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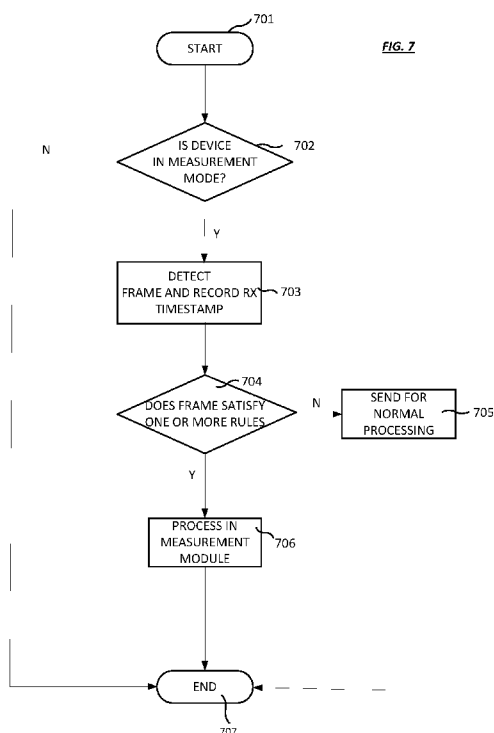
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## (54) Title: WIRELESS DEVICE RANGING



(57) Abstract: A method or apparatus for detecting, at a first wireless device, a measurement frame transmitted by a second wireless device; detecting, at the first wireless device, that a condition has been satisfied to cause the first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame; in response thereto, switching the wireless device to the timing estimation mode; processing the received measurement frame using a timing estimation operation; and causing the processed measurement frame to be used to determine a distance between the first device and the second device.



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## Wireless device ranging

### Field

The invention relates to ranging or positioning of wireless devices.

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### Background

In recent years people have used mobile devices to ascertain their current location.

Satellite navigation systems such as the Global Positioning System (GPS) or GLONASS  
10 (Globalnaya navigatsionnaya sputnikovaya sistema) are useful for tracking a device's  
position. However, these systems have been found to be rather unreliable in indoor  
environments.

It has been proposed to use wireless networks such as WLAN which can be used indoors to  
15 provide positioning information for devices. Such systems rely on an exchange of  
timestamp information contained within data packets sent between several devices within  
the network to obtain time-of-flight (ToF) data. ToF data can then be used to calculate the  
distance between a sending device and a receiving device. A localisation algorithm can be  
used to determine the position of the device.

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In systems such as IEEE 802.11 that use orthogonal frequency-division  
multiplexing (OFDM), a problem arises in detecting the starting point of a symbol  
contained within a data frame. This uncertainty leads to an error in the timestamp value  
for that symbol.

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Detecting the OFDM symbol boundary (e.g. the start of the symbol) in WLAN is usually  
done by coarse timing estimation algorithms, which may have an ambiguity in the order of  
Guard Interval duration. A commonly used method is the Schmidl-Cox (SC) algorithm,  
also known as modified double sliding window, or delay and correlate method. The SC  
30 algorithm exploits the structure of the training sequence in the WLAN OFDM preamble  
which needs to have two or more identical parts in time domain. Both training sequences  
in the WLAN OFDM preamble, the Long Training Sequence (LTS) and the Short Training  
Sequence (STS), have identical parts. The algorithm detects a data frame and finds the  
starting point of OFDM symbols by searching the received signal for such a sequence of  
35 training samples.

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The accuracy of timestamping can be improved using such a corrective algorithm. However, such algorithms are computationally expensive.

### Summary

5 A first aspect provides a method comprising detecting, at a first wireless device, a measurement frame transmitted by a second wireless device; detecting, at the first wireless device, that a condition has been satisfied to cause the first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame; in response thereto, switching the wireless device to the timing  
10 estimation mode; processing the received measurement frame using a timing estimation operation; and causing the processed measurement frame to be used to determine a distance between the first device and the second device.

Detecting that a condition has been satisfied may comprise identifying a trigger within a  
15 detected frame indicating that the first wireless device is to enter the timing estimation mode.

The trigger within the received frame indicating that the first wireless device is to enter the timing estimation mode may be located in the header of the received frame.  
20

The content within the received frame indicating that the first wireless device is to enter the timing estimation mode may be a trigger located in the payload of the received frame indicating that at least part of the received frame contains measurement symbols.

25 Identifying content within a received frame indicating that the first wireless device is to enter the timing estimation mode may comprise searching at a predetermined location within the payload of the received frame for a measurement symbol.

Detecting that the condition has been satisfied may comprise determining that a  
30 predetermined time period for entering the first device into the timing estimation mode has elapsed.

The predetermined time period for entering the first device into the device ranging mode may be determined by the first device.

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The method may further comprise selecting between a time-of-flight measurement mode and a fine timing measurement mode based on information contained in the frame header.

- 5 The method may further comprise using one or more rules to determine whether to enter the timing estimation mode.

The one or more rules may be based on one or more respectively of the frame address, device type, service information and trigger information to determine whether to enter the  
10 timing estimation mode.

The method may further comprise causing ranging information from a plurality of second devices to be used to estimate a position of the first device.

- 15 The first and second devices may be part of a WLAN network.

A computer program comprising computer readable instructions which, when executed by a computer, cause said computer to perform a method according to said first aspect may be provided.

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A second aspect provides an apparatus configured to detect a measurement frame transmitted by a second wireless device; detect that a condition has been satisfied to cause the apparatus to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame; in response thereto, switch the wireless device to  
25 the timing estimation mode; process the received measurement frame using a timing estimation operation; and cause the processed measurement frame to be used to determine a distance between the first device and the second device.

The apparatus may be configured to identify a trigger within a detected frame indicating  
30 that the apparatus is to enter the timing estimation mode.

The trigger within the received frame indicating that the first wireless device is to enter the timing estimation mode is located in the header of the received frame.

- 35 The content within the received frame indicating that the first wireless device is to enter the timing estimation mode may be a trigger located in the payload of the received frame indicating that at least part of the received frame contains measurement symbols.

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Identifying content within a received frame indicating that the first wireless device is to enter the timing estimation mode may comprise searching at a predetermined location within the payload of the received frame for a measurement symbol.

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Detecting that the condition has been satisfied may comprise determining that a predetermined time period for entering the first device into the timing estimation mode has elapsed.

10 The predetermined time period for entering the first device into the device ranging mode may be determined by the first device.

The apparatus may be further configured to select between a time-of-flight measurement mode and a fine timing measurement mode based on information contained in the frame  
15 header.

The apparatus may be further configured to use one or more rules to determine whether to enter the timing estimation mode.

20 The one or more rules may be based on one or more respectively of the frame address, device type, service information and trigger information to determine whether to enter the timing estimation mode.

The apparatus may be further configured to cause ranging information from a plurality of  
25 second devices to be used to estimate a position of the first device.

The apparatus and second devices may be part of a WLAN network.

A third aspect provides an apparatus, comprising: a controller; and a memory in  
30 which is stored computer readable instructions that, when executed by the controller, cause the controller to detect a measurement frame transmitted by a second wireless device; detect that a condition has been satisfied to cause a first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame; in response thereto, switch the first wireless device to the timing  
35 estimation mode; process the received measurement frame using a timing estimation operation; and cause the processed measurement frame to be used to determine a distance between the first device and the second device.

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A fourth aspect provides a non-transitory tangible computer program product in which is stored computer readable instructions that, when executed by a computer, cause the computer to detect a measurement frame transmitted by a second wireless device; detect that a condition has been satisfied to cause a first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame; in response thereto, switch the first wireless device to the timing estimation mode; process the received measurement frame using a timing estimation operation; and cause the processed measurement frame to be used to determine a distance between the first device and the second device.

### Brief description of the drawings

Embodiments will now be described by way of non-limiting examples with reference to the accompanying drawings, of which:

Figure 1 shows an example network topology;

Figure 2 is a block diagram providing a schematic illustration of a device;

Figure 3 shows an exchange of messages between two STAs in a fine time measurement configuration;

Figure 4 shows an exchange of messages between STAs in a time-of-flight measurement configuration;

Figures 5A-E show example frame structures;

Figure 6 illustrates a positioning window;

Figure 7 is a flow chart illustrating embodiments of the invention; and

Figure 8 is a flow chart illustrating embodiments of the invention.

### Detailed description

Embodiments of the invention provide for efficient processing of received timing measurement frames from which time values can be determined. Once obtained the accurate time values can be used for device ranging and localisation. Computing resources may be directed towards improving the accuracy of the time values obtained from the timing measurement frames. However, in embodiments of the invention these intensive processes are carried out only in response to certain conditions so that energy consumption is optimised.

In some embodiments of the invention, time of flight (TOF) measurement frames are transmitted from a first device to a second device. Each TOF measurement frame contains

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one or more measurement symbols, wherein each measurement symbol has an associated timestamp applied by the sending device. The one or more timestamp values may be processed by the receiving device to improve their accuracy. The timestamp values may then be used to determine a distance between the first and second device.

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In other embodiments of the invention, fine time measurement (FTM) frames may be exchanged between a first device and a second device. Respective devices may record when a FTM frame is transmitted and when a FTM frame is received. The time values so obtained may then be used to determine a distance between the first and second devices.

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Distance data between multiple pairs of devices in a network may then be provided to a localization algorithm to provide device location information relating to the devices within the network.

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A wireless communication scenario to which embodiments of the invention are applied is illustrated in Figure 1. Figure 1 illustrates a plurality of wireless devices 100, 102, 104, 106, 108, 109 that form an ad hoc network. The ad hoc network may comply with neighbour awareness networking (NAN) principles in accordance with the WLAN standard. The wireless devices may form a single network comprising one or more clusters of the same network, or the wireless devices may form two different wireless networks 110, 112. Each of the wireless devices employs a physical layer and a medium access control (MAC) layer that comply with wireless local area network (WLAN) specifications based on IEEE 802.11 standard but, in other embodiments, the wireless devices may support another wireless communication protocol as an alternative or in addition to the WLAN.

