA becomes (1/20 MHz)/10,000 = 5 ps, which corresponds to a ranging resolution of 1.5 mm for the difference in the distance traversed by the signal from the mobile device to each of the two antennas used for the TDOA (horizontal or vertical). To achieve the

same ranging resolution of 1.5 mm, a 200 GHz ADC sampling rate would be needed if the received first periodic signal is not time expanded.

[0024] In one embodiment, during the first predetermined time period, the first antenna 101 and the second antenna 102 may be configured to receive the first periodic signal. The signal received at the first antenna 101 may be expanded in the time domain using the first multiplier 111 and the second periodic signal generated by the generator 110 in order to acquire a first output signal which corresponds to the time expanded signal of the first periodic signal received by the first antenna 101. The signal received at the second antenna 102 may be expanded in the time domain using the second multiplier 112 and the second periodic signal generated by the generator 110 in order to acquire a second output signal which corresponds the time expanded signal of the first periodic signal received by the second antenna 102. The determining circuit 113 may be configured to determine the TDOA of the first periodic signal at the first antenna 101 and the second antenna 102 (e.g. the TDOA in the first direction) based on the first output signal and the second output signal.

[0025] Analogously, in one embodiment, during the second predetermined time period, the third antenna 103 and the fourth antenna 104 may be configured to receive the first periodic signal. The signal received at the third antenna 103 may be expanded in the time domain using the first multiplier 111 and the second periodic signal generated by the generator 110 in order to acquire a third output signal which corresponds to the time expanded signal of the first periodic signal received by the third antenna 101. The signal received at the fourth antenna 104 may be expanded in the time domain using the second multiplier 112 and the second periodic signal generated by the generator 110 in order to

acquire a fourth output signal which corresponds the time expanded signal of the first periodic signal received by the fourth antenna 104. The determining circuit 113 may be configured to determine the TDOA of the first periodic signal at the third antenna 103 and the fourth antenna 104 (e.g. the TDOA in the second direction) based on the third output signal and the fourth output signal.

[0026] The device 100 may be further configured to determine the location of the mobile device based on the determined TDOA in the first direction and the TDOA in the second direction.

[0027] FIG. 2 (a) shows a circuit diagram of a circuit 200 which may be configured to apply the time expansion technique in one exemplary embodiment. The circuit may include a clock signal source 242 which is configured to generate a periodic signal. The clock signal source 242 may generate a periodic signal with a second pulse repetition frequency, e.g. 19.998 MHz, for example. The circuit may further include a pulse generator (i.e. sampling pulse generator) 243. The output of the clock signal source 242 may be connected to the input of the pulse generator 243, such that the pulse generator 243 generates pulses at the same rate as the frequency of the input signal into the pulse generator 243. For example, with the input clock signals at a frequency of 19.998 MHz into the pulse generator 243, a pulsed signal with a pulse repetition frequency of 19.998 MHz is generated from the pulse generator 243. The signal output from the pulse generator 243 may be referred to as a local oscillator (LO) signal in this context. The circuit may further include a mixer sampler 244. The mixer sampler 244 may be configured to perform a multiplication operation of a received RF signal and the output signal of the pulse generator 243. The circuit may further include an active filter 245 for

filtering and amplifying the output signal of the mixer sampler 244. The output signal from the filter 245 has the overall shape of waveforms of the received RF signal but has been expanded in time domain. The output signal from the filter 245 may be referred to as the time expanded signal in this context. The time expanded signal may be further processed by an analogue-digital converter (ADC) 246 for sampling, and later sent to a field-programmable gate array (FPGA) (not shown) for further processing. The FPGA may be equipped with the knowledge of the time expanded waveform timing.

[0028] The pulse generator 243 may correspond to the generator 110 in of device 100 in FIG. 1. The mixer sampler 244 may correspond to the first multiplier 111 or the second multiplier 112 of device 100 in FIG. 1.

[0029] FIG. 2 (b) shows, in terms of the time expansion technique and with reference to FIG. 2 (a), a diagram which illustrates the waveforms of the received first periodic signal 211 (e.g. a received RF signal which is input into the mixer sampler 244), the second periodic signal 213 which is output of the pulse generator 243, the output signal 214 from the multiplier 244, and the time expanded signal 215 (e.g. the output signal from the filter 245), respectively. The RF signal 211 consists of a series of repetitive waveforms with a silent period between each two consecutive waveforms. The length of the silent period depends on the pulse duration (i.e. pulse width or waveform duration) t1 and pulse to pulse period t2. Each waveform 225 of the time expanded signal 215 has the shape of each waveform 221 of the received first periodic signal 211, but has been expanded in the time domain. The expansion factor may depend on the values of the frequencies of the received first periodic signal and the second periodic signal (e.g. LO signal). The example values given herein are only for illustration purpose. For example,

the RF signal 211 may correspond to a series of sinusoidal pulses or monocycles. A waveform in this context may refer to any repetitive portion of the received signal such as the portion 221 in signal 211 shown in FIG. 2 (b).

[0030] Turning back to the device 100 shown in FIG. 1, in one embodiment, the first periodic signal may include a plurality of waveforms. Each waveform may have a first pulse width (i.e. waveform duration), and there may be a timing interval between any two consecutive waveforms in the first periodic signal. For example, the first periodic signal may be a UWB signal that includes a plurality of pulses. For another example, the first periodic signal may be the signal 211 as shown in FIG. 2 (b), which includes a plurality of waveforms 221, each waveform 221 having a first pulse width t1, and there is a timing interval 230 between any two consecutive waveforms 221.

[0031] In one embodiment, the second periodic signal may include a plurality of waveforms. Each waveform may have a second pulse width, and there may be a timing interval between any two consecutive waveforms. For example, the second periodic signal may include a plurality of pulses. For another example, the second periodic signal may be the signal 213 as shown in FIG. 2 (b) which includes a plurality of pulses 223, each waveform 223 of the signal 213 having a second pulse width t3, and there is a timing interval 231 between any two consecutive waveforms 223. In one embodiment, each waveform of the second periodic signal may be or may include a pulse.

[0032] In one embodiment, the second pulse width is shorter than the first pulse width. For example, as illustrated in FIG. 2 (b), the first pulse width t1 is longer than the second pulse width t3. In an alternative embodiment, the first pulse width, t1, illustrated

in FIG. 2 (b) is shorter than the second pulse width t3. In a further alternative embodiment, the first pulse width t1 may be the same as the second pulse width t3.

[0033] In one embodiment, the second pulse width t3, illustrated in FIG. 2 (b) may be so long that the periodic waveforms 223 follow one after another in time, with no time duration between the completion of one waveform and the start of the next waveform, effectively making signal 213 a continuous but periodic signal with no breaks between the waveforms.

[0034] In one embodiment, the second pulse repetition frequency may be different from the first pulse repetition frequency. For example, the second pulse repetition frequency may be lower or higher than the first pulse repetition frequency.

[0035] In one embodiment, the first antenna 101 and the second antenna 102 are spaced apart in a first direction. In a further embodiment, the third antenna 103 and the fourth antenna 104 are spaced apart in a second direction, the second direction being at least substantially vertical to the first direction. For example, the device 100 may be configured to determine the distance between the device 100 and the mobile device A. The arrangement of the first to fourth antennas may enable the device 100 to determine the TDOA in both the first direction and the second direction, the second direction being at least substantially vertical to the first direction, such that the three dimensional location of the mobile device A may be determined by the device 100 based on the distance between the mobile device A and the device 100, the TDOA in the first direction, and the TDOA in the second direction.

[0036] In one embodiment, the distance between the first antenna 101 and the second antenna 102, and the distance between the third antenna 103 and the fourth antenna 104 is

in the range of 1 cm to 3 m. It is however noted that the distance between the first antenna 101 and the second antenna 102 and the distance between the third antenna 103 and the fourth antenna 104 is not limited thereto. Smaller or larger distances between the antennas may be used depending on the requirement of applications.

[0037] In one embodiment, during the first predetermined time period, the first antenna 101 is configured to be electrically connected to a first receiver chain included in the device 100, and the second antenna 102 is electrically connected to a second receiver chain included in the device 100. In a further embodiment, during the second predetermined time period, the third antenna 103 is configured to be electrically connected to the first receiver chain, and the fourth antenna 104 is configured to be electrically connected to the second receiver chain. In other words, the device 100 may include two receiver chains, and each receiver chain is used by two antennas. That is, the first antenna 101 and the third antenna 103 may use the first receiver chain, and the second antenna 102 and the fourth antenna 104 may use the second receiver chain. For example, a first switch may be used such that during the first predetermined time period the first antenna 101 is electrically connected to the first receiver chain, and during the second predetermined time period the third antenna 103 is electrically connected to the first receiver chain. Analogously, a second switch may be used such that during the first predetermined time period the second antenna 102 is electrically connected to the second receiver chain, and during the second predetermined time period the fourth antenna 104 is electrically connected to the second receiver chain. Accordingly, only two receiver chains are needed for processing of received signals of four antennas 101 to 104. In this context, the receiver chain refers to a circuit for processing a received signal.

[0038] In one embodiment, device 100 may further include a fifth antenna 105 and a sixth antenna 106. The fifth antenna 105 may be configured to, during a third predetermined time period, receive the first periodic signal. The sixth antenna 106 may be configured to, during the third predetermined time period, receiving the first periodic signal. The first multiplier 111 may be configured to, multiply the first periodic signal received by the fifth antenna 105 and the second periodic signal to acquire a fifth output signal. The second multiplier 112 may be configured to multiply the first periodic signal received by the sixth antenna 106 and the second periodic signal to acquire a sixth output signal. The determining circuit 113 may be configured to determine the time difference between the arrival time of the first periodic signal at the fifth antenna 105 and the arrival time of the first periodic signal at the sixth antenna 106 based on the fifth output signal and the sixth output signal. In one embodiment, the fifth antenna 105 and the sixth antenna 106 may be spaced apart in a third direction, wherein the third direction is at least substantially vertical to both the first direction and the second direction. The antenna arrangement according to this embodiment is further illustrated in the diagram 300 in FIG. 3.

[0039] As can be seen in FIG. 3, the first antenna 101 and the second antenna 102 are spaced apart in the first direction (x direction). The third antenna 103 and the fourth antenna 104 are spaced apart in the second direction (y direction), wherein y direction is at least substantially vertical to x direction. The fifth antenna 105 and the sixth antenna 106 are spaced apart in the third direction (z direction), wherein z direction is at least substantially vertical to both the x direction and the y direction.

[0040] With the first antenna 101, the second antenna 102, the third antenna 103, and the fourth antenna 104 arranged co-planar to the x-y plane, the estimated location of a mobile device A can be either in the front half-space or rear half-space of the x-y plane. It is however not be possible to differentiate between the two half-spaces. Normally this would not be an issue if the antennas of the base station, e.g. the device 100, are close to a wall or at the end of a room, which would allow only one possible solution for the position of the mobile device A. The embodiment where the device 100 further includes the fifth antenna 105 and the sixth antenna 106 may allow the device 100 to differentiate between the front and rear half-space of the x-y plane. With the additional set of antennas (e.g. the fifth antenna 105 and the sixth antenna 106), the device 100 may be configured to determine the TDOA of the first periodic signal at the fifth antenna 105 and the sixth antenna 106 in the third direction. With the determined TDOA in the first, second, and third direction, the position of the mobile device A may be unambiguously determined by the device 100 in the full three dimensional space, in all directions centered around the origin O of FIG. 3. The origin O is the point of intersection of the lines joining the phase centers of the 3 pairs of antennas (e.g. the pair of first antenna 101 and the second antenna 102, the pair of third antenna 103 and fourth antenna 104, and the pair of fifth antenna 105 and the sixth antenna 106).

[0041] In one embodiment, the distance between the fifth antenna 105 and the sixth antenna 106 is in a range of 1 cm to 3 m.

[0042] In one embodiment, during the third predetermined time period, the fifth antenna 105 is configured to be electrically connected to the first receiver chain, and the sixth antenna 106 is configured to be electrically connected to the second receiver chain.

In this embodiment, only two receiver chains may be used for six antennas. The first antenna 101, the third antenna 103, and the fifth antenna 105 may share the first receiver chain, and each of antennas 101, 103, and 105 may be electrically connected to the first receiver chain at different time intervals by way of, for example, a first switch. Analogously, the second antenna 102, the fourth antenna 104, and the sixth antenna 106 may share the second receiver chain, and each of antennas 102, 104, and 106 may be electrically connected to the second receiver chain at different times by way of, for example, a second switch.

[0043] In one embodiment, the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz. In an exemplary embodiment, the first pulse repetition frequency may be 20 MHz. The second pulse repetition frequency may be 19.998 MHz. It is however noted that the range of frequencies between 1 kHz and 100 MHz is not limited thereto. In actual fact, the frequency range may depend on the application and poses no direct limitation on the proposed time expansion technique.

[0044] The first periodic signal and the second periodic signal may each be a UWB signal. In this context, a UWB signal may refers to a sufficiently narrow radio frequency (RF) pulses with wide frequency bandwidths typically of at least 500 MHz. The frequency range of the first periodic signal and the second signal technique is however not limited to any particular bandwidth of spectrum of frequencies. The type of RF pulse, the bandwidth and frequency spectrum used may be chosen by the user of the technique based on various conditions such as the regulatory requirements, the availability of frequency spectrum, the channel conditions, and multipath environment, etc.

[0045] A person skilled in the art would appreciate that for the time expansion technique used, the use of 20 MHz for the pulse repetition frequency (PRF) and 19.998 MHz for the sampling PRF is only illustrative. The technique is independent of the PRF used in the signal to be time-expanded, and the sampling pulse repetition frequency is calculated from the PRF of the signal to be time-expanded and the desired time expansion factor. For the case illustrated herein, for the 20 MHz PRF, in order to achieve a 10000 times time expansion, a corresponding 19.998 MHz sampling pulse repetition frequency may be used.

[0046] In one embodiment, the first antenna 101 is configured to, during a fourth predetermined time period, receive the first periodic signal, and the second antenna 102 is configured to, during the fourth predetermined time period, receive the first periodic signal. In other words, in the embodiment wherein the device 100 includes two pairs of antennas (e.g. a first pair of the first antenna 101 and the second antenna 102, and a second pair of the third antenna 103 and the fourth antenna 104), the first pair of antennas and the second pair of antennas may take turns to receive the first periodic signal so that both the TDOA in the first direction and the TDOA in the second direction may be determined. In the embodiment wherein the device 100 includes three pairs of antennas (e.g. a first pair of the first antenna 101 and the second antenna 102, a second pair of the third antenna 103 and the fourth antenna 104, and a third pair of the fifth antenna 105 and the sixth antenna 106), the first pair, the second pair, and the third pair of antennas may take turns to receive the first periodic signal such that the TDOA in the first direction, the TDOA in the second direction, and the TDOA in the third direction may be determined.

[0047] FIG. 4 illustrates a flow diagram 400 for a signal processing method in one embodiment. The method shown in the flow diagram 400 may correspond to the device 100 as described herein.

[0048] In 401, during a first predetermined time period, a first periodic signal with a first pulse repetition frequency may be received by a first antenna. In 402, during the first predetermined time period, the first periodic signal may be received by a second antenna. In 403, a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency may be generated. In 404, the first periodic signal received by the first antenna and the second periodic signal may be multiplied to acquire a first output signal. In 405, the first periodic signal received by the second antenna and the second periodic signal may be multiplied to acquire a second output signal. In 406, the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna may be determined based on the first output signal and the second output signal. In 407, during a second predetermined time period, the first periodic signal may be received by a third antenna. In 408, during the second predetermined time period, the first periodic signal may be received by the fourth antenna. In 409, the first periodic signal received by the third antenna and the second periodic signal may be multiplied to acquire a third output signal. In 410, the first periodic signal received by the fourth antenna and the second periodic signal may be multiplied to acquire a fourth output signal. In 411, the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna may be determined based on the third output signal and the fourth output signal.

[0049] In one embodiment, the first periodic signal may include a plurality of waveforms, each waveform having a first pulse width, and there is a time interval between any two consecutive waveforms.

[0050] In one embodiment, the second periodic signal may include a plurality of waveforms, each waveform having a second pulse width, and there is a timing interval between any two consecutive waveforms. In a further embodiment, each waveform of the second periodic signal may be or may include a pulse.

[0051] In one embodiment, the second pulse width is shorter than the first pulse width. In an alternative embodiment, the second pulse width can be longer than the first pulse width. In a further alternative embodiment, the first pulse width can be the same as the second pulse width.

[0052] In one embodiment, the second pulse repetition frequency is lower than the first pulse repetition frequency. In an alternative embodiment, the second pulse repetition frequency is higher than the first pulse repetition frequency.

[0053] In one embodiment, the first antenna and the second antenna are spaced apart in a first direction. In a further embodiment, the third antenna and the fourth antenna are spaced apart in a second direction, the second direction being at least substantially vertical to the first direction.

[0054] In one embodiment, the distance between the first antenna and the second antenna, and the distance between the third antenna and the fourth antenna is in a range of 1 cm to 3 m.

[0055] In one embodiment, during the first predetermined time period, the first antenna is electrically connected to a first receiver chain, and the second antenna is

electrically connected to a second receiver chain. In a further embodiment, during the second predetermined time period, the third antenna is electrically connected to the first receiver chain, and the fourth antenna is electrically connected to the second receiver chain.

[0056] In one embodiment, the method as illustrated in the diagram 400 further includes during a third predetermined time period, receiving the first periodic signal using a fifth antenna. In one embodiment, the method as illustrated in the diagram 400 further includes during the third predetermined time period, receiving the first periodic signal using a sixth antenna. In one embodiment, the method as illustrated in the diagram 400 further includes multiplying the first periodic signal received by the fifth antenna and the second periodic signal to acquire a fifth output signal. In one embodiment, the method as illustrated in the diagram 400 further includes multiplying the first periodic signal received by the sixth antenna and the second periodic signal to acquire a sixth output signal. In one embodiment, the method as illustrated in the diagram 400 further includes determining the time difference between the arrival time of the first periodic signal at the fifth antenna and the arrival time of the first periodic signal at the sixth antenna based on the fifth output signal and the sixth output signal.

[0057] In one embodiment, the fifth antenna and the sixth antenna are spaced apart in a third direction, the third direction being at least substantially vertical to both the first direction and the second direction.

[0058] In one embodiment, the distance between the fifth antenna and sixth antenna is in a range of 1 cm to 3 m.

[0059] In one embodiment, during the third predetermined time period, the fifth antenna is electrically connected to the first receiver chain, and the second antenna is electrically connected to the second receiver chain.

[0060] In one embodiment, the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1kHz and 100 MHz. In an exemplary embodiment, the first pulse repetition frequency is 20 MHz. The second pulse repetition frequency is 19.998 MHz.

[0061] In one embodiment, the method as illustrated in the diagram 400 further includes during a fourth predetermined time period, receiving the first periodic signal using the first antenna. In one embodiment, the method as illustrated in the diagram 400 further includes during the fourth predetermined time period, receiving the first periodic signal using the second antenna.

[0062] FIG. 5 illustrates a radio communication system 550 which includes a base station 500 and a mobile device 510 according to one exemplary embodiment. As can be seen, a base station (BS) 500 may be configured to determine the location of a mobile device 510, and the BS 500 may use two antennas 501 and 502 which are spaced apart in the X direction to determine the time difference between the time that the signal transmitted from the mobile device 510 arrives at the antenna 501 (i.e. T1) and the time that the signal transmitted from the mobile device 510 arrives at the antenna 502 (i.e. T2). The TDOA in the X direction determined may be used by the BS 500 in the determination of the location of the mobile device 510.