20

In the WLAN specifications, a wireless network may be called a basic service set (BSS). While embodiments of the invention are described in the context of the IEEE 802.11 standard, it should be appreciated that these or other embodiments of the invention may be applicable to wireless networks based on other specifications, e.g. WiMAX Worldwide Interoperability for Microwave Access), UMTS LTE (Longterm Evolution for Universal Mobile Telecommunication System), mobile ad hoc networks (MANET), mesh networks, and other networks having cognitive radio features, e.g. transmission medium sensing features and adaptive capability to coexist with radio access networks based on different specifications and/or standards. Some embodiments may be applicable to networks having features under development by other IEEE task groups. Therefore, it will be understood that the following description may be generalized to other systems as well.

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The different wireless networks may operate at least partly on different channels, e.g. on different frequency channels. IEEE 802.11n specification specifies a data transmission mode that includes 20 megahertz (MHz) wide primary and secondary channels. The primary channel is used in all data transmissions with clients supporting only the 20 MHz mode and with clients supporting higher bandwidths. A further definition in IEEE 802.11n is that the primary and secondary channels are adjacent. The IEEE 802.11n specification also defines a mode in which a station (hereinafter STA) may, in addition to the primary channel, occupy one secondary channel which results in a maximum bandwidth of 40 MHz. IEEE 802.11ac specification extends such an operation model to provide for wider bandwidths by increasing the number of secondary channels from 1 up to 7, thus resulting in bandwidths of 20 MHz, 40 MHz, 80 MHz, and 160 MHz. A 40 MHz transmission band may be formed by two contiguous 20 MHz bands, and an 80 MHz transmission band may be formed by two contiguous 40 MHz bands. However, a 160 MHz band may be formed by two contiguous or non-contiguous 80 MHz bands. Different BSSs may employ different primary channels.

As mentioned above, the transmission band of a BSS contains the primary channel and zero or more secondary channels. The secondary channels may be used to increase data transfer capacity of a transmission opportunity (TXOP). The secondary channels may be called a secondary channel, a tertiary channel, a quaternary channel, etc. However, for the sake of simplicity the term secondary channel will be used as the common term to refer also to the tertiary or quaternary channel, etc. The primary channel may be used for channel contention, and a TXOP may be gained after successful channel contention on the primary channel. Some IEEE 802.11 networks are based on carrier sense multiple access with collision avoidance (CSMA/CA) for channel access. Some networks may employ enhanced distributed channel access (EDCA) which provides Quality of Service (QoS) enhancements to the medium access control (MAC) layer. The QoS enhancements may be realized by providing a plurality of access categories (AC) for prioritizing frame transmissions. The access categories may comprise the following priority levels in the order of increasing priority: background (AC\_BK), best effort (AC\_BE), video streaming (AC\_VI), and voice (AC\_VO). A higher priority frame transmission may use a shorter contention window and a shorter arbitration interframe spacing (AIFS) that result in higher probability of gaining the TXOP.

Furthermore, some networks may employ restricted access windows (RAW) where a reduced set of wireless devices of the wireless network may carry out channel contention.

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An access node or a master node may define the RAW and a group of wireless devices that are allowed to attempt the channel access within the RAW. Grouping allows partitioning of the wireless devices into groups and restricting channel access only to wireless devices belonging to a specified group at any given time period.

5 The time period may be enabled by allocating slot duration and a number of slots in RAW access. The grouping may help to reduce contention by restricting access to the medium only to a subset of the wireless devices. The grouping may also reduce the signalling overhead.

10 A wireless device initiating a TXOP in an 802.11 network may transmit a frame that triggers a network allocation vector (NAV). The frame may be a control frame such as a request to send (RTS) frame or a data frame. The frame may comprise a Duration field defining the duration of the NAV. Any other wireless device detecting the frame and extracting the Duration field suspends access to the same channel for the duration of the  
15 NAV. This mechanism may reduce simultaneous transmissions in the proximity that may be renamed as collisions. In some collisions the receiver cannot receive transmissions resulting to wasted transmission resources. The IEEE 802.11 networks may employ another collision avoidance mechanism called clear channel assessment (CCA). A wireless device trying to access the channel scans for the channel before the access. If the channel  
20 is sensed to contain radio energy that exceeds a CCA threshold, the wireless device refrains from accessing the channel. If the channel is sensed to be free and no NAV is currently valid, the wireless device may access the channel. A conventional value for the CCA threshold may be 82 decibelmilliwatts (dBm) or 62 dBm depending on a channel access scheme, for example.

25 The wireless devices 110, 112, 114 may employ a randomized backoff time defining a minimum time interval they refrain from frame transmissions after detecting that the channel is busy. During the channel sensing, the backoff time may be decremented while the channel is sensed to be idle or available for the channel access. When the backoff time  
30 reduces to zero and the channel is still sensed to be idle, the wireless device may carry out the frame transmission. The backoff time value may be maintained for the duration the channel is sensed to be busy and, in some systems, for a determined guard time interval (e.g. the AIFS) after the detection that the channel has become idle.

35 Applications for short-range wireless devices are evolving to include awareness applications providing the device with an awareness about the local network environment. An example of awareness network architecture is the Nokia AwareNet<sup>®</sup> framework, a

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network of wireless mobile devices self-organizing to support various applications, ranging from social networking to service discovery. Awareness information may be shared by a short-range wireless device sending an anonymous flooding message that may include a query, over an ad hoc network. A neighbouring short-range wireless device may  
5 reply to the flooding message over the ad hoc network with a response, such as a pointer to a discovered location-based service.

Awareness information may include any information and/or context about a local network environment as well as the users and communication devices within the local network  
10 environment. Wireless devices may continuously collect and exchange information with other devices in a local network environment. Awareness applications running on short-range wireless devices may create a network for sharing awareness information, locate and organize awareness information, form communities for sharing awareness information, manage power consumption for devices engaged in sharing awareness information,  
15 develop applications to take advantage of the awareness information, and maintain the privacy and anonymity of users sharing awareness information.

Awareness applications running on short-range wireless devices may employ a physical layer and a MAC layer based on the IEEE 802.11 specifications. The awareness application  
20 may build upon a scheme in which every device is responsible for participating in beaconing and all the other basic operations that keep the ad hoc network in operation. An ad hoc network may be designed to have one network identifier (NWID) that all of the devices in the network share. The NWID may be announced in the beacons transmitted by the devices. In the overall design, those devices that operate under same NWID are driven  
25 to use a common and shared schedule to allow for awareness information gathering among all the devices within range. The determination of which schedule is used by a device may be made by the network instance timer value, and this timer value is communicated in beacons in the timing synchronization function (TSF) value parameter. The devices may be required to operate by assuming the oldest TSF value (i.e. largest TSF  
30 value) contained in the received beacons that represent the network with the NWID in which the devices are operating. Alternatively the devices may be required to select the schedule to follow based on some other criteria than the TSF value. Beacons may, as an example, contain information other than the TSF that is used by the devices to determine which schedule to use for awareness information delivery.

35 When a wireless device transmits a Beacon, the Beacon MAC Header contains the device's own current TSF value. The device may automatically transmit a reply message when it

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receives a Beacon from another network, the reply message being referred herein as a beacon response message. The beacon response message contains the current TSF value of the replying network. Alternatively the beacon response message may contain other information that is used to determine which schedule to use.

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Wireless devices form a network where all devices in proximity may communicate with each other. When two or more groups of devices forming two or more instances of the network come close to each other, the two or more instances may merge to become one network instance.

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Devices may make a merging or join decision to change the instance autonomously based on the TSF information collected from Beacons received during scan periods or based on the TSF information collected from received beacon response messages. A merging decision may be performed when a device receives a Beacon or beacon response message with an older (greater) TSF value from another wireless device.

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Alternatively, a merging decision may be done based on some other information available in a Beacon or beacon response message from another wireless device. After the merging decision has been performed by a device, the device moves into the new network instance.

20

The awareness functionality in a short-range wireless device may be divided between four layers in the awareness architecture. The Awareness Layer and the Community Layer provide services for applications, i.e. provide the awareness application program interface (API).

25

Figure 2 is a schematic block diagram illustrating the components of one of the mobile devices shown in Figure 1. The device 100 comprises a processor or controller 120, a volatile memory such as a RAM 150 and a non-volatile memory or ROM 155. The ROM 155 has an operating system 156 and various applications 157 stored therein. The device 100 comprises various input/output components 158 such as a touchscreen, a keyboard, a microphone and speakers. The device 100 also comprises a power source 170 such as a battery. Components may be connected via a bus 175.

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The device comprises a WLAN chip 160 coupled to an antenna 171. The WLAN chip 160 comprises a processor or controller 161 and a memory 162. The WLAN chip 160 is configured to execute the processing steps described in detail below and can be considered to comprise a timing estimation module 163 controlled by the controller 161. The WLAN

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chip 160 comprises a clock 165 that may be based on a crystal oscillator. The clock can be any suitable clock known in the art. The WLAN clock may have a frequency of 40 MHz.

The device 100 may be a desktop computer, a laptop computer, a smartphone, a tablet  
5 computer, a PDA etc. The device 100 may therefore comprise one or more network interfaces 172 to connect to networks such as a mobile telephony network, for example a 3G, 4G or 5G network, a Bluetooth network and so forth, depending on the exact form of the device 100.

10 FIG. 3 is a diagram illustrating a message flow between wireless devices such as the device shown in Figure 2 in embodiments where two devices exchange fine timing measurement (FTM) frames. Hereinafter, the terms stations and devices are used interchangeably.

Figure 3 shows two stations STAs including a "requesting" STA 201 and a "receiving" STA 202. In this context, a requesting STA 201 and a responding STA 202 may be any of  
15 several transceiver devices including a mobile device (e.g., mobile device 100). A requesting STA 201 may obtain or compute one or more measurements of RTT based, at least in part, on timing of messages or frames transmitted between the requesting STA 201 and the responding STA 202.