[0063] FIG. 6 shows diagram 600 which illustrates the detailed antenna arrangement of the first antenna 101, the second antenna 102, the third antenna 103, and the fourth

antenna 104 of device 100 according to one exemplary embodiment. As explained with reference to FIG. 5, TDOA for a single direction (e.g. horizontal/vertical direction) may be obtained by placing two antennas (antennas 501 and 502 in FIG. 5) some distance apart (e.g. in horizontal/vertical direction). To obtain TDOA for both horizontal and vertical directions, four antennas 101 to 104 may be used by the device 100. That is, the first antenna 101 and the second antenna 102 may be arranged in the horizontal (x) direction, and the third antenna 103 and the fourth antenna 104 may be arranged in the vertical (y) direction. Normally each antenna has a corresponding receiver chain. In one embodiment, the device 100 includes two programmable switches 601 and 602 such that only two receiver chains are needed for the four antennas 101 to 104. As illustrated in FIG. 6, antenna 101 of horizontal (x) direction and antenna 104 of vertical (y) direction may be connected to a programmable switch 602 (controlled by device 100) that routes the signal to the device 100. Similarly, antenna 102 of horizontal (x) direction and antenna 103 of vertical (y) direction may be connected to a programmable switch 601 (controlled by device 100) that routes the signal to the device 100. The first antenna 101 and the second antenna 102 may provide TDOA information for horizontal direction, whilst the third antenna 103 and the fourth antenna 104 may provide TDOA information for vertical direction. During a first predetermined time period, the switches 601 and 602 may be controlled such that signals received by the first antenna 101 and the second antenna 102 are received and further processed by the device 100, and during a second predetermined time period, the switches 601 and 602 are switched such that signals received by the third antenna 103 and the fourth antenna 104 are received and further processed by the device 100. The programmable switches 601 and 602 may be controlled

by the device 100 such that the signals received by the first pair of the first antenna 101 and the second antenna 102 and signals received by the second pair of the third antenna 103 and the fourth antenna 104 are processed alternately over time such that both TDOA in the horizontal direction and TDOA in the vertical direction may be determined and updated over time. By using the programmable switches 601 and 602, the hardware complexity of the device 100 may be minimized as only two receiver chains are required for four antennas. In one example, the device 100 as illustrated in FIG. 6 may be provided in a base station or may be a base station. The device 100 may be configured to determine the location of a mobile device A. The device 100 may be configured to determine the distance between the device 100 and the mobile device A. The distance between the device 100 and the mobile device A may be determined based through two-way ranging, for example. The device 100 may be further configured to determine the TDOA of signals transmitted from the mobile device A both in the horizontal direction (x) and the vertical direction (y). Based on the distance between the device 100 and the mobile device and the determined TDOA in both the vertical and horizontal directions, the device 100 may be able to determine the location of the mobile device.

[0064] In the further embodiment wherein the device 100 may include six antennas, in one embodiment, only two receiver chains are required if the programmable switches are used in a similar manner as the switches described with reference to FIG. 6.

[0065] In order to determine the three dimensional position of a mobile device, a base station, e.g. the device 100 as described herein, requires both two-way ranging and TDOA (in at least both a horizontal direction and vertical direction). In this context, two-way ranging generally refers to the estimation of the distance between the base_station

and mobile device from the travel time of a radio signal from a transmitter on the base station to a receiver in the mobile device and then from a transmitter in the mobile device, back to a receiver in the base station.

[0066] FIG. 7 (a) illustrates, as an example, one possible method of how the location of a mobile device 711 may be determined by a base station 710 based on the two-way ranging and TDOA. In this example, it is assumed that the mobile device 711's antenna 723 and the base station 710's antennas, 721 and 722, are both in the x-z plane. In this example, it is also assumed that the base station 710 has a first antenna 721 and a second antenna 722 being spaced apart in the x-axis direction and the separation distance between the first antenna 721 and the second antenna 722 is d. It is further assumed that the location of the first antenna 721 in the x-z plane is (0,0), the location of the second antenna 722 in the x-z plane is (d,0), and the location of the mobile device's antenna 723 is (x_1,z_1), which is to be determined by the base station 710. Assuming the ranges, r_1 and r_2, between the base station antennas 721 and 722 and the mobile device's antenna 723 are known through two-way ranging. And also assuming that the time-difference-of-arrival of signals from the mobile device 711's antenna, 723, to the base station 710's antennas 721 and 722 is known precisely through the time expansion technique as ($\Delta t = t_1 - t_2$) where t_1 is the time of arrival of signal at the first antenna 721 and t_2 is the time of arrival of signal at the second antenna 722. Based on the above, it may be determined that:

$$x_1 = \frac{c\Delta t\left(c\Delta t + 2r_2\right) + d^2}{2d} \text{ and } z_1 = \pm\sqrt{r_1^2 - x_1^2}$$

where c is the velocity of propagation of the electromagnetic signals in the medium. From the above set of equations, it will be noticed that by using only two antennas in the

base-station 710, it may not be possible to resolve whether the z-coordinate (z_1)of the mobile device 711's antenna 723's position is positive or negative. A person skilled in the art would understand that by using a similar method but with an additional antenna on the base-station 710, which is spaced apart from antennas 721 and 722, in a direction other than the x-axis, for example located at position (d, d), the sign of the z-coordinate of the mobile device's antenna position can be resolved to be positive or negative. Similarly, a person skilled in the art would also understand that by using a similar method but by having a fourth antenna on the base-station 710, which is located at a position such that it is not co-planar with the other three base-station antennas, meaning, it does not lie on the same x-z plane, it would be possible to find precisely the position of the mobile device 711's antenna 723 (and consequently the mobile device 711's position) at any point in the full three dimensional space surrounding the base-station.

[0067] FIG. 7 (b) shows a radio communication system 750 which includes a base station 700 and a mobile device 701 according to one embodiment.

[0068] The base station 700 may be configured to determine the position of a mobile device 701. The base station 700 may be configured to transmit UWB signals with a 1 MHz PRF, for example. The mobile device 701 may serve as an active reflector which receives and re-transmits after a pre-determined delay, the UWB signals transmitted from the base station 700 upon successful reception. With this, the base station 700 is able to know exactly the time of sending and time of receiving, thereby determining the round-trip travel time of the signal to-and-from the mobile device. This technique is called two-way ranging as the range is determined from the signal traveling two-way (to-and-fro between the base-station and mobile device).

[0069] The device 100 as described herein may be configured to carry out two-way ranging in a similar manner. In this embodiment, the pulse repetition frequency that the device 100 uses to carry out two-way ranging may be different from the first periodic signal received from the mobile device in order to determine TDOA.

[0070] In one embodiment, the device 100 (e.g. as a base station) may be configured to initiate communication with the mobile devices in order to determine the location of the mobile devices. Each mobile device may have a unique identification number (ID) and is called by the device 100 in a round robin fashion. Upon confirmation of ID, each mobile device may reply to the device 100. The device 100, upon receiving the reply from each mobile device, may calculate the location of each mobile device via the timing information collected.

[0071] FIG. 8 illustrates the frame structure 800 received by the device 100 for three mobile devices in one exemplary embodiment. Based on the frame structure 800, the device 100 may be able to determine the three dimensional position of each of the three mobile devices. Each segment ID1 801 may contain information of a first mobile device, each segment ID2 802 may contain information of a second mobile device, and each segment ID3 803 may contain information of a third mobile device. For example, each segment ID2 802 may contain the a sub-segment 821 which contains ID of the second mobile device, a sub-segment 822 which contains information that may be used to carry out two-way ranging between the device 100 and the second mobile device, and a sub-segment 823 which contains information which may be used to determine TDOA for the second mobile device. Different segments for a same mobile device may be determined over different times.

[0072] FIG. 9 illustrates the circuit of a mobile device 900 in one exemplary embodiment. The device 100 as described herein may be configured to determine the location of the mobile device 900, for example. The device 100 may be a base station and is referred to as BS 100 in this exemplary embodiment.

[0073] As shown in FIG. 9, the mobile device 900 may include an antenna 901 for receiving or transmitting signals. The mobile device 900 may further include a switch 902, e.g. a single-pole double throw (SPDT) switch connected to the antenna 901. The mobile device 900 may further include a clock signal source 903, e.g. square wave source, which is configured to generate periodic signal. The clock signal source 903 may, for example, generate square waves with a frequency of 20 MHz. The mobile device 900 may further include another switch 904, e.g. SPDT switch with a second terminal 932 connected to the output of the clock signal source 903. The pole of the switch 904 may be connected to a pulse generator 905, wherein the pulse generator 905 may be configured to generate a pulsed signal with a same pulse repetition frequency as the input signal into the pulse generator 905. Accordingly, when the switch 904 is connected to the second terminal 932, the pulse generator 905 is configured to output a pulsed signal with a pulse repetition frequency (PRF) of 20 MHz when the clock signal source 903 generates square wave signal with PRF of 20 MHz. Further when the switch 904 is connected to its second terminal 932, the switch 902 may be connected to its second terminal 912 such that the output of the pulse generator 905 is connected the antenna 901, and the antenna 901 is accordingly configured to transmit a UWB signal with pulse repetition frequency of 20 MHz. This transmitted UWB signal with pulse repetition frequency of 20 MHz may be received by the device e.g. BS 100 and further processed by the BS 100 for the

determination of TDOA which may be further used in the localization of the mobile device 900.

[0074] The mobile device 900 may further include a receiver chain which includes a low-noise amplifier (LNA) 921, a band pass filter (BPF) 922, a radio frequency (RF) amplifier 923, a diode detector 924, a low-pass filter (LPF) 925, an intermediate frequency (IF) amplifier 926, and a comparator 927 being connected in series. The BS 100 may be configured to transmit a UWB signal in order to carry out two-way ranging. Such UWB signal may for example have a pulse repetition frequency of 1 MHz. The mobile device 900 may receive the UWB signal with pulse repetition frequency of 1 MHz using the antenna 901. The switch 902 is controlled by the FPGA 928 through the switch control signal 934. When the switch 902's pole is connected to a first terminal 911, the receiver chain of the mobile device 900 may be configured to process the received UWB signal with pulse repetition frequency of 1 MHz. The output of the comparator 927 may be connected to a field-programmable gate array (FPGA) 928. The FPGA 928 may be configured to control the switch 904, through a switch control signal 933. When the pole of the switch 904 is connected to the first terminal 931 and the switch 902 is connected to its second terminal 912, the UWB signal with pulse repetition frequency of 1 MHz, received through the receiver chain, is now re-transmitted or actively reflected by the mobile device through antenna 901. Upon the reception of the UWB signal of 1 MHz transmitted by the mobile device 900, the BS 100 may determine the range between the device 100 and the mobile device 900 which may be further used in the localization of the device 900.

[0075] FIG. 10 illustrates the circuit diagram of a device 1000 according to one exemplary embodiment. The device 1000 may be provided in a base station or may be a base station. The device 1000 may be referred to as BS 1000 in this exemplary embodiment. The device 100 as described herein may have the circuit diagram as BS 1000 in one exemplary embodiment. For illustration purpose, it is assumed that the BS 1000 may be configured to determine the location of the mobile device 900.

[0076] BS 1000 may have a transmission block 1010. The transmission block 1010 may be configured to transmit a UWB signal for the determination of range between the BS 1000 and the mobile device 900. The transmission block 1010 may include a clock signal source, e.g. a sinusoidal wave source 1070 which is configured to generate sinusoidal waves with a pulse repetition frequency of 1 MHz, for example. The output of the wave source 1070 may be connected to the input of a pulse generator 1071. The pulse generator 1071 may be configured to output a pulsed signal with the same pulse repetition frequency as the input signal into the pulse generator 1071. The transmission block 1010 may further include a switch 1072. When the polse of switch 1072 is connected to its first terminal 1081, the output of the pulse generator 1071 is electrically connected to an antenna 1005, such that the BS 1000 is configured to transmit a UWB signal with pulse repetition frequency of 1 MHz for the determination of the range between the BS 1000 and the mobile device 900. A second terminal 1082 of the switch 1072 may be connected to ground such that when the switch 1072 is connected to its second terminal 1082, the transmission block 1010 does not transmit any signal.

[0077] BS 1000 may further include two range estimation blocks 1006 and 1007 which are configured to determine the range between the BS 1000 and the mobile device 900.

[0078] BS 1000 may include a first antenna 1001 and a second antenna 1002 which are spaced apart in a first direction, and a third antenna 1003 and a fourth antenna 1004 which are spaced apart in a second direction, wherein the second direction is at least substantially vertical to the first direction.

[0079] The BS 1000 may include a first receiver chain which includes a low-noise amplifier (LNA) 1021, a band pass filter (BPF) 1022, and a radio frequency (RF) amplifier 1023 being connected to in series. The BS 1000 may include a second receiver chain which includes a low-noise amplifier (LNA) 1031, a band pass filter (BPF) 1032, and a radio frequency (RF) amplifier 1033 being connected to in series. The first receiver chain may be configured to process signals received by the first antenna 1001 or the fourth antenna 1004. The second receiver chain may be configured to process signals received by the second antenna 1002 or the third 1003.

[0080] The BS 1000 may further include switches 1011 and 1012 which may be SPDT switches. When the switch 1011 is connected to its first terminal 1091, the signal received by the first antenna 1001 may be processed by the first receiver chain, and when the switch 1011 is connected to its second terminal 1092, the signal received by the fourth antenna 1004 may be processed by the first receiver chain. When the switch 1012 is connected to its first terminal 1093, the signal received by the second antenna 1002 may be processed by the second receiver chain, and when the switch 1012 is connected to

its second terminal 1094, the signal received by the third antenna 1003 may be processed by the second receiver chain.

[0081] The output of the RF amplifier 1023 may be connected to the range estimation block 1006 for the determination of range between the BS 1000 and the mobile device 900. The range estimation block 1006 may include a diode detector 1024, a low-pass filter (LPF) 1025, an intermediate frequency (IF) amplifier 1026, and a comparator 1027 being connected in series. The output of the comparator 1027 may be connected to a FPGA (not shown). The output of the RF amplifier 1033 may be connected to the range estimation block 1007 for the determination of range between the device 1000 and the mobile device 900. The range estimation block 1007 may include a diode detector 1034, a low-pass filter (LPF) 1035, an intermediate frequency (IF) amplifier 1036, and a comparator 1037 being connected in series. The output of the comparator 1037 may be connected to a FPGA (not shown).

[0082] The BS 1000 may further include a TDOA estimation block 1008 which is used for the determination of TDOA in the first direction and the second direction. The TDOA estimation block 1008 may include a mixer sampler 1041 which is configured to perform a multiplication operation of its two input signals and an active filter 1042 being connected in series. The output of the active filter 1042 may be connected to an analogue-to-digital converter (ADC) 1044 and later to a FPGA (not shown) for the determination of TDOA. Similarly the TDOA estimation block 1008 may include another mixer sampler 1051 which is configured to perform a multiplication operation of its two input signals and an active filter 1052 being connected in series. The output of the active filter

1052 may be connected to an analogue-to-digital converter (ADC) 1054 and later to a FPGA (not shown) for the determination of TDOA.

[0083] The TDOA estimation block 1008 may further include a clock signal source generator 1060 which is configured to generate periodic signals with a pulse repetition frequency (PRF) being different from the received PRF transmitted by the mobile device 900 for the determination of TDOA. In this example, the mobile device 900 may transmit a UWB signal of a first pulse repetition frequency such as 20 MHz for the determination of TDOA at the BS 1000 side, and the clock signal source 1060 may be configured to generate wave signals with a second pulse repetition frequency of for example 19.998 MHz. The output of the clock signal source 1060 may be connected to the input of a pulse generator 1061, where the pulse generator 1061 is configured to output pulsed signals with a same pulse repetition frequency as the input signal into the pulse generator 1061. In this example, when the clock signal source 1060 is configured to generate wave signals of a second pulse repetition frequency of 19.998 MHz, the pulse generator 1061 is configured to output pulsed signals with the second pulse repetition frequency of 19.998 MHz. The output of the pulse generator 1061 may be connected to both an input of the mixer samplers 1041 and 1051 in the TDOA estimation block 1008.

[0084] The BS 1000 may further include switches 1013 and 1014. When the switch 1013 is connected to its first terminal 1095, the first receiver chain is connected to the range estimation block 1006 for the determination of range. When the switch 1013 is connected to its second terminal 1096, the first receiver chain is connected to the TDOA estimation block 1008 wherein the output of the RF amplifier 1023 is connected to an input of the mixer sampler 1041. When the switch 1014 is connected to its first terminal

1097, the second receiver chain is connected to the range estimation block 1007 for the determination of range. When the switch 1014 is connected to its second terminal 1098, the second receiver chain is connected to the TDOA estimation block 1008 wherein the output of the RF amplifier 1033 is connected to an input of the mixer sampler 1051.

[0085] For example, in operation, the switch 1072 may be connected to its first terminal 1081 such that a UWB signal of 1 MHz is transmitted by the antenna 1005. The transmitted UWB signal of 1 MHz will be received by the mobile device 900 and will then be transmitted or reflected back by the mobile device 900. After the transmission of the UWB signal of 1 MHz at the BS 1000 side, the switch 1072 may be switched to its second terminal 1082. In the meantime or at least around the same time, the switch 1011 may be connected to its first terminal 1091, the switch 1013 may be connected to its first terminal 1095, the switch 1012 may be connected to its first terminal 1093, and the switch 1014 may be connected to it first terminal 1097. With this configuration, the BS 1000 may receive the UWB signal of 1 MHz transmitted from the mobile device 900, and the BS 1000 may use its first receiver chain together with the range estimation block 1006, and/or the second receiver chain together with the range estimation block 1007, to determine the range between the BS 1000 and the mobile device 900. For example, the BS may be configured to determine the time Tx on its internal clock or counter at which the UWB signal of 1 MHz is transmitted from the BS 1000. The mobile device 900 may receive the UWB signal of 1 MHz and then reflect/re-transmit back the UWB signal of 1 MHz. There may or may not be a delay in the mobile device 900 side for processing the received UWB signal of 1 MHz. If there is a delay Ty, such a delay Ty may be known to the BS 1000. The BS 1000 may be further configured to determine the time Tz at which

the UWB signal of 1 MHz transmitted from the mobile device 900 is received by the BS 1000. Accordingly, the BS 1000 may calculate the time taken for signals to travel to-and-fro between the BS 1000 and the mobile device 900 to be (Tz-Tx-Ty). Based on the round-trip time, the distance between the BS 1000 and the mobile device 900 may be accurately estimated easily through [(Tz-Tx-Ty)/2] multiplied by the speed-of-light in the medium. The medium is normally free-space but could be other medium such as water or some other dielectric depending on the application.

[0086] Thereafter, the mobile device 900 may transmit a UWB signal of 20 MHz for the determination of TDOA by the BS 1000. In the BS 1000, the switch 1013 may be connected to its second terminal 1096, and the switch 1014 may be connected to its second terminal 1098. In the meantime, during a first predetermined time period, the switch 1011 may be connected to its first terminal 1091 and the switch 1012 may be connected to its first terminal 1093 such that the UWB signal of 20 MHz received by the antennas 1001 and 1002 are processed by the first receiver chain and the second receiver chain, respectively, in order for the BS 1000 to determine the TDOA in the first direction. During a second predetermined time period, the switch 1013 may remain to be connected to its second terminal 1096, and the switch 1014 may remain to be connected to its second terminal 1098. During the second predetermined time period, the switch 1011 may be connected to its second terminal 1092 and the switch 1012 may be connected to its second terminal 1094 such that the UWB signal of 20 MHz received by the antennas 1003 and 1004 are processed by the first receiver chain and the second receiver chain, respectively, in order for the BS 1000 to determine the TDOA in the second direction.

[0087] Thereafter, the BS 1000 may start another cycle of determination the range and TDOA by starting to transmit the 1 MHz UWB signal using the transmission block 1010 again. In this way, the BS 1000 may be able to determine the latest location of the mobile device 900.

[0088] In the example given above, the time expansion technique is applied by the generation of the pulsed signal of the second pulse repetition frequency of 19.998 MHz, the use of the mixer samplers 1041 and 1051. Each output from the active filters 1042 and 1052 is a time expanded waveform with 2 kHz pulse repetition frequency. Such time expanded waveform may then be sent to ADC with, e.g. 25 MHz sampling rate, and the digitized waveform may then be sent into FPGA for TDOA extraction. The TDOA information may be obtained via correlating the two time expanded received waveforms output from the active filters 1042 and 1052, respectively.

[0089] The device 100 as described herein may function as a base station and may be able to provide very high update rates of the location of a mobile device. The actual update rate would depend on the number of ranging and TDOA results that are averaged to get a single update of the mobile device's location. The fastest update rate would be when every set of ranging and TDOA (horizontal and vertical) results are used to calculate the position of the mobile device without further avaraging. In the example where the BS 100 is configured to determine the location of a single mobile device 900, and the BS 100 uses the UWB signal with 1 MHz to determine range, and applies time expansion technique to expand the received UWB signal of 20 MHz to determine TDOA, the the BS 100 may achieve an update rate of the mobile device's location of up to around 1 kHz. In particular, for the determination of range, the BS 100 may need about 1

μs to receive the ranging UWB signal of 1 MHz. Further, for the update of TDOA, the BS 100 may need 500 μs to recover a time expanded waveform in order to determine the TDOA in a first direction (e.g. a horizontal direction) and another 500 μs to recover a time expanded waveform in order to determine the TDOA in a second direction (e.g. a vertical direction). Thus, totally, to update the location of the mobile device 900, the BS 100 may take around 1001 μs which corresponds to an update rate of 1 kHz.