20 The requesting STA may transmit a fine timing measurement (FTM) request message or frame ("Request") to the responding STA 202. The FTM request may have a structure similar to that shown in Figure 5A. The structure of example data frames is discussed in more detail below.

25 This Request message is assigned a time value  $t_1$  indicating the time at which the Request message is transmitted by the requesting STA 201. The requesting STA 201 makes a record of  $t_1$ .

The responding STA 202 receives this Request and records a time value of  $t_2$ . The  
30 responding STA 202 makes a record of  $t_2$ . The responding STA 202 creates an acknowledgement message or frame ("ACK") and transmits this ACK in response.

The responding STA 202 makes a record of time value  $t_3$ . Time value  $t_3$  is the time at which the ACK is transmitted by the responding STA 202.

35 The requesting STA 201 receives the ACK and records the time of receipt as  $t_4$ .

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Consequently, the requesting STA 201 has a record of  $t_1$  and  $t_4$ . The responding STA 202 has a record of  $t_2$  and  $t_3$ .

In some embodiments the requesting STA 201 transmits the time values  $t_1$  and  $t_4$  to the responding STA 202. In other embodiments, the responding STA 202 transmits the time values  $t_2$  and  $t_3$  to the requesting STA 201.

Once the requesting STA 201 or the responding STA 202 has received time values from the other device, the requesting STA 201 or the responding STA 202 may then obtain or compute an RTT measurement based, at least in part, on time stamp values ( $t_1, t_2, t_3, t_4$ ).

The RTT is given by the expression:

$$RTT = (t_4 - t_1) - (t_3 - t_2).$$

In embodiments where FTM messages are exchanged between devices, the requesting STA 201 is responsible for measuring the times  $t_4$  and  $t_1$  precisely. The times  $t_2$  and  $t_3$  times are measured by the responding STA 202. Thus, the implementations of the requesting and requested STAs can optimize the timing measurement inside the respective device using a corrective algorithm described in more detail below. The device does not need to indicate to other devices how it obtains these times.

In other embodiments, WLAN ranging of devices within a network may be performed using an alternative mechanism referred to herein as Time-of-flight (TOF) measurement.

Figure 4 shows three devices 100, 102 and 104, which are nodes in a WLAN network. In TOF measurement, each device broadcasts a TOF measurement frame  $T$  periodically to other devices in the network. Device 100 broadcasts a first message  $T_1$ . Device 102 broadcasts a message  $T_2$  a predetermined interval after  $T_1$ . Device 104 broadcasts a message  $T_3$  a predetermined interval after  $T_2$ . The first device 100 broadcasts a second message  $T_4$  a predetermined interval after  $T_3$  and so forth. Thus, each device in the network may broadcast messages  $T$  periodically.

In these embodiments the receiving devices may obtain the clock drift between the clock of the receiving device and the clock of the ranged device, i.e. the device that sent the TOF message. The ranging operation may use the clock of the receiving device to synchronize the ranging operations and use other device clocks within the network to maintain the timing synchronization function (TSF) of the network. The use of separate clocks helps to

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maintain the clock used for ranging to proceed monotonically without adjustments caused by the topology and other STAs in the network.

Embodiments of the invention that use TOF ranging provide a measurement scheme that is able to transmit a frame containing a measurement symbol having a single time instance from one device and let other devices detect the time of the measured symbol. The devices that know the clock difference may then range the distance between the devices by estimating the difference between the time of frame arrival and the timestamp of the frame.

Figure 5B shows an example frame 500 whereby a measurement symbol 501 is contained in the frame after other data in the payload. Figure 5C shows an example frame 510 whereby a measurement symbol 501 is contained in the frame before the other data in the payload.

The devices may determine the clock difference or clock rate by receiving multiple frames having a timestamp and measurement symbol. The clock difference is detected by comparing how much the device's own clock has progressed compared to other device's clock.

The timestamp of the first measurement frame is used as a synchronization reference point between the transmitting and receiving device clocks. The precise synchronization reference point may be the start of the preamble, end of the preamble, the first symbol, a specific symbol or the last symbol of the transmitted frame.

The receiving device determines the clock difference between the receiving device and the transmitting device by receiving multiple frames, each containing a measurement symbol, each symbol having its own respective timestamp. The clock difference is detected by comparing how much the receiving device's own clock has progressed compared to clock of the transmitting device during transmission of successive frames.

The message that contains the timestamp and the measurement symbol can be received by many ranging devices. Each device determines the clock difference and uses the time difference to range the distance between the devices. More details of the TOF mechanism and its operation can be found in Synchronization and Ranging by Scheduled Broadcasting by Hassan Naseri *et al* which is incorporated herein by reference.

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The FTM Request and Response messages sent in the embodiment shown in Figure 3 and the messages sent in embodiments using TOF measurement shown in Figure 4 may take the form of WLAN data frames. An example of such a frame 300 is shown in Figure 5A.

The frame 300 comprises a preamble 301, a PLCP (Physical Layer Convergence Protocol) header 302, a MAC (Media Access Control) header 303, a data payload 304 containing data expressed in symbols, and a frame check sequence (FCS) 305.

In embodiments using TOF measurement, the frame contains one or more measurement symbols and a timestamp indicating to the receiving device the time at which the symbol was transmitted.

In the embodiment shown in Figure 3, each STA within the network is configured to send Request messages as well as to respond to received Request messages.

In TOF measurement embodiments, a message may be sent and a basic acknowledgement message (ACK) received in accordance with the IEEE 802.11 standard. However, in TOF embodiments the ACK is not used in the ranging process.

The accuracy of each of the time values used to calculate the RTT or the TOF can be improved using the Schmidl-Cox algorithm or any other suitable algorithm known in the art for improving timing values in message frames. The processing of the time values is performed at the timing estimation module 163. Time of Arrival (TOA) estimation for OFDM symbols can be problematic because of cyclic prefix. Detecting the OFDM symbol boundary (start of the symbol) in WLAN is usually done by coarse timing estimation algorithms, which may have an ambiguity in the order of OFDM symbol guard interval duration. A commonly used method is Schmidl-Cox (SC) algorithm, also known as modified double sliding window algorithm, or delay and correlate method. The SC algorithm exploits the structure of the training sequence that needs to have two or more identical parts in time domain. Both training sequences in the WLAN OFDM preamble, Long Training Sequence (LTS) and Short Training Sequence (STS), have identical parts. The algorithm detects a data frame and finds the starting point of OFDM symbols by searching the received signal for such a sequence of training samples.

As described above, devices within the network periodically send beaconing signal frames containing timing synchronisation function (TSF) values during discovery windows (DWs). Each DW has a defined start time and end time.

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In an ad hoc network each device within the network sends a Beacon frame during a predefined Discovery Window. The devices within the network synchronise their clocks to the first received of these beaconing signals. In infrastructure networks, devices within the network synchronise their clocks to TSF values contained in a Beacon frame received from the network Access Point (AP).

In embodiments of the invention, a time period, referred to herein as a Positioning Window (PW), during which FTM or TOF measurement frames are to be sent, is defined in relation to the start time of the DW. Figure 6 shows the intervals between DWs and respective Positioning Windows (PWs).

For example, the start time of the PW may be defined as  $\delta t$  after the start time of the DW. An example of  $\delta t$  may be around 20 Time Units (Tus), where a Tu is 1,024 ms. The DW may have a duration of 16 Tus, therefore having a 20 Tus allows sufficient time for anychannel switching that may be required. The PW may be specified to operate in a specific channel. The channel may be selected by the STA that initiated the PW or it may be specified in the WLAN or NAN standard. If the PW happens on a different channel to the DW, the WLAN chip may need time to change the channel which can take 1-2 ms.  $\delta t$  may therefore be set at 20TUs.

The start time may be contained within the Beacon frame. The start time may be selected by the device that first starts to operate during the PW. The other devices in the network may try to find an existing PW and if they do not find one, they may create a new PW. A device which generates the period may be called an “owner” of the period. The owner is responsible to adjust the period start and end times of the channel, so that the period has enough time to transmit all desired frames.

Alternatively, the PW may have constant start and end times that are specified by the NAN (neighbour awareness networking) standard in embodiments where the network is a NAN network. The fixed PW may be derived from the TSF. This has the advantage that no protocol overhead is required, no device needs to set up the PW and STAs in the network may decide whether they want to participate in measurement. Devices not participating may enter a sleep mode to save energy.

In any case, all devices are notified when the measurement frames related to device-to-device positioning are to be transmitted.

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The PW may signal which measurement scheme is used during the period. Thus, the devices may transmit frames of either the FTM measurement scheme or the TOF measurement scheme during the PW. Alternatively, a PW may be allocated to carry only frames related to FTM or TOF mechanism. The selection of the frames that are  
5 transmitted during the PW may help devices to lower the power consumption. For instance, if a device is capable only to perform either of the ranging mechanisms the device may select to be available only during either mechanism.

Each PW, during which measurement frames containing measurement symbols are  
10 received, typically has a duration of less than 10ms. This duration may be selected by the first device that creates the PW. Alternatively, the duration may be specified in the NAN standard.

If a device that wishes to transmit a frame during a PW detects that there is no capacity to  
15 transmit messages during the PW, the device may create a new PW by transmitting a publish message with new PW start time and the duration.

During the PW, frames received at the STAs within the network may be redirected to the timing estimation module 163 located in the WLAN chip 160. The timing estimation  
20 module 163 may be configured to perform symbol timing estimation on received measurement symbols in embodiments utilising TOF measurement. The timing estimation module 163 may be configured to perform TOA estimation for FTM measurement frames received in embodiments employing FTM.

25 The timing estimation module 163 may check if the received frame is related to the FTM ranging mechanism or the TOF ranging mechanism.

When a FTM request frame is received at the responding device 202, the responding STA  
30 202 estimates the time-of-arrival  $t_2$  of the frame. The responding STA 202 applies a time value  $t_2$  to the received request message and performs timing estimation at its timing estimation module 163 to obtain an accurate value for  $t_2$ .

A response message may be sent at time  $t_3$ . If the FTM request is specifically addressed to the responding STA, the responding STA 202 obtains and records the  $t_2$  and  $t_3$  times and  
35 responds to the frame with a FTM Response message as shown in Figure 3.

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The FTM Response message is sent to the requesting STA 201 at time  $t_3$  so that it may be received during a PW. The requesting STA 201 applies a time value  $t_4$  to the response message and performs timing estimation at its timing estimation module 163 to obtain an accurate values  $t_4$ .

5

Referring to Figure 3, the requesting STA 201 is configured to send the Request message during a PW and the responding STA 202 is configured to send the ACK as a response to the Request message during a PW. Thus, the timestamp values that are determined for  $t_2$  and  $t_4$  benefit from the improvement afforded by the timing estimation module.

10

The times  $t_1$ ,  $t_2$ ,  $t_3$  and  $t_4$  can then be used by the requesting STA 201 or the responding STA 202 to calculate the distance between the requesting STA 201 and the responding STA 202. Alternatively, the values  $t_1$ ,  $t_2$ ,  $t_3$  and  $t_4$  may be output to another node to calculate the RTT and the pairwise distance between the requesting STA 201 and the

15

responding STA 202 can be calculated. Pairwise distances from several pairs of devices may be provided to a localization module to determine the locations of the devices in the network.

20

During the PW the FTM request frame may be directly transmitted to a STA without additional signalling. Typically each measurement is established with setup signalling. The STA that wishes to initiate the ranging measurement transmits a request to perform FTM. The responding STA 202 responds with a response to accept the measurement. The target of the signalling is to ensure that the respective devices are capable to perform the measurement and that they are available to make the measurements of the  $t_1$ ,  $t_2$ ,  $t_3$  and

25

$t_4$ .

30

When a PW is applied, the STA may know which STA has set up the PW, or the MAC addresses of the STAs that are performing ranging during the period. The STA may perform ranging with these devices during the PW without additional request and response signalling. The setup signalling avoidance reduces the signalling overhead in the network.

35

The FTM request frame may be indicated by a field in the PLCP header or in the MAC header. The field value may indicate that the responding STA 202 should measure the  $t_2$  and  $t_3$  times and later provide the information to the requesting STA 201. The measurement indication in the PLCP or MAC header may enable payload transmission during the PW and reduces the management frames transmission overhead. In one

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embodiment, the measurement results for t2 and t3 from a previous FTM Response frame may be resent and the requesting STA 201 may obtain t2 and t3 times from these frames. Using the timing estimation module 163 during predefined periods reduces the time that the measuring STAs need to maintain the timing estimation module 163 active.

5

In embodiments where TOF measurement is used, the WLAN processor 161 checks subsequently which received frames contained a measurement symbol and which were other frames, like ordinary data frames. The frames containing a measurement symbol may have a specific frame type, or they may contain signalling in the PLCP or the MAC  
10 header. This information specifies the location of the measurement symbol in a frame. The precise time of arrival of the frame may be obtained by correlating a received measurement symbol with samples of reference measurement symbols stored at the receiving device in a database or look-up table. The WLAN chip may have a symbol buffer for buffering received symbols after passing through the analog to digital converter. At the  
15 buffer, the WLAN chip may perform a correlation operation meaning it compares the buffered symbol to determine whether it substantially matches the pilot. If it is a match, correlation gives a high peak as a result.

At the end of the PW, the processor chip reverts to a normal operational mode. That is to  
20 say, symbols contained within frames received outside the PW are not processed at the symbol timing estimation module. Furthermore, the STA may be configured so as not to transmit TOF or FTM request frames outside the PW.

Figure 7 is a flow chart illustrating embodiments of the invention. The process starts at  
25 step 701.

At step 702, the STA determines whether it is in a timing measurement mode. In other words, the STA may detect whether a PW is ongoing. If the PW is not ongoing, the process ends and the STA continues to perform operations in accordance with any of the current  
30 radio specific operations, for instance according to IEEE 802.11 (WLAN), NAN, BT, or LTE standard.

If the STA is in measurement mode, the process continues to step 703.

35 At step 703 a STA detects a data frame. The receiving STA applies a receive (RX) timestamp to the detected frame.

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If the TOF mechanism is used, the STA obtains the or each measurement symbol and the included transmission (TX) time stamp for the or each measurement symbol contained within the measurement frame.

- 5 In FTM mode, a responding device 202 may apply a TOA timestamp indicating time value t2 to a received FTM Request message. A requesting device 201 may apply a TOA timestamp indicating time value t4 to a received FTM Response message.

When the PW is ongoing, the STA process continues to step 704 or step 706.

10

Step 704 is an optional step. The WLAN chip processor 161 may determine if a detected frame is to be processed by the timing estimation module 163 in accordance with one or more rules. Example rules include whether the receiving device is addressed in the frame. This may involve checking the MAC header to determine if the receiving device is  
15 addressed by the frame.

In some embodiments, if the frame is not addressed to the receiving device the device directs the detected frame for normal processing in accordance with any of the current radio specific operations, for instance according to IEEE 802.11 (WLAN), NAN, BT, or  
20 LTE standard.

However, in other embodiments the rules may allow for broadcast frames (i.e. frames not addressed to a particular STA) to be processed at step 706.

- 25 Alternative rules include the receiving STA selecting a group of sending devices whose frames it processes. The group of devices may be selected based on one or more of: the RSSI value of the received frame, the service that the devices are supporting, the type of the device (AP, mesh point, STA, GO, anchor master) or based on the distance to anchor master. The STA may process the received timing measurement frames from the group  
30 regardless of the MAC address of the transmitted frames.

The WLAN chip processor 161 may also check whether the frame related to ranging measurement in general or to FTM or TOF ranging in particular and selects the operation accordingly. This may be indicated by a trigger located in the frame header or elsewhere  
35 in the frame. If the frame does not relate to ranging measurement in general or to FTM or TOF ranging in particular then the detected frame may be directed for normal processing

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at step 705 in accordance with any of the current radio specific operations, for instance according to IEEE 802.11 (WLAN), NAN, BT, or LTE standard.

If the frame satisfies the one or more rules then the process continues to step 706. If the frame fails to satisfy the one or more rules then the detected frame is directed for normal processing at step 705 in accordance with any of the current radio specific operations, for instance according to IEEE 802.11 (WLAN), NAN, BT, or LTE standard.

In embodiments that do not require the step 704, all frames that are detected whilst the device is in a measurement mode proceed to step 706. For example, in embodiments using the FTM mechanism, a receiving STA 202 may measure the time value  $t_2$  when the FTM Request frame is detected. The requesting STA 201 may measure the time value  $t_4$  when the FTM Response is received. The time value information from these two instances may be obtained by the respective STAs even when the frames are not specifically addressed to that STA. The STA may use the information to estimate the distance of the STAs that transmitted the frames to the measuring STA 201.

In embodiments using TOF ranging, the measurement symbols received during the PW are diverted to the timing estimation module 163 subject to any rules that may be required at step 704.

In FTM embodiments, at step 706, the TOA timestamp applied to a received FTM message is supplied to the timing estimation module 163. An algorithm, such as the Schmidl-Cox algorithm is then used to improve the accuracy of the time values applied to the FTM Request and Response messages. Alternatively or additionally a Fast Fourier Transform - Weighted Least Squares (FFT-WLS) algorithm may be applied at the timing estimation module 163 that can also provide the timing error. After FFT-WLS a sufficiently accurate value may be achieved for ranging purposes.

In TOF embodiments, once the measurement frame has been directed towards the timing estimation module 163, the measurement symbols are analysed, at step 706.

In TOF embodiments, each of the received symbols to be analysed is compared with a stored reference symbol to determine whether it is a measurement symbol. This can be done in any suitable manner such as through autocorrelation or cross-correlation. Each symbol has an associated transmit (TX) timestamp. The timestamp of each symbol determined to be a measurement symbol is extracted from the frame.

The value of the TX timestamp for each of the symbol in the frame together with the RX timestamp applied to the or each symbol is recorded and processed at the timing estimation module. The symbol timing estimation module uses a corrective algorithm  
5 such as the Schmidl-Cox algorithm or any other suitable corrective algorithm that is known in the art. The correction algorithm is used in order to mitigate various errors that are present when detecting symbol boundaries.

The method ends at step 707.

10 In TOF ranging embodiments, the corrected RX timestamp values obtained using the algorithm at step 706 re used to calculate a distance estimate between the sending device and the receiving device. Multiple devices within the network are configured to both send and receive measurement messages. Distance estimates may thus be obtained between  
15 each pair of devices in the network. These estimates may be output to a server that is configured to map the positions of the devices using any suitable localisation algorithm. This can be done in any suitable way known in the art.

20 In FTM embodiments, the corrected timestamps  $t_2$  and  $t_4$  may be used to improve the estimate of the RTT described above.

In alternative embodiments, whether a detected frame is to be directed to the timing estimation module is based on whether the received frame contains a trigger. Frames containing trigger may be redirected to the timing estimation module 163.

25 Figure 8 is a flow chart illustrating the process followed by embodiments of the invention wherein the trigger is included within the FTM or TOF frame. The frame can be any of the FTM Request message, the FTM Response message or the TOF message described above.

30 The process begins at step 801. At step 802, a STA detects a data frame. At step 803, the receiving STA analyses the frame and determines whether it contains a trigger to process the frame using the timing estimation module 163.

35 In one embodiment where TOF measurement is used, a frame 310 is detected, of a type shown in Figure 5D. A trigger 311, for example information indicating that one or more measurement symbols are located in the frame and their location within the frame, may be contained within the PLCP header 302. Alternatively, the trigger 311 may be located in the

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MAC header 303. When the receiving device decodes the PLCP header or MAC header and determines that there are one or more measurement symbols in the frame 310, the WLAN module switches to a timing measurement mode. The trigger may provide the information of the position of the measurement symbol, for instance whether the measurement symbol is the first symbol contained in the frame, or the last symbol of the transmitted data payload.