[0090] The device 100 as described herein may be configured to determine the distance of a mobile device which is located within a distance where it is able to receive the relevant signals transmitted from device 100 and the device 100 is able to receive the relevant signals from that particular mobile device.

[0091] The performance of the device 100 as described herein is tested. Accuracy (or location error) may be considered to be a potential bias, or systematic effect/offset of a positioning system. Usually, mean distance error is adopted as the performance metric, which is the average Euclidean distance between the estimated location and the true location. In the test, 3 parameters, i.e. TDOA of vertical and horizontal direction and range, are collected for location calculation.

[0092] Measurement has been carried out to check the accuracy of the device 100 as described herein. With fixed Y-distance 300 cm from the antennas, experimental data with varying X (e.g. horizontal direction) and Z (e.g. vertical direction) was collected and compared to the data calculated from actual location. The results show the errors of the TDOA in horizontal direction are between -1.5 cm to 1.05 cm or equivalent to -50 ps to 35ps, errors of the TDOA in vertical direction are between -2.23 cm to 1.37 cm or equivalent to -74 ps to 45 ps. FIG. 11 (a) shows diagram 1101 wherein the ranging error

in the horizontal direction, which is between -1.5 cm to 1.5 cm. FIG. 11 (b) shows the diagram 1102 wherein the ranging error in the vertical direction, which is between -1.5 cm to 1.5 cm.

[0093] Using the TDOA and ranging errors, the maximum position error may be simulated to be within 30 cm. By assuming the error to be Gaussian distributed, the position error is calculated to be smaller than 10 cm in 95% of the time.

[0094] Standard deviation in the location error is another parameter to test the performance of the device 100 which reflects how consistently the system works. For raw ranging data collected, the standard deviation is measured to be around 2.5 cm; whereas for data after process, the standard deviation is smaller than 1 cm.

[0095] The device 100 as described herein may be applicable to precise positioning of asset or precision asset location such as in robot navigation and control, and tracking of airborne objects, seaborne objects or ground objects. Precise positioning is also useful in gaming and medical applications.

[0096] In various embodiments, a high precision localization or positioning in two-dimensional and/or three dimensional space using a single base station is provided.

[0097] In various embodiments, both range and angles of arrival may be used to locate objects. For example, the single base station may determine the location of a mobile device by using programmable switches, two-way ranging via active reflector technique, time-difference-of-arrival (TDOA) combined with time expansion technique so as to provide accurate, fast, and wide-coverage three-dimensional positioning using single base station.

[0098] In various embodiments, a method and system of localization using a single UWB base-station is provided where both range and angles of arrival are used to locate objects. In an embodiment, the method includes using programming switches, computing range, computing time-difference-of-arrival (TDOA) by combining time-expansion techniques to provide accurate, fast, and wide-coverage three-dimensional positioning using single base station.

[0099] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

What is claimed is:

1. A device for performing signal processing, comprising:

a first antenna configured to, during a first predetermined time period, receive a first periodic signal with a first pulse repetition frequency;

a second antenna configured to, during the first predetermined time period, receive the first periodic signal;

a generator configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency;

a first multiplier configured to multiply the first periodic signal received by the first antenna and the second periodic signal to acquire a first output signal;

a second multiplier configured to multiply the first periodic signal received by the second antenna and the second periodic signal to acquire a second output signal;

a determining circuit configured to determine the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna based on the first output signal and the second output signal;

a third antenna configured to, during a second predetermined time period, receive the first periodic signal;

a fourth antenna configured to, during the second predetermined time period, receive the first periodic signal;

wherein the first multiplier is configured to multiply the first periodic signal received by the third antenna and the second periodic signal to acquire a third output signal;

wherein the second multiplier is configured to multiply the first periodic signal received by the fourth antenna and the second periodic signal to acquire a fourth output signal;

wherein the determining circuit is configured to determine the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna based on the third output signal and the fourth output signal.

2. The device as claimed in claim 1, wherein the first periodic signal comprises a plurality of waveforms, each waveform having a first pulse width, and wherein there is a timing interval between any two consecutive waveforms.

3. The device as claimed in claim 2, wherein the second periodic signal comprises a plurality of waveforms, each waveform having a second pulse width, and wherein there is a timing interval between any two consecutive waveforms.

4. The device as claimed in claim 3, wherein each waveform of the second periodic signal comprises a pulse.

5. The device as claimed in any of claims 1 to 4, wherein the first antenna and the second antenna are spaced apart in a first direction.

6. The device as claimed in claim 5, wherein the third antenna and the fourth antenna are spaced apart in a second direction, the second direction being at least substantially vertical to the first direction.

7. The device as claimed in claim any of claims 1 to 6, wherein the distance between the first antenna and the second antenna, and the distance between the third antenna and the fourth antenna is in a range of 1 cm to 3 m.

8. The device as claimed in any of claims 1 to 7, wherein during the first predetermined time period, the first antenna is configured to be electrically connected to a first receiver chain comprised in the device, and the second antenna is electrically connected to a second receiver chain comprised in the device.

9. The device as claimed in claim 8, wherein during the second predetermined time period, the third antenna is configured to be electrically connected to the first receiver chain, and the fourth antenna is configured to be electrically connected to the second receiver chain.

10. The device as claimed in any of claims 1 to 9, further comprising:

a fifth antenna configured to, during a third predetermined time period, receive the first periodic signal;

a sixth antenna configured to, during the third predetermined time period, receiving the first periodic signal;

wherein the first multiplier is configured to, multiply the first periodic signal received by the fifth antenna and the second periodic signal to acquire a fifth output signal;

wherein the second multiplier is configured to multiply the first periodic signal received by the sixth antenna and the second periodic signal to acquire a sixth output signal;

wherein the determining circuit is configured to determine the time difference between the arrival time of the first periodic signal at the fifth antenna and the arrival time of the first periodic signal at the sixth antenna based on the fifth output signal and the sixth output signal.

11. The device as claimed in claim 10, wherein the fifth antenna and the sixth antenna are spaced apart in a third direction, the third direction being at least substantially vertical to both the first direction and the second direction.

12. The device as claimed in any of claims 10 and 11, wherein the distance between the fifth antenna and sixth antenna is in a range of 1 cm to 3 m.

13. The device as claimed in any of claims 10 to 12, wherein during the third predetermined time period, the fifth antenna is configured to be electrically connected to the first receiver chain, and the sixth antenna is configured to be electrically connected to the second receiver chain.

14. The device as claimed in any of claims 1 to 13, wherein the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz.

15. The device as claimed in claim 14, wherein the first pulse repetition frequency is 20 MHz.

16. The device as claimed in claim 14 or 15, wherein the second pulse repetition frequency is 19.998 MHz.

17. The device as claimed in any of claims 1 to 16, further comprising:

wherein the first antenna is configured to, during a fourth predetermined time period, receive the first periodic signal;

wherein the second antenna is configured to, during the fourth predetermined time period, receive the first periodic signal.

18. A signal processing method, comprising:

during a first predetermined time period, receiving a first periodic signal with a first pulse repetition frequency using a first antenna;

during the first predetermined time period, receiving the first periodic signal using a second antenna;

generating a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency;

multiplying the first periodic signal received by the first antenna and the second periodic signal to acquire a first output signal;

multiplying the first periodic signal received by the second antenna and the second periodic signal to acquire a second output signal;

determining the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna based on the first output signal and the second output signal;

during a second predetermined time period, receiving the first periodic signal using a third antenna;

during the second predetermined time period, receiving the first periodic signal using the fourth antenna;

multiplying the first periodic signal received by the third antenna and the second periodic signal to acquire a third output signal;

multiplying the first periodic signal received by the fourth antenna and the second periodic signal to acquire a fourth output signal;

determining the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna based on the third output signal and the fourth output signal.

19. The method as claimed in claim 18, wherein the first periodic signal comprises a plurality of waveforms, each waveform having a first pulse width, and wherein there is a timing interval between any two consecutive waveforms.

20. The method as claimed in claim 19, wherein the second periodic signal comprises a plurality of waveforms, each waveform having a second pulse width, and wherein there is a timing interval between any two consecutive waveforms.

21. The method as claimed in claim 20, wherein each waveform of the second periodic signal comprises a pulse.

22. The method as claimed in any of claims 18 to 21, wherein the first antenna and the second antenna are spaced apart in a first direction.

23. The method as claimed in claim 22, wherein the third antenna and the fourth antenna are spaced apart in a second direction, the second direction being at least substantially vertical to the first direction.

24. The method as claimed in claim any of claims 18 to 23, wherein the distance between the first antenna and the second antenna, and the distance between the third antenna and the fourth antenna is in a range of 1 cm to 3 m.

25. The method as claimed in any of claims 18 to 24, wherein during the first predetermined time period, the first antenna is electrically connected to a first receiver chain, and the second antenna is electrically connected to a second receiver chain.

26. The method as claimed in claim 25, wherein during the second predetermined time period, the third antenna is electrically connected to the first receiver chain, and the fourth antenna is electrically connected to the second receiver chain.

27. The method as claimed in any of claims 18 to 26, further comprising:

during a third predetermined time period, receiving the first periodic signal using a fifth antenna;

during the third predetermined time period, receiving the first periodic signal using a sixth antenna;

multiplying the first periodic signal received by the fifth antenna and the second periodic signal to acquire a fifth output signal;

multiplying the first periodic signal received by the sixth antenna and the second periodic signal to acquire a sixth output signal;

determining the time difference between the arrival time of the first periodic signal at the fifth antenna and the arrival time of the first periodic signal at the sixth antenna based on the fifth output signal and the sixth output signal.

28. The method as claimed in claim 27, wherein the fifth antenna and the sixth antenna are spaced apart in a third direction, the third direction being at least substantially vertical to both the first direction and the second direction.

29. The method as claimed in any of claims 27 and 28, wherein the distance between the fifth antenna and sixth antenna is in a range of 1 cm to 3 m.

30. The method as claimed in any of claims 27 to 29, wherein during the third predetermined time period, the fifth antenna is electrically connected to the first receiver chain, and the sixth antenna is electrically connected to the second receiver chain.