The trigger may contain an identifier that may be unique for a group of devices, or to a service or to a device type. The STA may use an identifier contained within a detected frame to decide whether to receive the frame and to process it further. The frame may then be redirected to the timing estimation module 163. The measurement symbols contained within the data payload may be processed by the symbol timing estimation module.

In some embodiments, the form of the symbol may have commonly known value for instance the value may be standardised in order to avoid overhead in the measurement protocol.

In some embodiments, multiple measurement symbols may be included in the frame. Each of these symbols has an associated TX timestamp.

In some embodiments, the first symbol in a frame 320 itself could be used as a trigger symbol 321, as shown in Figure 5E. Again, the form of such a measurement symbol is communicated to devices in the network in advance. The presence of a measurement symbol in a received frame is determined at the receiving device using a correlation function.

In this case the receiving device detects the trigger symbol and subsequently switches to the measurement mode. Subsequent incoming measurement symbols are transferred to the symbol timing estimation module.

In other embodiments, measurement symbols are located in a place known to all devices in the network. For example, the first symbol in the frame after the MAC header may be designated as containing a measurement symbol. The location of measurement symbols can be communicated to network devices in advance via management frames. During transmission of frames, the receiving device needs only to check for the presence of

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measurement symbols in the predetermined location within the received frame. Thus, processing power is used efficiently.

If the receiving STA determines at step 803 that the frame does not contain a trigger, the frame is processed normally at step 804. That is to say, the received frame is processed in accordance with any of the current radio specific operations, for instance according to IEEE 802.11 (WLAN), NAN, BT, or LTE standard. Since these frames do not contain timing measurement symbols related to time measurement, it is not necessary to direct them to the symbol timing estimation module. These frames are processed in accordance with a standard orthogonal frequency division multiplexing (OFDM) or OFDMA processing techniques. For example, these frames may be directed to a module that removes the guard interval and makes a serial to parallel operation needed in a fast Fourier transform module.

If the receiving STA determines at step 803 that the frame does contain a trigger, the frame is directed to the timing estimation module at step 805 so that the measurement symbols can be analysed.

In embodiments using TOF ranging, the frames containing a trigger are diverted to the timing estimation module 163. The value of the TX timestamp for the or each measurement symbol in the frame together with the RX timestamp applied to the or each symbol is recorded and processed at the timing estimation module. The symbol timing estimation module may improve the time stamp preciseness with algorithms such as the Schmidl-Cox algorithm or any other suitable algorithm that is known in the art. The correction algorithm is used in order to mitigate various errors that are present in the timestamp value of the device clock.

Once the TOF measurement frame has been directed towards the symbol timing estimation module, the measurement symbols are analysed, at step 805. Each of the received symbols to be analysed is compared with a stored reference symbol to determine whether it is a measurement symbol. This can be done in any suitable manner such as through autocorrelation or cross-correlation. Each symbol has an associated TX timestamp and an RX timestamp. The timestamps of each symbol determined to be a measurement symbol are extracted from the frame and analysed.

In embodiments using the FTM mechanism, the timing estimation module 163 processes the TOA timestamps  $t_2$  or  $t_4$  as appropriate may improve the time stamp preciseness with

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an algorithm such as the Schmidl-Cox algorithm or any other suitable algorithm that is known in the art.

If the measured frame is an FTM Request and the frame is addressed to the responding STA 202, the responding STA 202 transmits an FTM Response and obtains the transmission time T<sub>3</sub> for the Response frame.

The process ends at step 806.

The foregoing embodiments are exemplary. Although the specification may refer to “an”, “one”, or “some” embodiment(s) in several locations, this does not necessarily mean that each such reference is to the same embodiment(s), or that the feature only applies to a single embodiment.

Single features of different embodiments may also be combined to provide other embodiments. Furthermore, words “comprising” and “including” should be understood as not limiting the described embodiments to consist of only those features that have been mentioned and such embodiments may contain also features/structures that have not been specifically mentioned.

In the foregoing, it will be understood that the described processors may be any suitable type of processing circuitry. For example, the processing circuitry may be a programmable processor that interprets computer program instructions and processes data. The processing circuitry may include plural programmable processors.

Alternatively, the processing circuitry may be, for example, programmable hardware with embedded firmware. The or each processing circuitry or processor may be termed processing means.

The term ‘memory’ when used in this specification is intended to relate primarily to memory comprising both non-volatile memory and volatile memory unless the context implies otherwise, although the term may also cover one or more volatile memories only, one or more non-volatile memories only, or one or more volatile memories and one or more non-volatile memories. Examples of volatile memory include RAM, DRAM, SDRAM etc. Examples of non-volatile memory include ROM, PROM, EEPROM, flash memory, optical storage, magnetic storage, etc.

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Reference to "computer-readable storage medium", "computer program product", "tangibly embodied computer program" etc, or a "processor" or "processing circuit" etc. should be understood to encompass not only computers having differing architectures such as single/multi processor architectures and sequencers/parallel architectures, but also specialised circuits such as field programmable gate arrays FPGA, application specify circuits ASIC, signal processing devices and other devices. References to computer program, instructions, code etc. should be understood to express software for a programmable processor firmware such as the programmable content of a hardware device as instructions for a processor or configured or configuration settings for a fixed function device, gate array, programmable logic device, etc.

It should be realised that the foregoing embodiments are not to be construed as limiting and that other variations and modifications will be evident to those skilled in the art. Moreover, the disclosure of the present application should be understood to include any novel features or any novel combination of features either explicitly or implicitly disclosed herein or in any generalisation thereof and during prosecution of the present application or of any application derived therefrom, new claims may be formulated to cover any such features and/or combination of such features.

Embodiments of the present invention may be implemented in software, hardware, application logic or a combination of software, hardware and application logic. The software, application logic and/or hardware may reside on memory, or any computer media. In an example embodiment, the application logic, software or an instruction set is maintained on any one of various conventional computer-readable media. In the context of this document, a "computer-readable medium" may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer.

A computer-readable medium may comprise a computer-readable storage medium that may be any tangible media or means that can contain or store the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer as defined previously.

According to various embodiments of the previous aspect of the present invention, the computer program according to any of the above aspects, may be implemented in a computer program product comprising a tangible computer-readable medium bearing

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computer program code embodied therein which can be used with the processor for the implementation of the functions described above.

5 If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined.

10 Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

**Claims**

1. A method comprising:  
detecting, at a first wireless device, a measurement frame transmitted by a second  
5 wireless device;  
detecting, at the first wireless device, that a condition has been satisfied to cause  
the first wireless device to enter a timing estimation mode in order to perform a timing  
estimation operation on the measurement frame;  
in response thereto, switching the wireless device to the timing estimation mode;  
10 processing the received measurement frame using a timing estimation operation;  
and  
causing the processed measurement frame to be used to determine a distance  
between the first device and the second device.
- 15 2. The method of claim 1, wherein detecting that a condition has been satisfied  
comprises identifying a trigger within a detected frame indicating that the first wireless  
device is to enter the timing estimation mode.
3. The method of claim 2, wherein the trigger within the received frame indicating  
20 that the first wireless device is to enter the timing estimation mode is located in the header  
of the received frame.
4. The method of claim 2, wherein the content within the received frame indicating  
that the first wireless device is to enter the timing estimation mode is a trigger located in  
25 the payload of the received frame indicating that at least part of the received frame  
contains measurement symbols.
5. The method of claim 2, wherein identifying content within a received frame  
indicating that the first wireless device is to enter the timing estimation mode comprises  
30 searching at a predetermined location within the payload of the received frame for a  
measurement symbol.
6. The method of claim 1, wherein detecting that the condition has been satisfied  
comprises determining that a predetermined time period for entering the first device into  
35 the timing estimation mode has elapsed.

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7. The method of claim 6, wherein the predetermined time period for entering the first device into the device ranging mode is determined by the first device.

8. The method of any preceding claim, further comprising selecting between a time-of-flight measurement mode and a fine timing measurement mode based on information contained in the frame header.

9. The method of any preceding claim, further comprising using one or more rules to determine whether to enter the timing estimation mode.

10. The method of claim 9, wherein the one or more rules are based on one or more respectively of the frame address, device type, service information and trigger information to determine whether to enter the timing estimation mode.

11. The method of any preceding claim, further comprising causing ranging information from a plurality of second devices to be used to estimate a position of the first device.

12. The method of any preceding claim, wherein the first and second devices are part of a WLAN network.

13. An apparatus configured to:  
detect a measurement frame transmitted by a second wireless device;  
detect that a condition has been satisfied to cause the apparatus to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame;  
in response thereto, switch the wireless device to the timing estimation mode;  
process the received measurement frame using a timing estimation operation; and  
cause the processed measurement frame to be used to determine a distance between the first device and the second device.

14. The apparatus of claim 13, wherein being configured to detect that a condition has been satisfied comprises being configured to identify a trigger within a detected frame indicating that the first wireless device is to enter the timing estimation mode.

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15. The apparatus of claim 14, wherein the trigger within the received frame indicating that the first wireless device is to enter the timing estimation mode is located in the header of the received frame.

5 16. The apparatus of claim 14, wherein the content within the received frame indicating that the first wireless device is to enter the timing estimation mode is a trigger located in the payload of the received frame indicating that at least part of the received frame contains measurement symbols.

10 17. The apparatus of claim 14, wherein identifying content within a received frame indicating that the first wireless device is to enter the timing estimation mode comprises searching at a predetermined location within the payload of the received frame for a measurement symbol.

15 18. The apparatus of claim 13, wherein detecting that the condition has been satisfied comprises determining that a predetermined time period for entering the first device into the timing estimation mode has elapsed.

19. The apparatus of claim 18, wherein the predetermined time period for entering the  
20 first device into the device ranging mode is determined by the first device.

20. The apparatus of any preceding claim, further configured to select between a time-of-flight measurement mode and a fine timing measurement mode based on information contained in the frame header.

25

21. The apparatus of any preceding claim, further configured to use one or more rules to determine whether to enter the timing estimation mode.

22. The apparatus of claim 21, wherein the one or more rules are based on one or more  
30 respectively of the frame address, device type, service information and trigger information to determine whether to enter the timing estimation mode.

23. The apparatus of any preceding claim, further configured to cause ranging  
35 information from a plurality of second devices to be used to estimate a position of the first device.

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24. The apparatus of any preceding claim, wherein the first and second devices are part of a WLAN network.

25. A computer program comprising computer readable instructions which,  
5 when executed by a computer, cause said computer to perform a method according to any preceding claim.

26. An apparatus, comprising:  
a controller; and

10 a memory in which is stored computer readable instructions that, when executed by the controller, cause the controller to:

detect a measurement frame transmitted by a second wireless device;

detect that a condition has been satisfied to cause a first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the  
15 measurement frame;

in response thereto, switch the first wireless device to the timing estimation mode;

process the received measurement frame using a timing estimation operation; and

20 cause the processed measurement frame to be used to determine a distance between the first device and the second device.

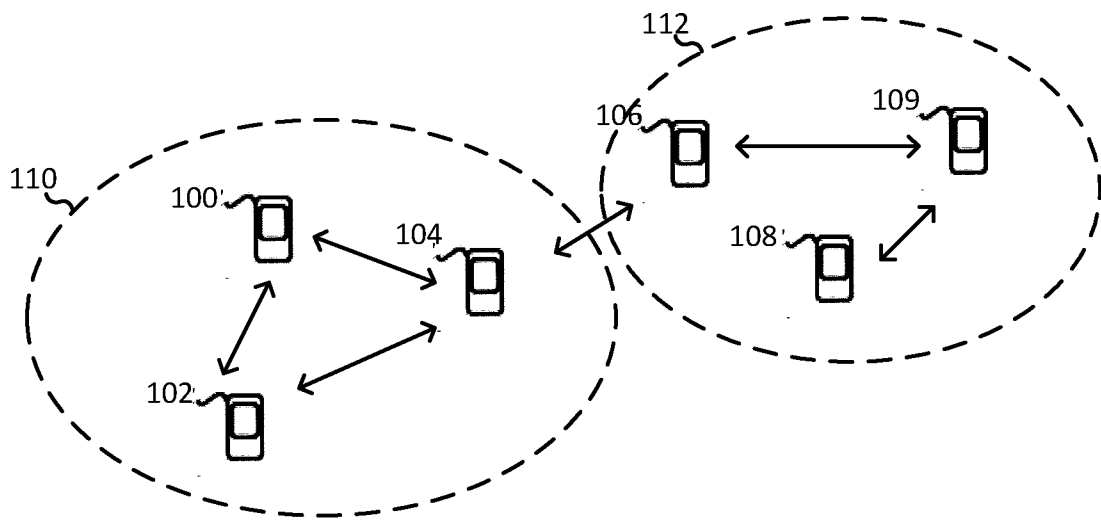
27. A non-transitory tangible computer program product in which is stored computer readable instructions that, when executed by a computer, cause the  
25 computer to:

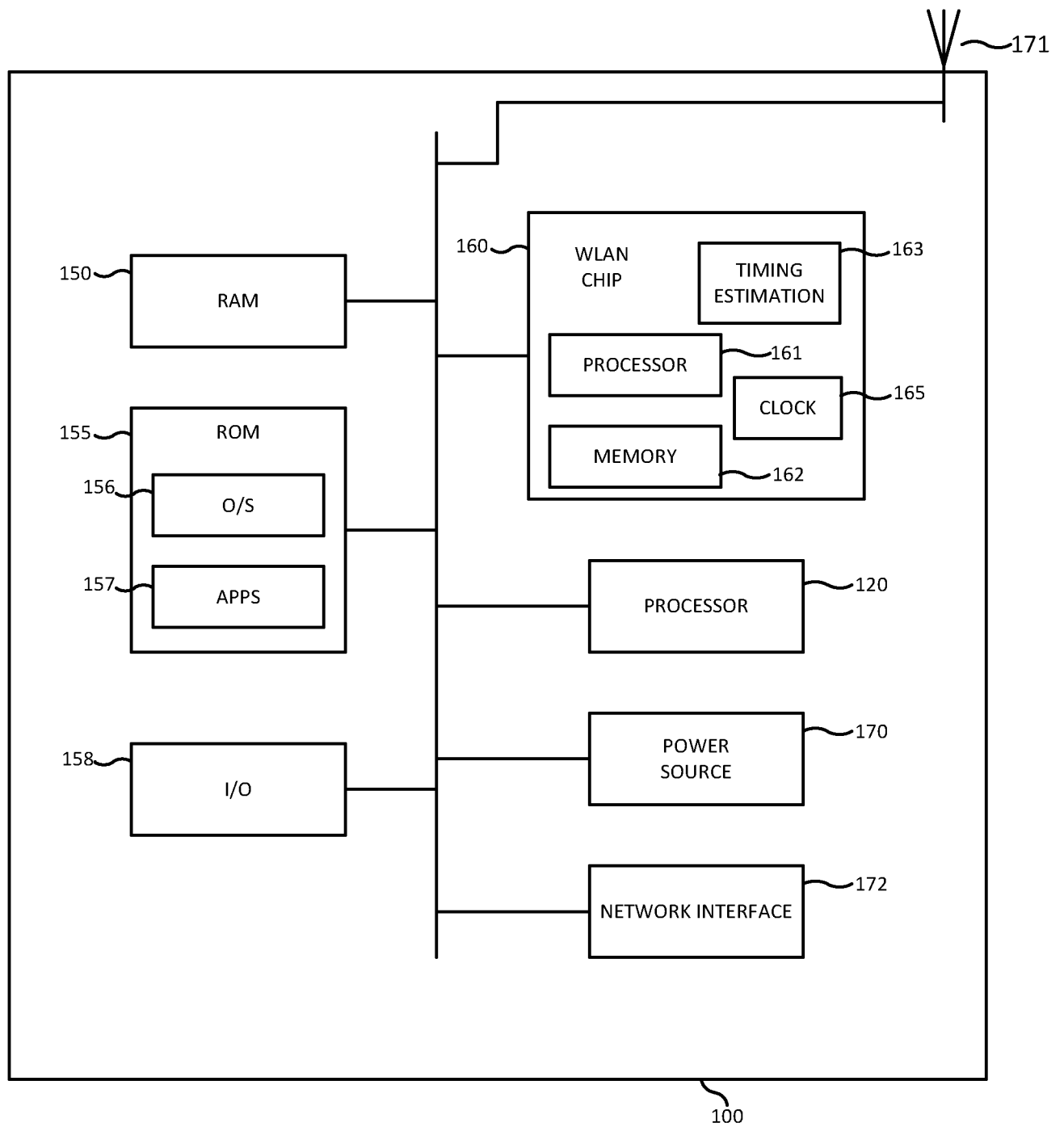
detect a measurement frame transmitted by a second wireless device;

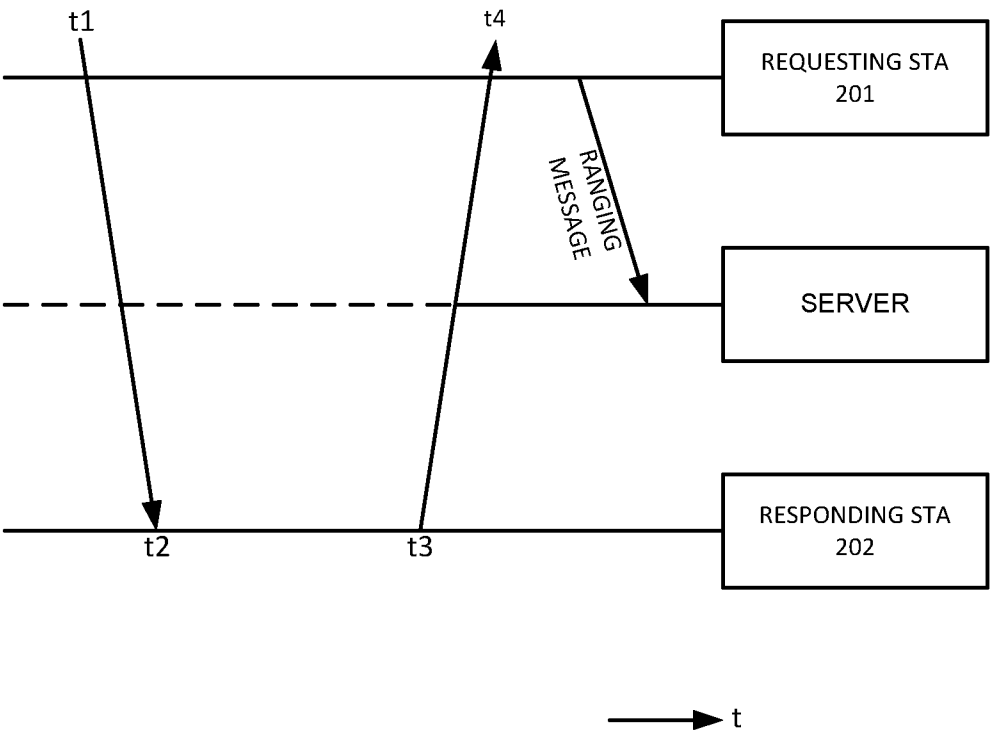
detect that a condition has been satisfied to cause a first wireless device to enter a timing estimation mode in order to perform a timing estimation operation on the measurement frame;

30 in response thereto, switch the first wireless device to the timing estimation mode; process the received measurement frame using a timing estimation operation; and cause the processed measurement frame to be used to determine a distance between the first device and the second device.