31. The method as claimed in any of claims 18 to 30, wherein the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz.

32. The method as claimed in claim 31, wherein the first pulse repetition frequency is 20 MHz.

33. The method as claimed in claim 31 or 32, wherein the second pulse repetition frequency is 19.998 MHz.

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34. The method as claimed in any of claims 18 to 33, further comprising:

during a fourth predetermined time period, receiving the first periodic signal using the first antenna;

during the fourth predetermined time period, receiving the first periodic signal using the second antenna.

FIG. 1

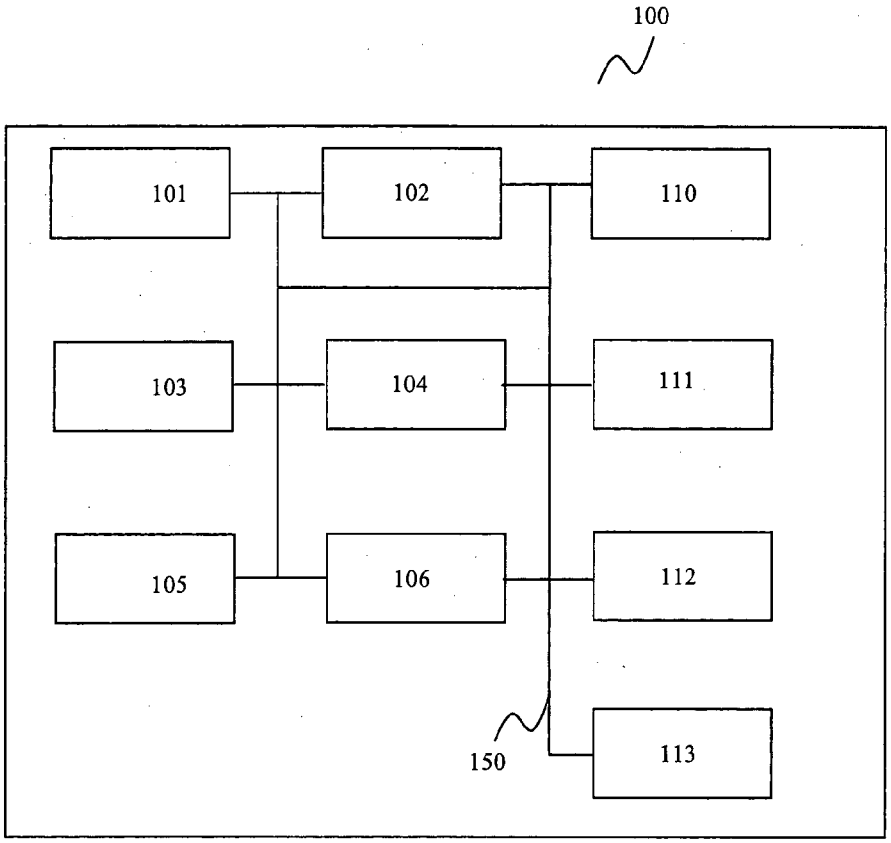


FIG. 2 (a)

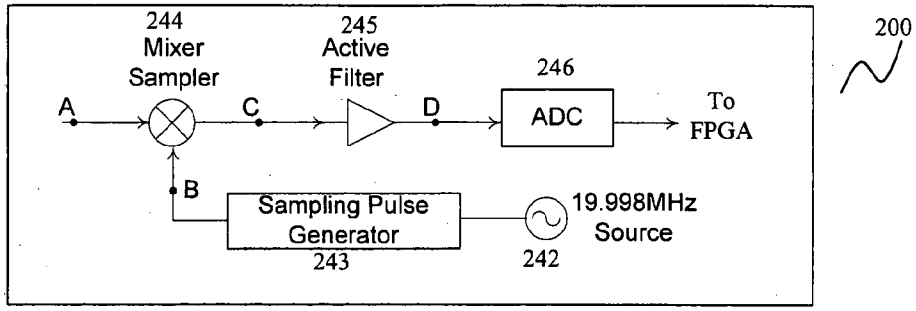

244
Mixer
Sampler
245
Active
Filter
246
ADC
To
FPGA
200
A
C
D
B
Sampling Pulse
Generator
243
19.998MHz
Source
242

FIG. 2 (b)

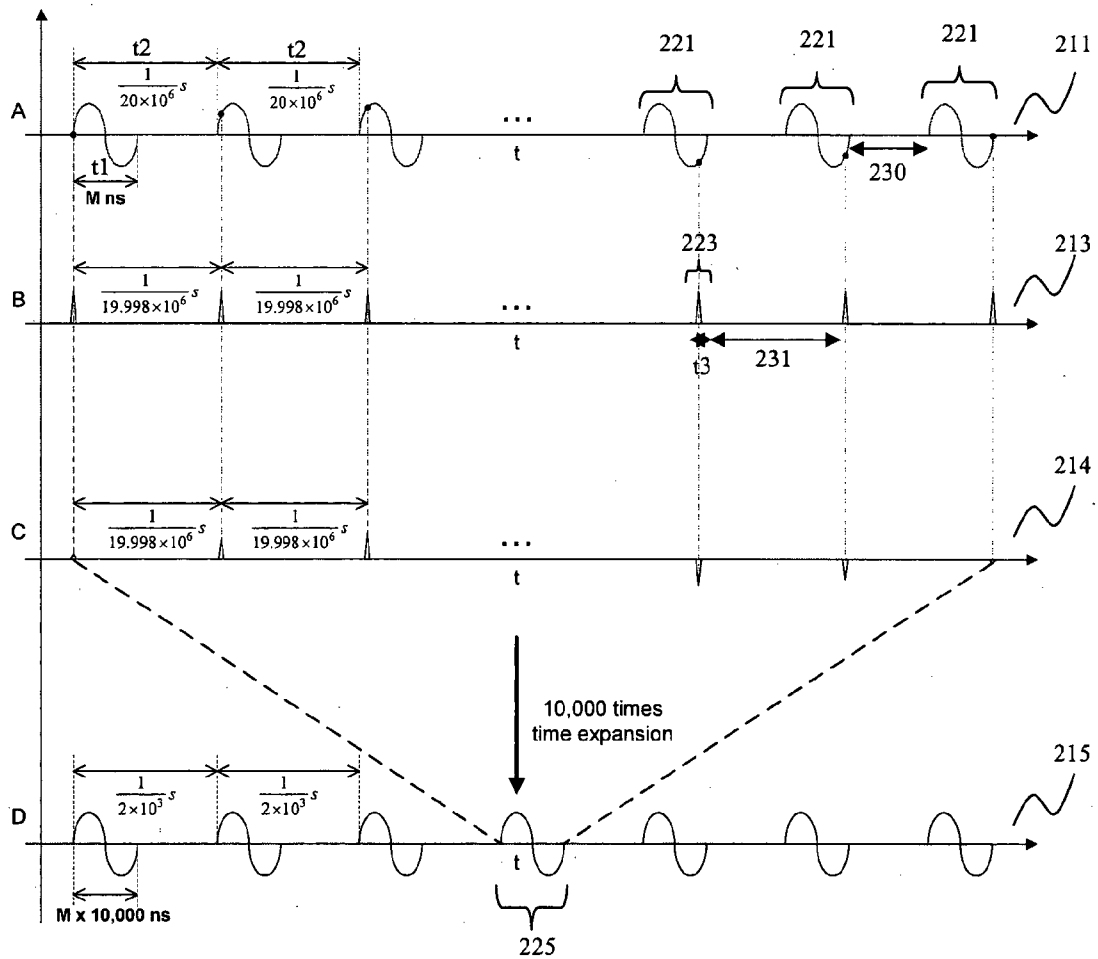

t2
t2
221
221
221
211
A
t1
M ns
230
223
213
B
t3
231
214
C
10,000 times
time expansion
215
D
M x 10,000 ns
225