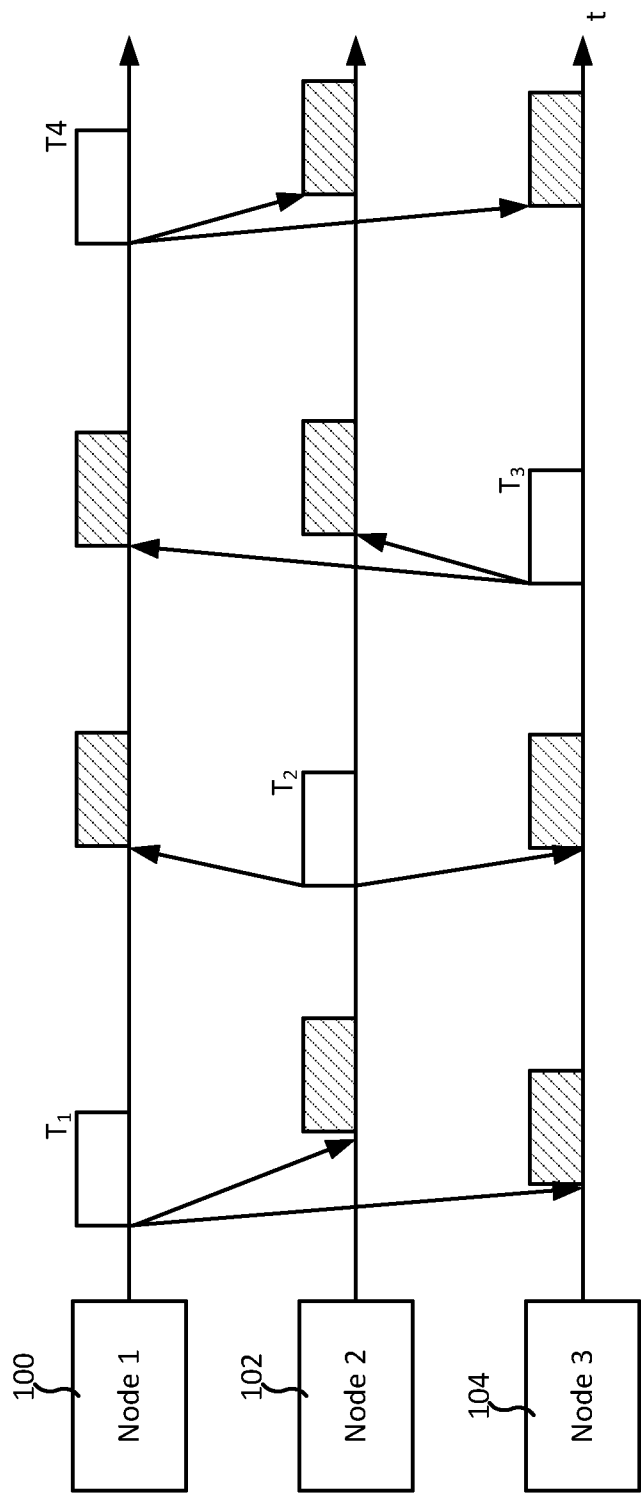
1/9

**FIG. 1**

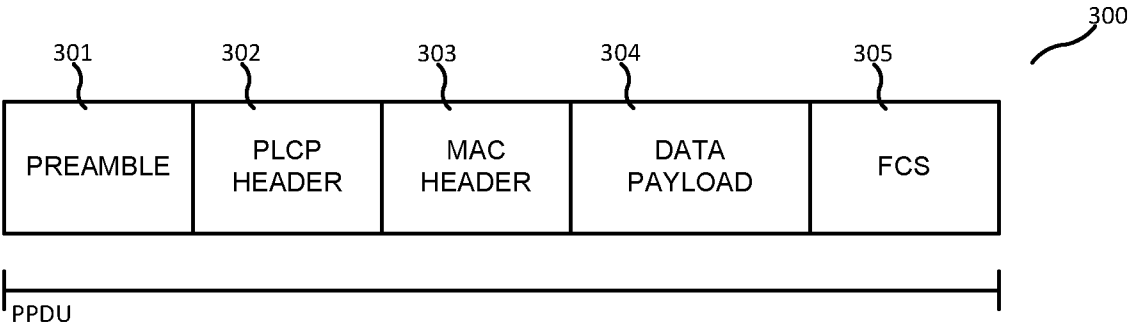
**FIG. 2**



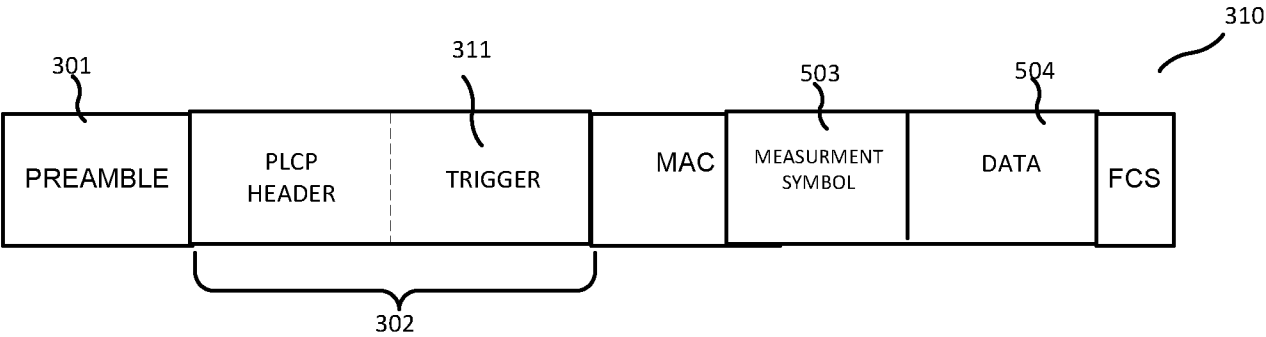
**FIG. 3**



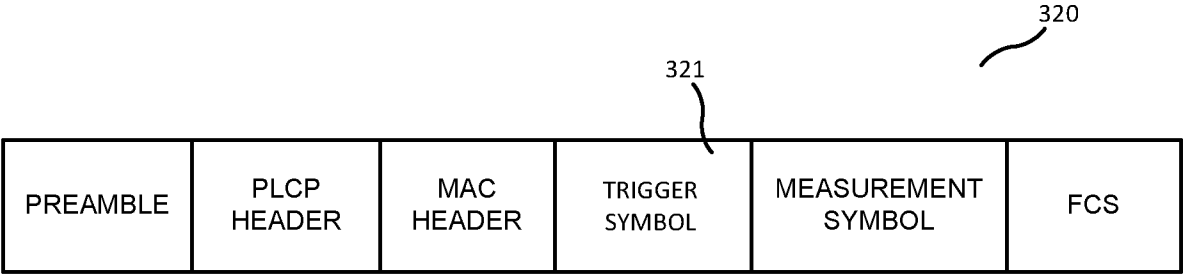
**FIG. 4**



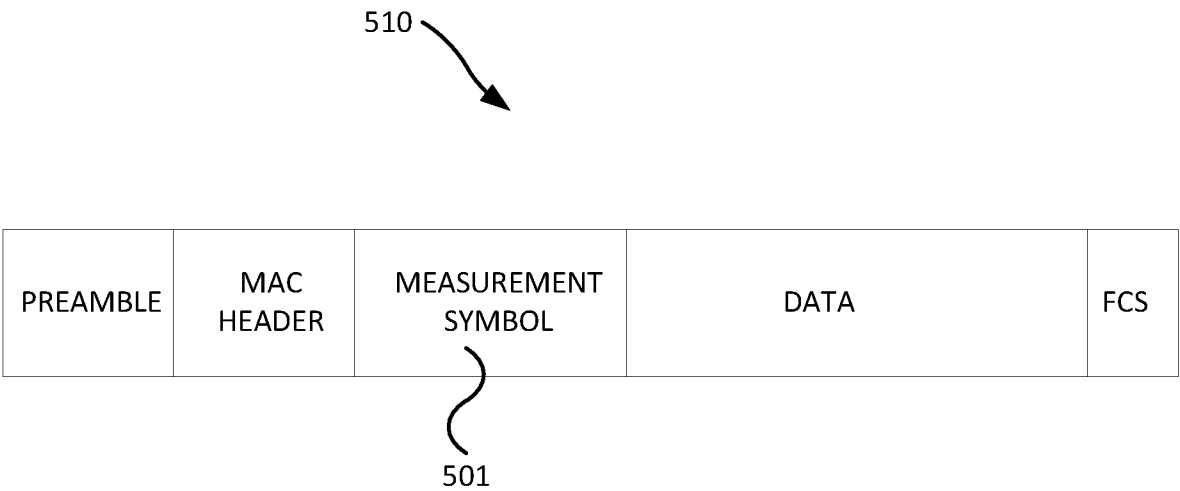
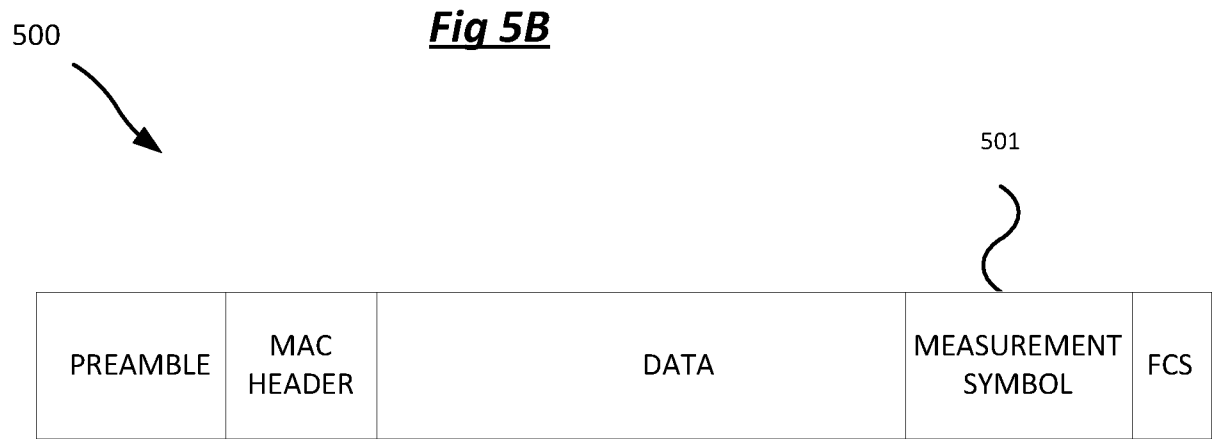
**FIG. 5A**