FIG. 3

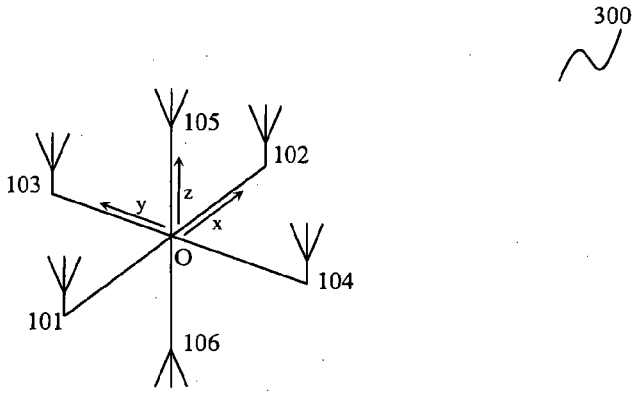


FIG. 4

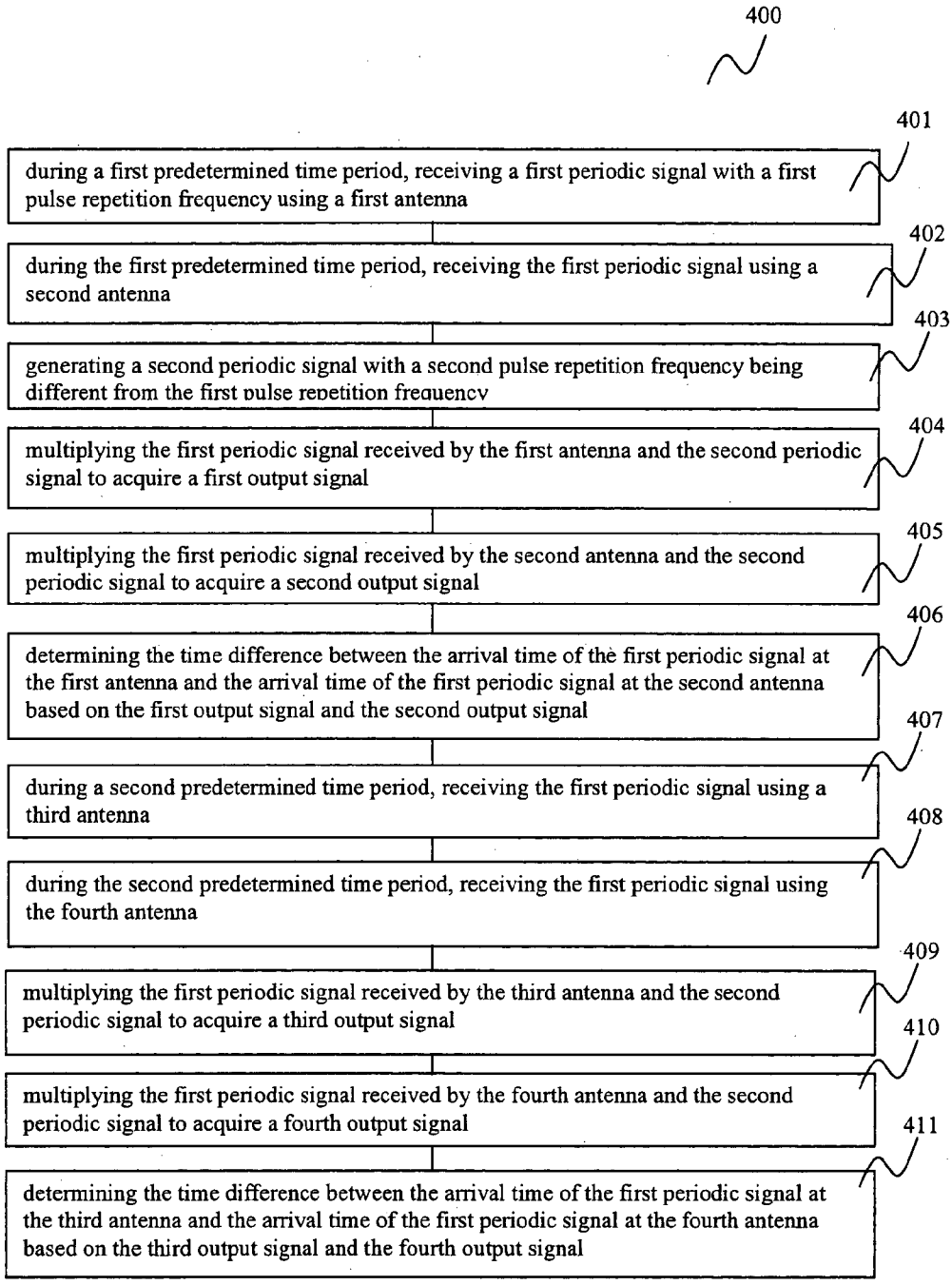

400
401
during a first predetermined time period, receiving a first periodic signal with a first pulse repetition frequency using a first antenna
402
during the first predetermined time period, receiving the first periodic signal using a second antenna
403
generating a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency
404
multiplying the first periodic signal received by the first antenna and the second periodic signal to acquire a first output signal
405
multiplying the first periodic signal received by the second antenna and the second periodic signal to acquire a second output signal
406
determining the time difference between the arrival time of the first periodic signal at the first antenna and the arrival time of the first periodic signal at the second antenna based on the first output signal and the second output signal
407
during a second predetermined time period, receiving the first periodic signal using a third antenna
408
during the second predetermined time period, receiving the first periodic signal using the fourth antenna
409
multiplying the first periodic signal received by the third antenna and the second periodic signal to acquire a third output signal
410
multiplying the first periodic signal received by the fourth antenna and the second periodic signal to acquire a fourth output signal
411
determining the time difference between the arrival time of the first periodic signal at the third antenna and the arrival time of the first periodic signal at the fourth antenna based on the third output signal and the fourth output signal

FIG. 5

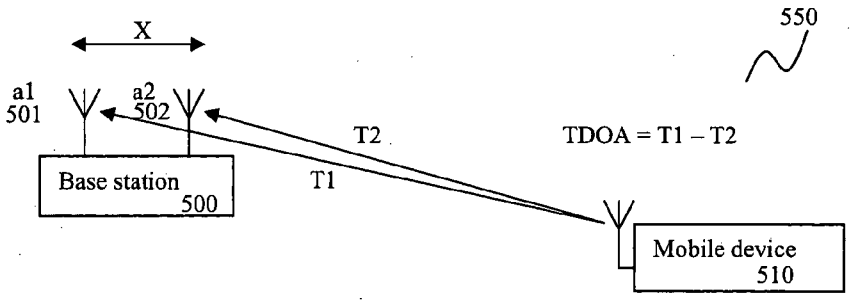

X
550
a1
501
a2
502
T2
TDOA = T1 – T2
T1
Base station
500
Mobile device
510

FIG. 6

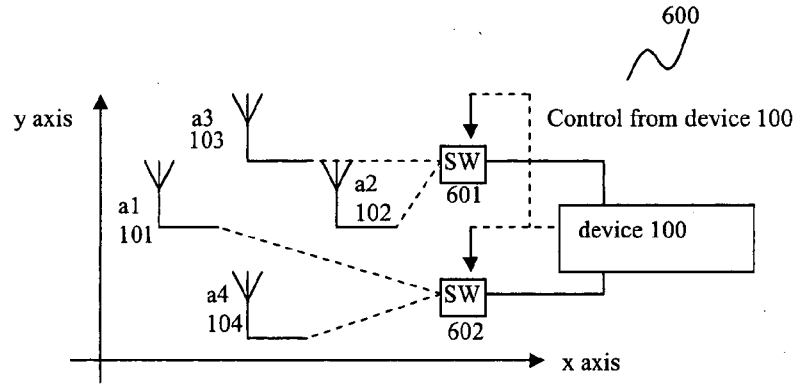

600
y axis
a3
103
Control from device 100
SW
601
a2
102
a1
101
device 100
a4
104
SW
602
x axis

FIG. 7 (a)

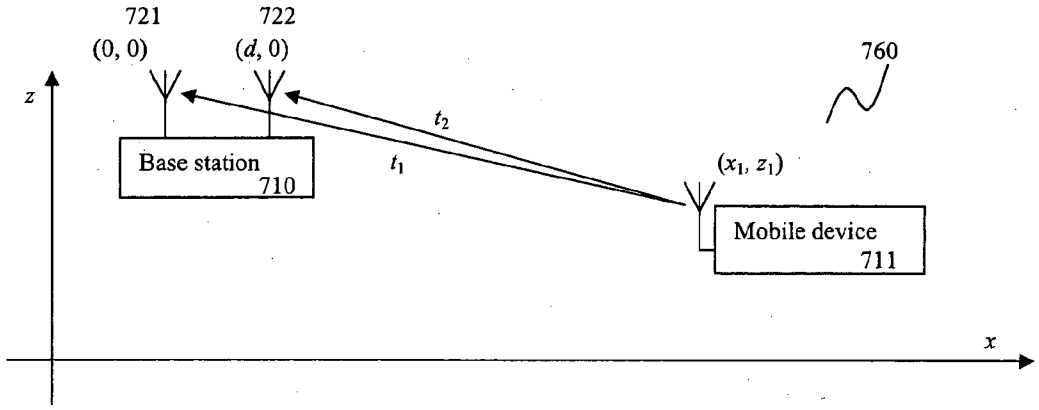

721
722
(0, 0)
(d, 0)
760
z
t_2
t_1
Base station
710
(x_1, z_1)
Mobile device
711
x

FIG. 7 (b)

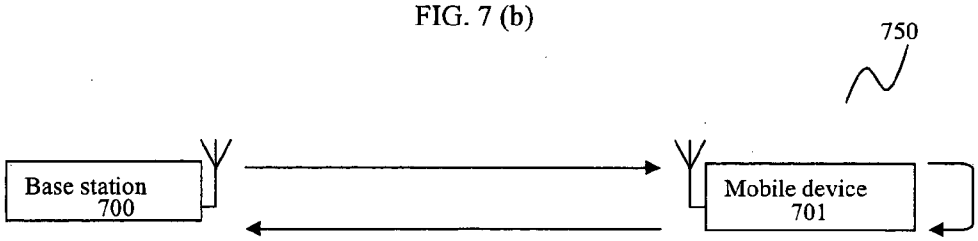

750
Base station
700
Mobile device
701

FIG. 8

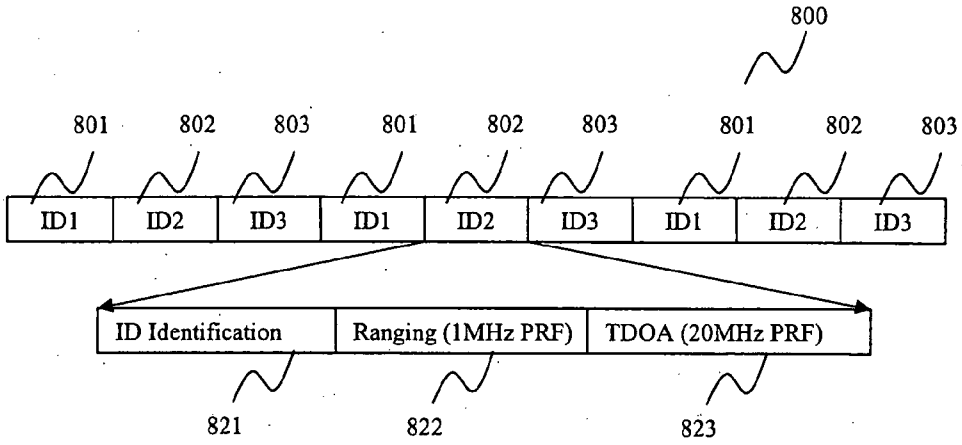

800
801
802
803
801
802
803
801
802
803
ID1
ID2
ID3
ID1
ID2
ID3
ID1
ID2
ID3
ID Identification
Ranging (1MHz PRF)
TDOA (20MHz PRF)
821
822
823