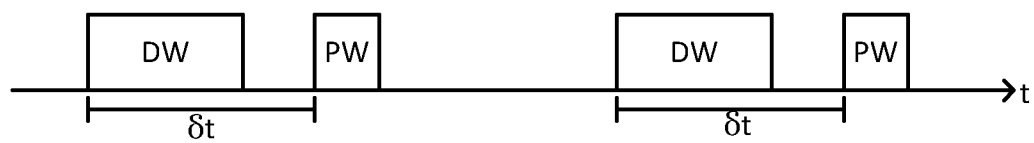
**FIG. 5D**



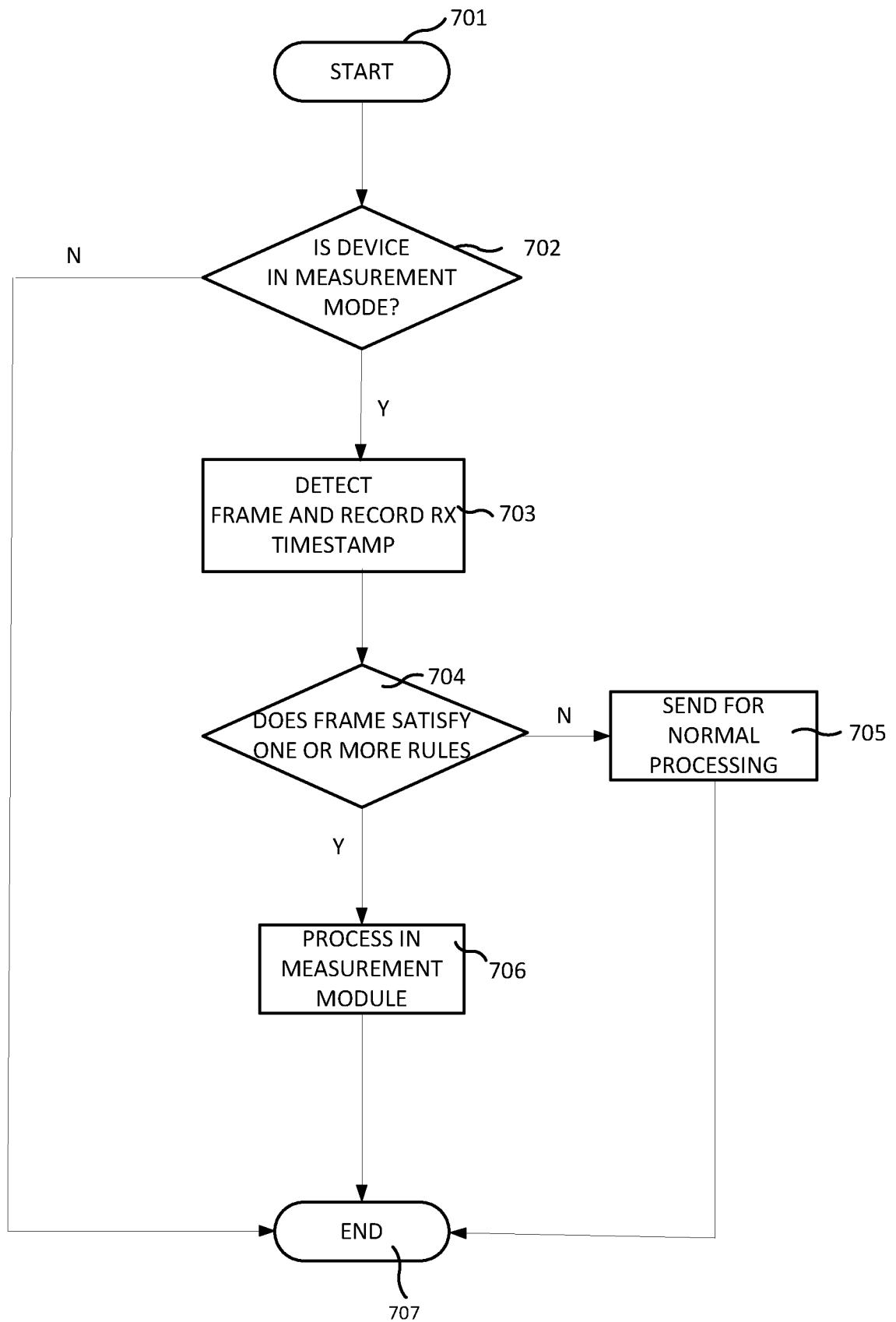
**FIG. 5E**



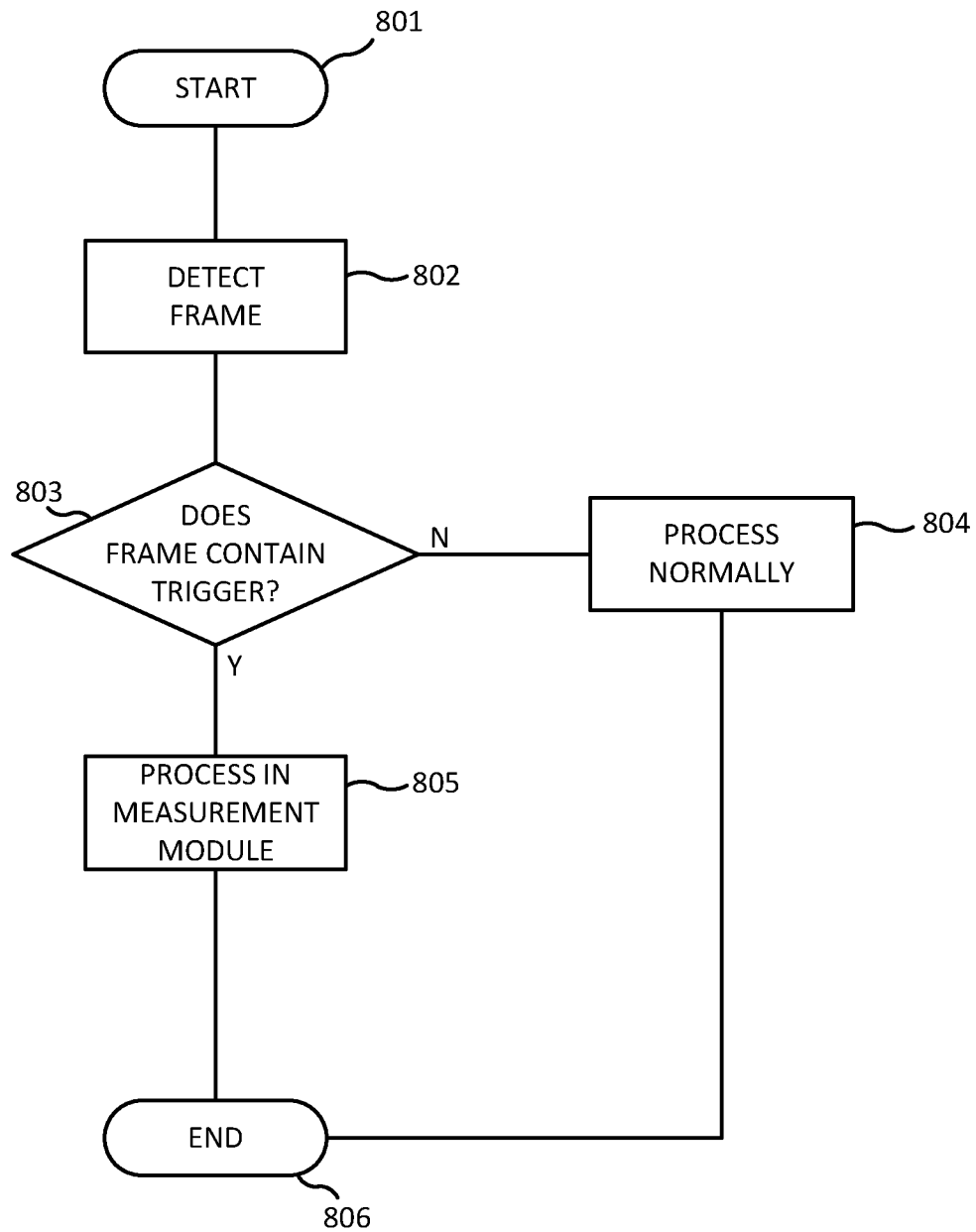
**Fig 5C**

**FIG. 6**

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**FIG. 7**

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**FIG. 8**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2015/050267

**A. CLASSIFICATION OF SUBJECT MATTER**

See extra sheet

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: G01S, H04L, H04W

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

FI, SE, NO, DK

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

EPO-Internal &amp; translations from Thomson Reuters and IPPH/SIPO, WPIAP, XP3GPP, XPAIP, XPESP, XPETSI, XPI3E, XPIEE, XPIETF, XPIOP, XPMISC, XPRD, INSPEC, TDB, NPL

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                  | Relevant to claim No.                            |
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☒ Further documents are listed in the continuation of Box C.
☒ See patent family annex.

|                                                                                                                                                                         |                                                                                                                                                                                                                                                  |
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Date of the actual completion of the international search

29 September 2015 (29.09.2015)

Date of mailing of the international search report

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## INTERNATIONAL SEARCH REPORT

International application No.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

International application No.

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CLASSIFICATION OF SUBJECT MATTER

IPC

**G01S 11/02** (2010.01)

**H04W 64/00** (2009.01)

**G01S 5/14** (2006.01)

**G01S 13/74** (2006.01)

**H04W 84/02** (2009.01)

**INTERNATIONAL SEARCH REPORT**  
**Information on Patent Family Members**

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