FIG. 9

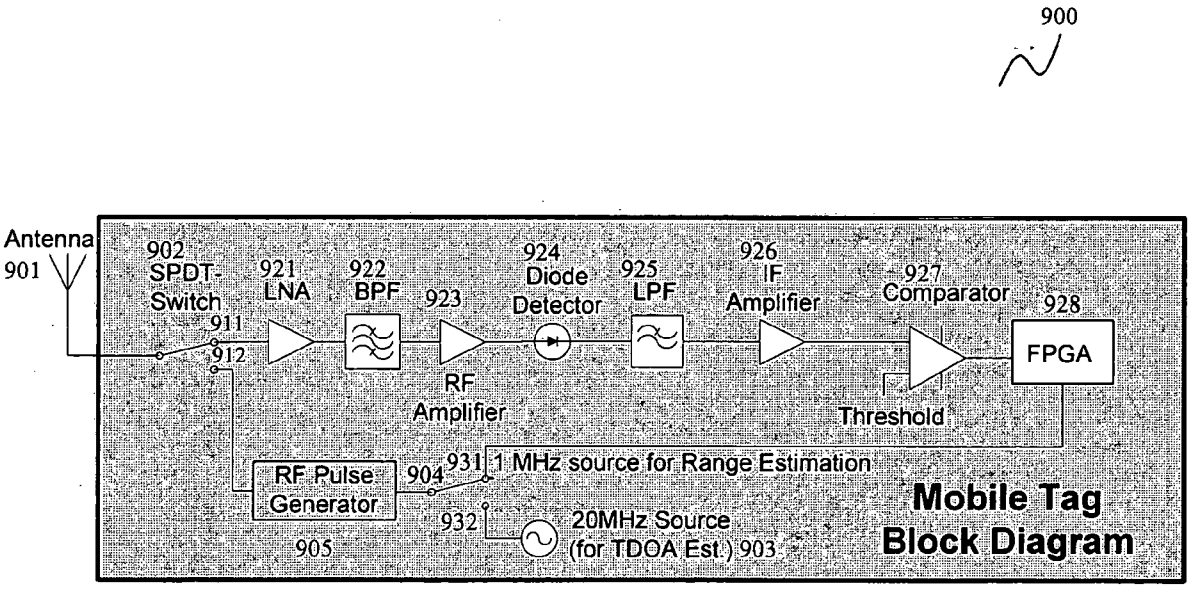

900
Antenna
901
902
SPDT-
Switch
911
912
921
LNA
922
BPF
923
RF
Amplifier
924
Diode
Detector
925
LPF
926
IF
Amplifier
927
Comparator
928
FPGA
Threshold
RF Pulse
Generator
905
904
931
1 MHz source for Range Estimation
932
20MHz Source
(for TDOA Est.) 903
Mobile Tag
Block Diagram

FIG. 10

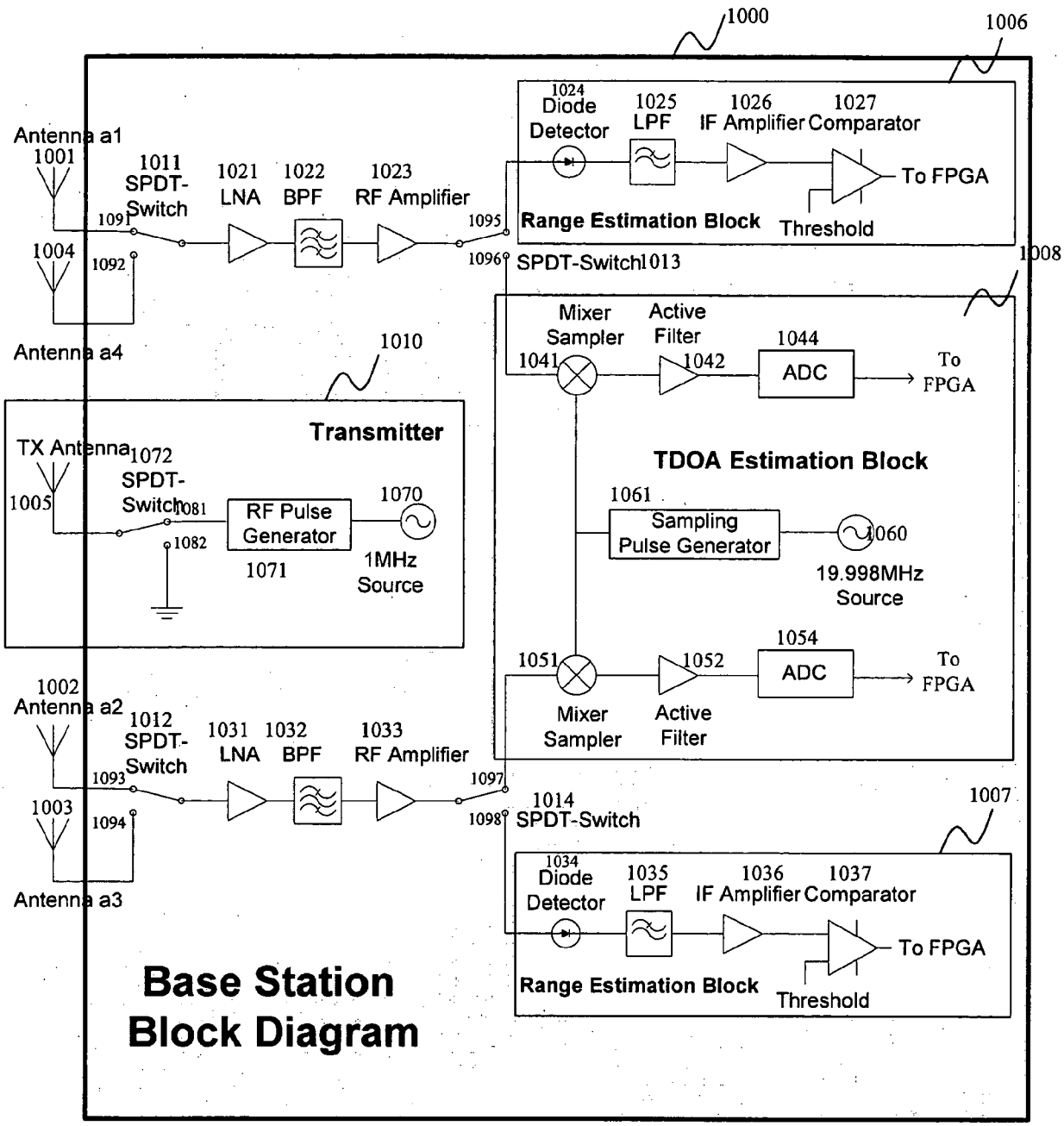
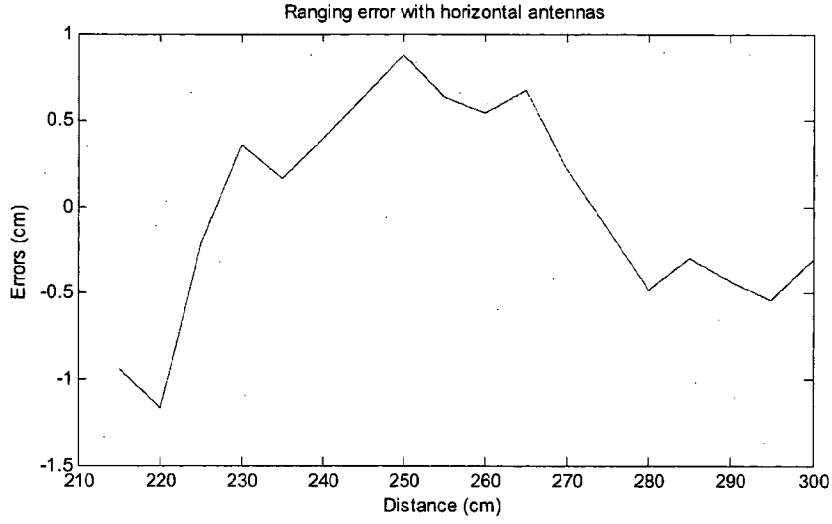
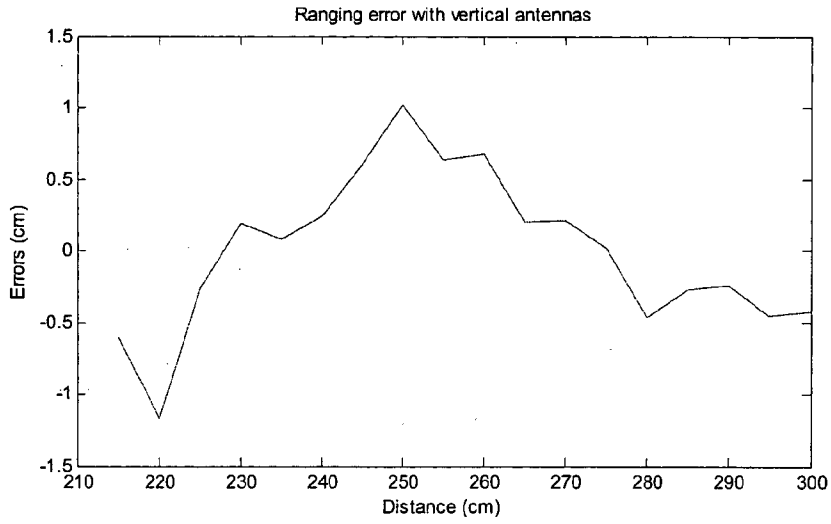

1000
1006
1024
Diode Detector
1025 LPF
1026 IF Amplifier
1027 Comparator
To FPGA
Range Estimation Block
Threshold
Antenna a1
1001
1011 SPDT-Switch
1021 LNA
1022 BPF
1023 RF Amplifier
1091
1095
1004
1092
1096
SPDT-Switch1013
1008
Antenna a4
Mixer Sampler
Active Filter
1044
1041
1042
ADC
To FPGA
1010
Transmitter
TX Antenna
1005
1072 SPDT-Switch
1081
1082
RF Pulse Generator
1071
1070
1MHz Source
TDOA Estimation Block
1061
Sampling Pulse Generator
1060
19.998MHz Source
1054
1051
1052
ADC
To FPGA
Mixer Sampler
Active Filter
1002
Antenna a2
1012 SPDT-Switch
1031 LNA
1032 BPF
1033 RF Amplifier
1093
1097
1003
1094
1098
1014 SPDT-Switch
1007
1034
Diode Detector
1035 LPF
1036 IF Amplifier
1037 Comparator
To FPGA
Range Estimation Block
Threshold
Antenna a3
Base Station
Block Diagram

FIG. 11 (a)



1101

FIG. 11 (b)



1102

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2011/000130

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G01S 1/24 (2006.01) *H04W 64/00* (2009.01)

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)

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 practicable, search terms used)
WPI: time, arrival, uwb, location, periodic
Google Patents & Esp@ce: uwb antenna mobile location time difference periodic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2009/143559 A1 (COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION) 3 December 2009 Abstract; Fig. 6	

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

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"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

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Date of the actual completion of the international search	Date of mailing of the international search report
30 May 2011	7 JUN 2011
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **JAMES WILLIAMS** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6283 2599

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/SG2011/000130

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
WO	2009/143559	AU	2009253724	EP	2294439

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX