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**(54) Title**: DEVICE AND METHOD FOR CALCULATING TIME OF ARRIVAL OF A FRAME IN A WIRELESS NETWORK

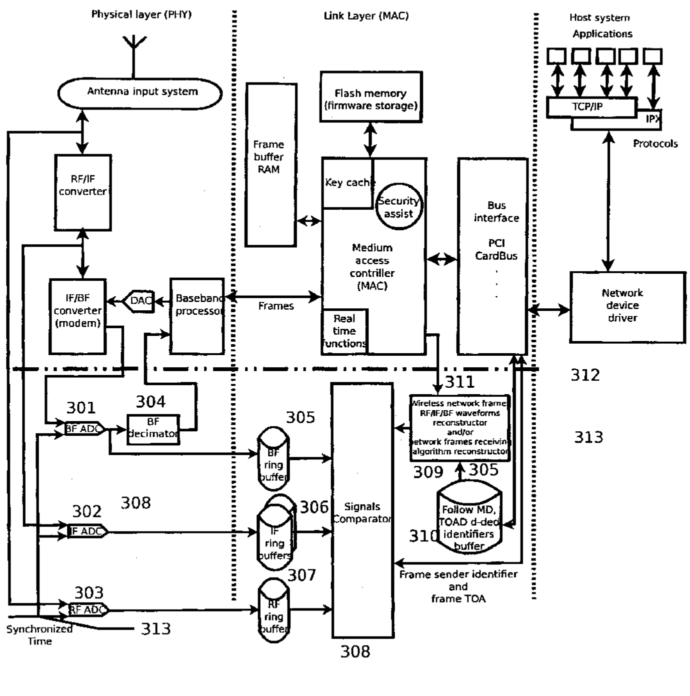


FIG. 5

**(57) Abstract**: For completely received and decoded network frames, a method for locating the start of a received signal, including storing an original waveform stream in a time-indexed buffer, reconstructing an ideal waveform based on the received packet, selecting and/or analyzing an optimal part of the reconstructed waveform, for use of the selected part in comparison with the previously stored original waveform, comparing the received (stored) and original (ideal) waveform or waveform representation, and optionally analyzing the results for use in TOA and/or TOAD calculation, signal quality analysis, AP time synchronization.

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# DEVICE AND METHOD FOR CALCULATING TIME OF ARRIVAL OF A FRAME IN A WIRELESS NETWORK

## CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional patent application no. 61/239,084 filed September 2, 2009.

## FIELD OF THE INVENTION

The present invention relates to finding the start of a transmitted waveform in a wireless network, in general and, more particularly to methods, devices and a system for determining Time of Arrival (TOA) or Time of Arrival Differences (TOAD) of waveforms in a wireless signal stream.

## BACKGROUND OF THE INVENTION

Wireless networks are very popular and play an increasing role in network technology. As a non-limiting example, wireless network technologies may be implemented by the IEEE 802.11, 802.15 - 802.22 standards families. Usually spread spectrum is used for network communications. The noise-shaped waveforms make it impossible to determine "a priori" an arrival of not predefined signal. This gives rise to two important consequences: The TOA (time of arrival) for a not predefined signal cannot be determined in a straight-forward way; The waveform of a not predefined signal cannot be recognized in a straight-forward way.

The knowledge of a received waveform of a signal by itself and/or in comparison with an abstract or ideal waveform of that signal can be used to solve a lot of problems and to supply additional services. A non-limited group of examples includes:

1. Knowledge of the TOA or/and TOAD of signals provides the network with: position location capabilities: both network clients and network infrastructure objects, such as Access Points, can be located.

2. The capability to analyze and improve time synchronization of network components.

3. Comparison of an abstract/ideal waveform of a signal with the signal that is actually received provides excellent information for network functionality improvements.

The determination of the location position of a wireless device has become very important for many reasons, including, for example:

1. Legal. The E911 demands for providing source location coordinates of a caller are obligatory for systems using a network for voice and/or video communications.
2. Location Based Services (LBS). These include: asset assistance, health assistance, Location Based Advertisement (LBA), etc.
3. Mobility Communication Optimization. The mobile device (MD) location, velocity and acceleration information can be used for mobile communications optimization with final purpose to provide seamless reconnection.

Usually the position of an object in space is determined using distance or angle measurements from known points to the object to be located. If some signal propagates with a known velocity, the distance measurements can be replaced by the propagation time measurements. To do this, one must identify as an event an arrival of a signal used for propagation time measurements and measure the TOA or/and TOAD of the signal used for propagation time measurements. TOA measurements can be performed by triangulation-type algorithms to determine location position.

In location systems, great attention is paid to the multipath problem. The radio beam from a Mobile Device (MD) can arrive at an Access Point (AP) by several paths, due to refraction or can propagate not in a straight line. This can result in "several distances". About 20-30 years ago, one of the inventors of the present invention developed and published an algorithm of source location in a nonhomogeneous medium with multipath and not straight beam propagation. For this reason, the multipath problem is not considered to be critical for source location and is not relevant to the present invention.

Two ways to determine location on a base of signal propagation time measurements are known in the art: Systems based on a measurement of TOA; and Systems based on a measurement of Time of Arrival Differences (TOAD).

It is important to understand that systems based on time measurements are very sensitive to the accuracy of time synchronization. This accuracy must be within nanoseconds. The modern art of time synchronization can provide such accuracy. For large outdoor areas, modern, relatively inexpensive GPS systems with an accuracy of 15 nsec are suitable.

Systems are known in the art which use predefined signals or the known sending time of a particular symbol. A great number of network communication systems are based on standards which exclude such an approach.

Systems are also known in the art which use continuous correlation analyses of input radio signals in order to determine the event of arrival of the same signal from the same source to several receiving points and calculating TOAD. Such an approach assumes that received and stored radio signals are sent to some facility which provides correlation and TOAD calculations. This very resource demanding approach, works well in Nanosecond Pulse Location and in laboratory experiments with a limited number of APs, but is not applicable in large wireless systems.

Signal analysis is very important to ensure reliable network operations. In most modern wireless systems, the on-line time signal analyses are limited by signal strength measurements and noise estimations. This is not enough for good network functionality control. Accordingly, one can get a great advantage from the capability to determinate the waveform of an actually received signal and an opportunity to compare it with an abstract/ideal waveform of the signal with the same information content and generated according to the same standard.

## SUMMARY OF THE INVENTION

The present invention relates to methods, devices and a system for determining TOA or TOAD of received network frames by comparing a selected portion of the transmitted frame with the received signals, using this to determine the TOA or TOAD and to determine the quality of the signal transmitted and/or for the location of a mobile device in the network. According to the invention, it is possible to select an optimal portion of the waveform (which, in some cases, can be the whole frame) on which to perform the comparison between the reconstruction and the actual received frame. For example, one criterion for an optimal frame can be the frame having the highest Signal to Noise Ratio, calculated for this frame or portion of frame. This optimal portion can be one or more waveform parts having characteristics that are easy to recognize, depending on the selected method of comparison, and having known time shifts from the start of the frame. These time shifts can be used for calculating TOA.

Thus, the invention provides, for completely received and decoded network frames, a method for locating the start of a received signal, including storing an original waveform stream or/and waveform representation in a time-indexed buffer, reconstructing an ideal waveform based on the received packet, analyzing and/or selecting an "optimal" segment or part of the reconstructed waveform/waveform representation, for use of the selected part or segment in comparison with the previously stored original waveform/waveform representation, (optionally) analyzing and/or choosing an optimal method of comparison or set of methods for comparing the waveform representation with the original waveform, comparing the received (stored) and original (ideal) waveform/waveform representation, and (optionally) analyzing the results from the previous step for use in TOA and/or TOAD calculation (location application), signal quality analysis, determining of changes occurring in the network, causes and wireless interfaces maintenance operation (e.g., signal quality control, improving of SNR, load balancing, etc...).

According to other embodiments of the invention, there is provided, for completely received and decoded network frames:

1. Actual received signals buffering.
2. On the basis of the informational contents of an actual received frame:
   a. Selecting of a Ideal/Abstract frame waveform or/and waveform representation type;
   b. Choosing an appropriate method of search for an actually received waveform.
   c. Reconstruction of the selected type of the Ideal/Abstract frame waveforms or a part of the waveform or/and their representations or/and Simplified Reconstruction of the frame waveform or part thereof;
3. Using the method selected in step 2.b, searching for the actually received frame waveform in the signals buffered during step 1 and utilizing at least one reconstruction from step 2.c.
4. Analyzing the results of the previous steps, including determination of TOA of an actually received frame waveform.
5. Providing results of step 4 to information receivers including, but not limited by:
   a. TOA – to client position location servers;
   b. TOA, waveforms - to client position location servers which will first determine TOAD and after that will determine client position location based on TOAD;
   c. TOA, waveforms of frames sent by APs – to servers responsible for APs time synchronization improvement;
6. Mutual analyses of Ideal/Abstract and actually received data for solving a wide range of tasks of improving functionality of all members of wireless network and network infrastructure.

An advantage of this invention is that a wide range of applications can be implemented, based on this patent.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the presented invention will become apparent from the detailed description of the invention which follows, in light of the accompanying drawings in which:

**FIG. 1** is general system diagram of a wireless network system capable of reconstructing abstract/ideal waveforms of completely received and decoded network frames, search in input signal streams of a network device for the actually received waveforms of network frames, determining TOA of the waveforms of the identified network frames, using found actually received network frames waveforms and/or their abstract/ideal waveforms and/or the capability of determining client position location of wireless devices, according to embodiments of the present invention.

**FIG. 2** is block diagram of a circuit responsible for reconstructing abstract/ideal waveforms of completely received and decoded network frames, searching in input signal streams of a network device for the actually received waveforms of network frames, determining TOA of the waveforms of the network frames, according to the embodiments of the present invention.

**FIG. 3** is a logical operating diagram of a circuit shown on **FIG.2**.

**FIG. 4** is a general structure of an 802.11 interface according to the prior art.

**FIG. 5** is a general structure of an 802.11 interface modified according to the invention to be capable of reconstructing abstract/ideal waveforms of completely received and decoded network frames, searching in input signal streams of a network device the actually received waveforms of network frames, determining TOA of the waveforms of the network frames, according to the embodiments of the present invention.

**FIG. 6** is a UML sequence-type operating diagram of a wireless network capable to use data supplied by device implementing embodiments of the invention.

**FIG. 7** is a logical operating diagram of a wireless network, according to embodiments of the invention.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method for locating the start of a received signal, including storing an original waveform stream or/and waveform representation in a time-indexed buffer, reconstructing an ideal waveform based on the received packet, analyzing and/or selecting an "optimal" segment or part of the reconstructed waveform/waveform representation, for use of the selected part or segment in comparison with the previously stored original waveform/waveform representation, and comparing the received (stored) and original (ideal) waveform/waveform representation. The method may include analyzing and/or choosing an optimal method of comparison or set of methods for comparing the waveform representation with the original waveform. The method may further include analyzing the results of the comparison for use in TOA and/or TOAD calculation (location application), signal quality analysis, determining of changes occurring in the network, causes and wireless interfaces maintenance operation (e.g., signal quality control, improving of SNR, load balancing, etc...).

In particular, the invention relates to methods, devices and a system for partial or/and complete reconstructing of abstract/ideal waveforms and/or waveform representations (Continuous or/and Discrete Transform, Wavelet Transform, etc) in Base Band Frequency (BF) or/and Intermediate Frequency (IF) or/and Radio Frequency (RF) for completely received and decoded network frames in a wireless communication network, and for searching in the input RF and/or IF and/or BF signal streams of a wireless network device for actual received waveforms or/and waveform parts or/and waveform representations or/and representations of waveform parts which correspond to those reconstructed waveforms or waveform representations. These may be used for determining Time of Arrival (TOA) of the waveforms of a network frame, for determining Time of Arrival Differences (TOAD) of the waveforms of a network frame at different points of reception, mutual analyses of abstract/ideal waveforms and actually received waveforms or/and their representations. A wireless network system according to the invention is capable of using this data, among other things, for determining client position location and/or for Access Point time synchronization improvement, as well as for quality of signal analyses, analysis and improvement of functionality of network Access Points (AP); analysis and improvement of functionality of network clients; analysis and improvement of time synchronization of network components; analysis and improvement of functionality of the network system; analysis and improvement of functionality of a network system infrastructure.

It will be appreciated that different terms are used in different types of wireless networks - frame, package, packet, etc. For purposes of the present invention, all are included in the term "frame", which is used to designate a transmission unit which may require some network translation. These terms are close to terms used in the IEEE 802.11 family.

While the invention is operative for many of the wireless standards, the 802.11 family will be used for exemplary embodiments, which do not limit the generality of the invention or its usability under other wireless standards.

It will be appreciated that different terms are used in different types of wireless networks to identify the network members. In most cases, a MAC address is used.The term "MD identifier" is used for purposes of the present invention. This is done to eliminate excessive dependence on a particular standard. The latter makes it possible to use the abbreviation MAC, as it is used in 802.11 and other standards families as standing for "Media Access Control" layer.

As mentioned above, it is deemed to be impossible, *a priori*, to determine the arrival of a network frame waveform. However, reliable operation of wireless networks is determined by extracting of information by complex signal processing, so this apparent paradox has a technical solution.

In its most general form, the proposed method can be described as follows:

1. A network operates according to a certain protocol (802.11 or whatever group of standards).
2. Some network member transmit a frame which is received by other network members (sometimes referred to herein as clients or APs . A good, non-limiting example from the 802.11 standard group is a "Probe Request" frame, which is broadcast by WiFi clients to all visible APs. This frame hosts client identification information, can be accepted by all visible APs of all networks deployed in this location, and the AP is not obligated to answer it.
3. The frame is received and decoded by some plurality of network members.
4. The accomplished fact of receiving and decoding the network frames and the network frame information content are used to determine any or all of the following:
   network frame abstract/ideal waveform; part of an abstract/ideal waveform of the network frame; the representation of an abstract/ideal waveform of the network frame; the representation of a part of an abstract/ideal waveform of the network frame; the actually received network frame waveform on any or all frequencies (RF,IF,BF); part of the actually received waveform of the network frame; a representation of the actually received waveform of the network frame; a representation of a part of the actually received waveform of the network frame.

Thus, once the system has reconstructed abstract/ideal waveforms or/and their representations of completely received and decoded network frames, and searched in input signal streams of a network device for the actual received waveforms of network frames or/and there representations, any or all of the following can be performed:

- determination of time features of the frame, including the TOA or/and TOAD and duration of the actual received network frame waveform ;
- analysis and improvement of functionality of network Access Points (AP);
- analysis and improvement of functionality of network clients;
- analysis and improvement of time synchronization of network components;
- analysis and improvement of functionality of the network system;
- analysis and improvement of functionality of the network system infrastructure;
- to fulfill any additional tasks defined for the system, including, but not limited to:
  - network clients position location;
  - AP and other network elements time synchronization improvements.

According to embodiments of the invention, this can be carried out as follows, for completely received and decoded network frames:

i) The actual received signals are buffered.

ii) On the basis of the informational contents of an actual received frame:

   (a) Selecting of a Ideal/Abstract frame waveform or/and waveform representation type;

   (b) Choosing an appropriate method of search for an actually received waveform.

   (c) Reconstruction of the selected type of the Ideal/Abstract frame waveforms or/and their representations or/and Simplified Reconstruction of the waveforms;

iii) Using the method selected in step ii.b, searching for the actually received frame waveform in the signals buffered during step i and utilizing at least one reconstruction from step ii.c.

iv) Analyzing the results of the previous steps, including determination of TOA of an actually received frame waveform.

v) Providing results of step 4 to information receivers including, but not limited by:

(a) TOA – to client position location servers;

(b) TOA, waveforms - to client position location servers which will first determine TOAD and after that will determine client position location based on TOAD;

(c) TOA, waveforms of frames sent by APs – to servers responsible for APs time synchronization improvement;

vi) Mutual analyses of Ideal/Abstract and actually received data for solving a wide range of tasks of improving functionality of all members of the wireless network and network infrastructure.

This usage of parts of waveforms and waveforms representations deserves an additional explanation.

**Usage of parts of waveforms.**

It will be appreciated that the present invention incorporates, where possible, conventional “known signal pattern” methods. As mentioned above in the method description, we examine a case when a network system and all its components work according to some not modified standard. With this limitation, the usage of “known signal pattern” methods will be limited mainly by some synchronization fields of the frames. For example, for the 802.11 group of standards, it will probably be a part of the preamble of PLCP and a part of some MAC frames. In the latter case, several “signal patterns” are needed. For this group, “reconstruction of a part of an ideal/abstract waveform” is just an extraction the signal pattern from a constant memory.

Much more interesting is the situation with a real reconstruction of parts of a waveform:

1. The usage of a part of a wave frame can decrease the demands to the method implementation equipment.
2. The part can be selected in a way which makes the search in a stored input signals buffers much easier.
3. The frame identification (discussed in detail below) must be updated by the time difference from the selected part of the waveform (network frame) to the real beginning of the frame. This is not hard.
4. Mutual usage of several different, possibly intersecting parts, can improve TOA accuracy and accuracy of estimation of TOA.
5. Known time shifts between different parts of the network frame can be utilized to improve TOA detection accuracy.
6. It is incorrect that reconstruction of a part of a waveform can be accomplished only by cutting part from a completely reconstructed waveform. However, particular methods of reconstruction are out of the scope of this patent.

It is a particular feature of the present invention that utilization of a portion of the waveform for reconstruction and/or searching saves physical and time resources for the network.

**Usage of representations of waveforms.**

The simplest example of waveform representation is a Continuous or Discrete Transform, for which the correspondence between waveform and representation has been proved, although, generally speaking, the correspondence is not obligatory. Fourier Transform is a common example, i.e., the spectrum is the waveform representation. However, it will be appreciated that, in practice, for signals with limited frequency ranges, the differences in frequencies which are far from the main frequency range are ignored.

Particular waveforms transforms are out of scope of this patent, but transforms such as Wavelet Transform, Fractal and Multifractal methods are very useful during frame reconstruction, search and comparison These tools are very computation thrifty, and work excellently with short and not stationary signals. The latter makes them especially interesting for working with segments of a frame waveform.

It will be appreciated, that these new methods work better than well known in the art correlation methods.

Without loss of generality, as a non-limiting example of the proposed method, the following embodiment can be implemented:

1. Input RF signals and/or signals down-banded to IF and/or BF of a network device are buffered. Signal samples are stored with timestamps.
2. The arrived network frame signal is recognized and decoded by appropriate network standard signal processing algorithms, sometimes very comprehensive. (The group of 802.11 standards can be taken as a non- limiting example.)
3. The informational contents and knowledge of the applicable network standard are used to reconstruct an abstract/ideal network frame waveform on IF and/or RF and/or BF frequencies, a representation of the waveform, or preferably part of the waveform, or a representation of a part of the waveform.
4. The actual received waveform of the received and completely decoded network frame is found in RF and/or IF and/or BF data previously stored in a buffer. The search for the received frame waveform is implemented using:
    - a data processing algorithm from the network standard, which may be simplified or/and modified based on knowledge of the already received and decoded network frame;
    - a signal pattern search based on data reconstructed during step 3, above;

- a signal representation search, based on representations calculated during step 3, above;
- any combination of the previous items.

It will be appreciated that any pattern recognition method can be implemented, not only correlation.

The TOA of the waveform of the completely received and decoded network frame is now determined using the time stamps and, if necessary, the known time from the start of the frame to the reconstructed part of the waveform or part of the representation of the waveform of the frame is determined. It will be appreciated that the use of representations, e.g., spectrum, for signal searching is known in the art, and any conventional method can be employed.In the following examples and embodiments, we will use minimal waveform representations based methods. Different portions of the waveform can be treated differently, in terms of the method of reconstruction or representation, in terms of method of comparison and in terms of treatment of resulting data. The waveform can be stored in the best form for the particularly treatment.

As a nonrestrictive example, the system according to the invention includes: a plurality of mobile devices (MD);

- devices capable of implementing the proposed method (for the location calculation application, at least three devices, preferably more);
- an optional server or servers for position location or/and utilizing knowledge of found waveforms and/or their representations and/or TOA and/or TOAD.

The devices capable of implementing this method may be independent devices or may update conventional APs that lack the capability to implement this method. For position location purposes, the devices capable of implementing this method of calculating TOA must be synchronized in time and have known antenna coordinates.

It is a particular feature of the invention that, contrary to conventional methods which rely on an event oriented approach (i.e.: "... the location event is initialized by the Client by sending a frame; the AP answers ..."), the present invention utilizes monitoring and can search for the arrival of any received frame, even from a device that is not part of the network. Thus, the AP operates normally, receives network frames, decodes them and provides the data to all the required layers of network protocols.

The determination of TOA of a frame waveform is made by implementing the method described above.

According to existing protocols, each frame includes an identifier of the device which sent it.

The use of reconstructed waveforms and/or the representations of already received and completely decoded network frames means that the system need not store any predefined signals. After the frame is received and decoded, the algorithm implemented in the wireless interface for receiving and decoding of network frames can be represented by a simplified sequence of known steps. This simplified sequence of steps can be modified to use timestamps stored with the received signals (which are not required for the standard algorithm) and to adopt higher/other sampling rate of the data and can be easily implemented using the data with time stamps stored in the buffer. In the present invention, this is called "the reconstruction of the receiving network frames algorithm".

A location server communicates with the wireless network and receives the calculated TOAs of a frame from several devices or APs. It then implements a location algorithm, which calculates the MD coordinates. Alternatively, the location algorithm can be implemented on the mobile device, if it is a client of the network. From the network and functional point of view, the mobile device client does not differ from a dedicated location server. The MD with the location algorithm can detect its own location.

When all the TOA calculating devices are perfectly synchronized in time, the TOAs of received frames which are stored in buffers can be sent to the server for determining the TOADs, rather than TOA. Sometimes the usage of a TOAD for location calculations can reach better accuracy than the calculations on the basis of TOA. The estimation of a TOAD by comparing waveform samples from a pair of transmitters can also provide better accuracy in some cases.

At the same time, a waveform sample or its representation can be sent to the server from a set of devices and/or APs. Those samples can be used by the server.

According to an alternative embodiment of the invention, the system operates as follows:

1. Input RF signals and/or signals down-banded to IF and/or BF of a network device are buffered. Signal samples are stored with timestamps.
2. An arrived network frame signal is recognized and decoded by appropriate network standard signal processing algorithms.
3. The informational contents and knowledge of the applicable network standard are used to determine the time interval which hosts the actually received waveform of a frame in the IF and/or RF and/or BF buffers. The simplified algorithm is used to search for the waveform in a buffer.
4. Data for this time interval are moved from input IF and/or RF and/or BF buffers to some intermediate storage.
5. The system checks whether the number of devices which received the particular frame is enough to solve the task defined for the system. For example, the number of APs which received a frame must be at least 3, for the MD position location task.
6. If the system check succeeds, the time interval data stored in intermediate storage for the waveform fragment or/and its representations are sent to the servers, which implement the task defined for the system. For example, TOAD and position location calculations.

The base method described above can be modified and adapted to a particular task. It is a particular feature that the present system dramatically decreases resource demands, as compared to known in the art methods of continuous or semi-continuous signal correlation processing, based on Nanosecond Pulse Location.

In network systems not capable of location determination, waveforms of the received frames by themselves and/or the results of comparison with reconstructed abstract/ideal waveforms can be sent to the application server responsible for utilization of this information for the particular applications required.

The network system of the present invention can combine, in an unlimited manner, a plurality of applications, for example, network devices location, monitoring of Quality of Signal, wireless controller maintenance and fine tuning, Quality of Service applications, and others. This is because waveforms are an excellent source of information for functionality control.

There are no requirements for mobile devices operative in the system according to the invention, other than the protocol implemented in a particular wireless network. If the server is located on the MD, it will be an additional application for the MD.

The task of network member position location is considered particularly because of its great importance in all network applications. However, it will be appreciated that the method of the present invention has much wider applicability. Moreover, this method advantageously provides an opportunity to replace or update the "Location Server" by some other server which will implement most or all network opportunities mentioned in the method description.

The position location of mobile clients (MD) will be described. This does not limit the generality of the applicability of the method for location position of any wireless network object located under the radio coverage of a network. The wireless network object whose position will be determined need not be a member of the network which will determine its location position.

The device which implements the present method may be implemented as part of an AP or as a separate device. The separate device can be installed near an AP and, in such a way, can upgrade a conventional AP. Alternatively, the separate device, equipped with an antenna having known coordinates, can be installed separately, specifically for method implementation. In the same manner, the method can be implemented on any independent wireless network member, whether it is mobile or not mobile client or just any other wireless network device.

It is important to understand, that the device that implements the proposed method can implement it under several different wireless network standards.

FIG. 1 is a general system diagram of a wireless network system capable of locating wireless mobile devices. The system includes a plurality of access points (AP) 1 and/or a plurality of independent devices 13 capable of implementing the present invention, a plurality of mobile devices 2 – 9 and a server 10. All these Access Points 1 and independent devices 13 are referred to herein as APs (as defined above) and are coupled to server 10. Facilities 11 supplying wireless connectivity with APs 1 are coupled to the APs 1 and to server 10, as by a cable network infrastructure 12. The mobile devices may include one or more of: a mobile phone client 2 with wireless capabilities, a tag 3 (usually some small device used in asset assistance to mark some asset), an IP phone 4, a pager 5, a PDA 6, a notebook 7 or similar computer client, a wireless camera 8, or a wireless client with self location capabilities. It is possible that any wireless client, within system radio coverage, can be located. Reliable location needs at least 3, preferably 4 or more, measurements of TOA, which differs from the ideal deployment for networking radio coverage. Thus, devices 13 may be utilized to fulfill the topology of the network to suit the demands of location calculation. In the following text, the terms "AP" and “wireless client (MD)” will be used to refer to all above-mentioned cases, but without any preference or limitation to any of them.

**FIG. 2** is a block diagram of a circuit responsible for implementation of the proposed invention method, according to major embodiments of the invention. This is a non-limiting example of a device that can implement all measurements described in the invention of abstract/ideal and actually received waveforms of the network frames. The illustrated circuit in can be built into the circuit which implements a

WiFi network interface, for example. This illustration in no way limits the general applicability of the block diagram shown in **FIG. 2**. As was stated above, it is possible to use waveforms representations and partial usage of waveforms. It is easy to see, that this can be easily incorporated into all the examples described below.

The circuit operation scenario inside an Access Point (AP) is as follows:

1. Default behavior:

   1.1 Only "Probe Request" frames are evaluated. Under the frame of 802.11 standard, the client sends this frame about 10 times a second.

   1.2 Only TOA of a frame from MD is determined.

2. Input Signals:

   2.1 RF signal.

   2.2 A Time Synchronization Signal (218), used to synchronize Analog to Digital Converters (ADC 204 – 206) and digitized signals timestamps.

   2.3 Wireless network frame informational contents, including MD identification and protocol dependent information 219 are received, typically from the Medium Access Controller or from an external network interface.

3. The circuit behavior can be modified by "Follow MD" and "Waveform Needed" input signals (220) stored in a buffer 211.

The RF signal of a network frame is received by the antenna and processed by the RF input circuits 201. After that, the signal is processed by an RF Analog to Digital Converter (ADC) 206. The digitized RF signal is stored by an RF Buffer 210, possibly a ring buffer. After input processing 201the RF signal is also processed by an RF/IF (Radio Frequency to Intermediate Frequency) converter 202. The IF signal is processed by an IF ADC 205 and stored by an IF buffer 209. In practice, several intermediate frequencies can be used. All of them can be digitized and stored, each in its own IF Buffer 209, several of which are shown. The IF signal is also processed by a demodulator 203 (Intermediate Frequency to Baseband Frequency converter). The resulting BF signal is digitized by a BF ADC 204 and stored by BF Buffer 208.

RF ADC 206, IF ADC 205 and BR ADC 204 are all synchronized by a synchronization time signal 218, which is received from an external source. This synchronization time signal can be a modern GPS signal or other signal from sources of time synchronization known in the art. The location accuracy of a system according to the invention, among other factors, is defined by the accuracy of time synchronization of the APs. The usage of accessible GPS with 15 nsec accuracy makes it possible to implement a system with accuracy of about 5 m, which is better than an ordinary GPS working in non differential mode. In fact, better accuracy can be reached by the present invention using the ability of the proposed system to measure time differences between APs.

The device is controlled by a "Follow MD" and/or "Waveform Needed" Identifiers buffer 211. "Follow MD" and/or "Waveform Needed" are configuration parameters input to the APs. Buffer 211 stores information concerning additional services demanded by/to clients, described by their identifiers, received from a source 220.

For a particular MD, 10 position locations/network frames analyses per second may be not enough. In this case, the identifier of this client can be inserted into a "Follow MD" list. For devices from this list, all network frames will be evaluated. In addition, for a particular MD, waveforms may need to be sent elsewhere, for example, to the Position Location Server for TOAD determination and/or time for time synchronization improvement.

It will be appreciated that, while the TOA calculations from two APs can be used to determine the distance to a third AP or a mobile device, the reverse is also true. If the distance between the three network elements is known, it is possible to calculate the TOA and use these calculations to improve the AP time synchronization between the APs in any known fashion, such as adding a delta to later calculations, or correcting the AP, or causing the server to measure shifts in the field.

The AP receives wireless network frames, MD identifiers and protocol dependent information from an external source 219. This source can be an AP, a Medium Access Controller of a wireless interface (see, for example, FIG. 5) or a wireless analysis facility (usually a wireless interface in a Monitoring Mode with package analysis software). The received frames are stored and processed by a RF/IF/BF wireless network frames waveforms reconstructor and/or a network frames receiving algorithm reconstructor 207, which operates according to the information received from 211. Reconstructed abstract/ideal wireless network frame waveforms and/or reconstructed receiving network frame algorithm and MD identifiers are sent to a signal comparator 212 through connections 216 and 217.

Reconstruction is based on information in an already received and completely decoded network frame and knowledge about the wireless standard implemented by the network. According to some embodiments of the invention, the entire network frame, or/and its representation, will be reconstructed, although only a portion may be sent to signals comparator 212. According to other embodiments of the invention, only a selected portion of the network frame or/and its representation will be reconstructed.

Using the information received from the reconstructor 207, the signal comparator 212 performs one or several of the following actions:

1. Searches in the buffers for the signal which matches the abstract/ideal waveforms of the wireless network frame reconstructed by reconstructor 207, calculates TOA and prepares the TOA with the MD identifier for sending out through line 222 to the location server.

2. Search in the buffers for the signal which matches the abstract/ideal waveforms representation of the wireless network frame reconstructed by reconstructor 207, calculate TOA and prepare the TOA with the MD identifier for sending out through line 222 to the location server.

3. If TOA is calculated based on reconstruction of the received network frame algorithm, then it is implemented for searching the content of the buffers to

find the network frame; TOA and accuracy are calculated and, with the MD, are prepared for sending out through line 222 to the location server.

4. If TOAD is calculated, the actual waveform stored in the buffers is prepared for sending through line 222, in addition to items (1) and/or (2) and/or (3).

It will be appreciated that:

1. In practical implementations, not all signals must be digitized and stored in the buffers. Which signal to use is a question of convenience and of the particular network standard. Definitely, there is a great difference in resources required by ADC and the buffers for different frequencies bands. Those differences are acceptable and become less critical with progress in technology.

2. The radio channel of a standard wireless interface has delays, which create problems with accuracy of TOA determination using BF and IF. For this reason, and in some cases, the radio channel must be calibrated.

3. In a TOA only calculation device, the radio channel can be specially designed according to a criterion "to keep signal waveform recognition" without frame decoding. Typically, frame decoding is a stage that follows demodulation. In some systems, it is combined with demodulation. Correct decoding is a main purpose of all signal processing; but for waveform comparison, good reliability can be achieved without reliable decoding. The radio channel can be simplified to avoid uncontrolled delays. In this case, a completely decoded network frame can be received from an external interface through the line 219.

4. In some cases, several intermediate frequencies can be used. The signal delay of the first IF will be less than that of the next IF.

**FIG. 3** is a UML (Unified Modeling Language) sequence-like operating diagram of the operation of a portion of the circuit of **FIG. 2**. It illustrates the main parallel processes for the bottommost flow of the circuit of **FIG. 2**. As a non-limiting embodiment, only the case of operating with waveforms reconstruction is presented. This diagram can be implemented in hardware and/or in software. The contents of the received frame with the MD identifier is sent to the wireless network frames RF/IF waveforms reconstructor (block 302).

The system determines (block 306) whether the frame is a Probe Request, and/or the MD is on the "Follow MD" list and/or is stored in the "TOAD demanded" buffer. Since it is, then a frame waveform or partial frame waveform reconstruction is prepared (block 308) and performed (310). Data regarding the MD is stored in the “Follow MD” and/or “TOAD demanded” identifiers buffer (block 304), and this information is used in (block 306).

The frame waveform is reconstructed for RF and/or IF and/or BF (block 310) and the system starts a TOA search by comparing waveforms (block 312). This is accomplished for BF, IF and RF frequencies by finding the best compared waveform in the appropriate buffer (block 314), as by means of wavelets or fractals. This waveform will be searched for in the RF, IF and/or BF buffers, where the corresponding digitized input data streams are stored, as described above.

If using a reconstructed ideal/abstract waveform or/and a portion of a reconstructed ideal/abstract waveform or/and their representations, in (block 312) the actually received waveform is found, and its TOA, MD identification and other parameters are prepared for sending out of the device. If the MD identification is also found in the "TOAD demanded" buffer (block 318), then the found actually received waveform is added to the output parameters (block 319).

FIG. 4 illustrates a general structure of a conventional 802.11 WiFi interface, according to the prior art. Most conventional WiFi interfaces and chipsets fit this diagram, which will be well understood by those skilled in the art.

FIG. 5 illustrates the general structure of a standard wireless 802.11 interface, modified in accordance with the present invention, to permit it to perform TOA and TOAD calculations and use them to perform location calculations and quality of signal calculations. This interface is a combination of the prior art interface (FIG. 4) with the circuit of FIG. 2, and includes the following modifications.

1. A BF decimator 304 is provided, receiving data from the IF/BF converter (modem) via the BF ADC, and returning processed data to the baseband processor. The ADC rate of a "standard" BF ADC may not be enough for TOA calculation purposes. For this reason, two ADCs, working in parallel (not shown), can be used – one with a rate needed for Baseband Processing and another with a rate needed for TOA calculation. Alternatively, a single ADC 301 can be utilized with a decimator 304 coupled after it. The latter case is shown on **FIG. 5**. For example, in 802.11* interfaces, the ADC rate is usually about 40 MSPS. This limits the location accuracy to 8-9 m. This may not be enough for Asset Assistance Tasks.
2. Line 311 is equivalent to line 219 on FIG.2 – the incoming wireless frames contents is received from a Medium Access Controller.
3. Line 312 is equivalent to line 220 of FIG.2.
4. Line 313 is equivalent to line 222 of FIG.2.

The bidirectional arrangement of lines 312 and 313 is typical for communications with a Bus Interface. Operation is substantially as described with regard to **Fig.** 3. As can be seen, in this AP circuitry, the frames contents from the MAC are introduced to the wireless network frame RF/IF/BF waveforms reconstructor. The reconstructed waveforms or/and partial waveforms or/and representations are sent to the signals comparator 308. Frame sender identifier and the frame TOA and other results of block 308 are sent to the bus interface.

It will be appreciated that an AP capable of MD location can be implemented based on a computer with some hardware superfluity. To implement the invention on a computer, one needs: a computer 400, a GPS unit 402, an SDR set, which consists of a Radio Transceiver 404 and an ADC 406. As one can see, the invention is implemented on a base of a standard desktop/laptop/embedded computer. The hardware superfluity is used to decrease the amount of new development by using a prior existing AP and Network Sniffer software.

All other cases with usage of reconstructed abstract/ideal waveforms and/or waveforms representations can be proved for each particular pattern recognition method. The most obvious one is the Simplified Reconstruction Algorithm. Obviously, the usage of a "weight function", which represents possible destruction of the abstract/ideal waveform by a real hardware channel, can greatly improve pattern recognition reliability and accuracy.

It is obvious that TOA determination accuracy depends on signal frequencies, sampling frequencies and details of the wireless standard.

It will be appreciated that the method of the invention can be implemented in real time. It can be implemented without a buffer or with a very small one, used to adapt the decimation and some time delays. The implementation without a buffer in "a strange form" makes this patent very, very general.

The art of time synchronization is a further aspect of the present invention. In the text below, there is shown, in a non-limiting manner, that the capability to calculate TOAD can be used for time synchronization of APs. This is an illustrative example which in no manner limits the application of any alternative method of time synchronization of the network system members, but presents an additional way to utilize the invention features in a real system.

With reference to **FIG. 1**,

1. There are shown a plurality of $n$ of APs (1, 13).
2. At time $t_k^0$ AP number $k$ sent a frame received by all the others.
3. AP $i$ receives the frame at time moment $t_k^i$ .
4. Let us suggest, that AP $i$ is synchronized in time with an error $\Delta t_i$ which with appropriate accuracy is substantially constant during the described measurement, which in practice can take less then several seconds.

5. In this case, the TOAD $t_k^{ij}$ between AP and AP can be presented in a form:

   $t_k^{ij} = t^i_{absolute(k)} + \Delta t_i - t^j_{absolute(k)} - \Delta t_j = t^{ij}_{absolute(k)} + \Delta t_i - \Delta t_j$ , or

   $\Delta t_i - \Delta t_j = t_k^{ij} - t^{ij}_{absolute(k)}$ (1) , where:

   $t^i_{absolute(k)}$ and $t^j_{absolute(k)}$ - "absolute exact time" of arrival of frame AP $k$ at APs $i$ and $j$ ;

   $t^{ij}_{absolute(k)} = t^i_{absolute(k)} - t^j_{absolute(k)}$ - absolute exact time time of arrival difference between AP $i$ and AP $j$ for frame sent from AP $k$ . This is known thanks to the known AP coordinates and is constant;

   $t_k^{ij}$ - is a measured TOAD between AP $i$ and AP $j$ for frame sent from AP $k$ .

6. For a frame sent from one AP, from $n$ we get $\frac{(n-2)(n-1)}{2}$ equations (1). Providing TOAD measurements by sending frames from each of $n$ frames, we will get an over determined system from $\frac{(n-2)(n-1)n}{2}$ equations (1) for $n$ unknown parameters $\Delta t_i$ .

The solution of the above system of equations (1), for example with a least square method, will provide a time correction for APs. Obviously APs can be grouped by those "in line of view" and obviously those groups can have intersected subsets of APs. This decreases the dimension of the system of equations and provides additional opportunities for time synchronization.

The wireless network system described above is a non-limiting example having the capability to find actually received network frames waveforms and/or their abstract/ideal waveforms and/or capable of determining client position location and/or time synchronization improvement. It is capable of locating the position of a MD in communication with a wireless network and to improve time synchronization of AP, as well as utilization of all or any other features of received network frames determined by the network device of the AP.

The system includes:

- a plurality of APs, as defined above, capable of finding waveforms of actually received network frames and/or their abstract/ideal waveforms and/or calculating their TOA;
- a plurality of mobile devices without requirements or limitations in addition to the standard applications implemented by the wireless network;
- a server (LS) which communicates with the APs throughout the network.

The antenna coordinates of the APs are known. All APs are synchronized in time. The APs and MDs communicate using wireless communication signals, typically spread spectrum.

The server receives from the APs the measured TOA and MD identifiers and calculates the coordinates of the MD location. In some cases, waveforms of received frames are sent to the location server for determining the Time of Arrival Differences (TOAD). The TOAD of a frames sent by APs can be used to improve time synchronization of APs, as described above.

As stated above, the proposed system works in a "monitoring manner". Each AP operates normally, i.e., receives network frames, decodes them and presents the received data (including contents) to all the required layers of the network protocols (see, for example, Fig. 4).

As was mentioned above, according to various protocols, all mobile clients periodically transmit what is called in 802.11 a "Probe Request" - a special frame which is received by all APs. This frame hosts client identification. All clients send this before their association with a particular network and after the association. It is sent ~5-10 times per second. It is a particular feature of the invention that usage of such frame makes it possible to locate any mobile client in the covered area. The client need not to be a member of a network in order to be located - even while trying to find a network to connect to, it will send such requests and can be located. Thus, this is very strong solution.

If 5-10 location calculations per second are not enough for the desired accuracy, then additional transmission frames from a particular mobile device can be utilized, in addition to the “Probe Request” frames. In the drawings, this is indicated as “Follow MD” – a mobile device which must be "followed” more closely. If an AP is capable of determining the location of a MD and is used for TOA detection of all types of frames (not only “Probe Request” type), then tracking very detailed location of one's path can be done only for the frames transmitted by the network clients associated with this AP. At the same time, it means that other APs capable to determine the locations of a MD are not able to determine TOA of all types of frames of the clients not associated with them. Alternatively, the wireless interface of a separate device can operate in what is called “monitoring mode” in 802.11 and in some other standards. In this mode, all frames of all clients in a covered area that are acceptable with the wireless interface (i.e., are in a comparable standard) can be reconstructed. This makes the separate devices working in a “monitoring mode” attractive for some applications.

The system can be used to calculate TOAD. While location based on TOAD can be more accurate, the traffic to the location server will be larger. For TOAD, waveforms or/and their representations must be transferred.

For TOA based location, only numbers (TOA, MD identifiers and some limited additional information) are required. This limited “additional information” preferably includes the information that identifies a particular frame and, in case when parts of a frame are used, identification of those parts. The list of such information is easy to build and it is outside of this patent. However, it is important to mention that it is taken into account. A MD rapidly sends frames one after another. To determine location of the MD, the TOA of the same frame must be measured by several APs. Sequential frames sent by the MD differ in some way, even if they are of the same type. This can be, for example, the time of sending of a frame by MD. Depending on the type of frame, there can be a list of such frame fields which can be used to identify the particular frame. It is important to underline that "time of sending and/or receiving" of the frame are not usable for location purposes, because they are not accurate.

FIGS 6a and 6b summarize the proposed invention method. The method is implemented to actually received and completely decoded frames (1). A wireless interface receives the frame as a radio signal (RF) which can be down banded to lower frequencies IF and BF. Those data streams are digitized and buffered (block 2). ADCs providing sampling are synchronized by external precise synchronization signals. Synchronization signals are often, but not necessarily, presented by PPS (Pulse per Second) and ADC timing pulses series. This makes it possible to store digitized data streams indexed by time. As usual, the sampling rate must be not less than Nyquist frequency of a data stream. The buffer size can vary from relatively small for actually received waveform search algorithm like "Reconstructed Simplified Algorithm" to the length capable to store a maximum frame length plus frame processing delay plus time needed for frame information contents based reconstructions.

Block (3) illustrates the next three significant steps:

- Analysis of Frame Informational Contents and previous reconstructions results.
- Selection of Ideal/Abstract Waveform reconstruction type.
- Selection of Actually Received Waveform Search Method.

Analysis of Frame Informational Contents and previous reconstructions results is done on the basis of the Frame Informational Contents and Previous reconstructions results. The choices of Ideal/Abstract Waveform reconstruction types are as follows:

1. No reconstruction.
2. Simplified Reconstructed Algorithm.

3. Permanent predefined waveform samples extraction.
4. Permanent predefined waveform representations extraction
5. Informational contents dependent permanent predefined waveforms samples extraction.
6. Informational contents dependent permanent predefined waveforms representation extraction.
7. Informational contents dependent waveforms portions.
8. Informational contents dependent waveforms representations, whole waveform or partial.
9. Frame waveform, whole waveform or partial.
10. Frame waveform representation, whole waveform or partial.
11. Fractal/multifractal model.
12. Any combination of items 2 – 11.

The options of choices of Actually Received Waveform Search Methods is:

1. Simplified Reconstructed Algorithm based signal search.
2. Signal pattern search.
3. Representation based/utilizing signal search.
4. Fractal/multifractal model based/utilizing signal search.
5. Any combination of items 1-5.

Block (4) implements the reconstructions selected by block (3).

If for some reason reconstruction is not successful, operations of blocks (3) and (4) can be repeated (small reconstruction cycle).

After selection of Ideal/Abstract Waveform reconstruction type, Actually Received Waveform Search Method and successful reconstruction, blocks (6) and (7) will provide:

- Search for actually received waveform.
- Determine waveform parameters including TOA.
- Prepare results probably including waveforms for presenting to results receivers.

- Analyze Search Results.

If waveform search was unsuccessful and time remains for processing (the next new frame has not arrived), the actions of blocks (3) – (9) can be repeated (big reconstruction cycle).

If there is no more time, the current data can be stored in a line for postponed processing (block (11)).

In case of successful waveform search, the retrieved data can be used (block (10). Mutual processing of Ideal/Abstract reconstructions and Actual Received Data can be implemented.

**FIG.** 7 is a UML sequence-type operating diagram of a wireless network capable of using data supplied by device implementing the method of the present invention, in general, and of MD location, in particular. Several working in parallel objects are shown:

1. Any mobile devices under the radio coverage of a system (30). The mobile device is not necessary connected (associated) to the system.

2. A mobile device with a Location Server installed on it (21). Such device must be connected to the network.

3. Access Points (APs) (30). For ease of description, only one is shown. In fact, there are a plurality of APs. An AP can be an AP implementing the proposed method or a regular AP updated by a device implementing the proposed method, as described above. Preferably, each AP permanently runs means implementing proposed method. This not shown explicitly, as continuous process is considered to be an internal feature of AP (30). It is also preferred that the AP be able to process at least some frames from other APs.

4. A Location Server (10). The system may include a plurality of servers (10). For this example, a single Location Server is chosen. In practice, servers (10)

can be servers that were updated or replaced to have the capability to utilize the data supplied by the APs implementing the proposed method.

At the beginning of the activity, the Location Server (10, 20) must initiate the APs (30) with "Follow MD" and "TOAD demanded" parameters needed by the server, messages (11, 21). It will be appreciated that the server can follow the movements of any mobile client. For a server located on a mobile client, the same is true. After initiation, the APs can operate with the servers.

Mobile devices (20) work in a normal way. When they need to, they transmit to the APs or broadcast frames (messages 41, 42).

Processing according to the proposed method will be carried out when the AP receives a frame suggested for signal on this AP according to the above described initialization. In the illustrated example, it's a "Probe Request" frame or any frame from a client whose identifier is in "Follow MD" configuration for this AP. After the successful processing, the AP send messages (31, 32, 33) to the Location Server (10) which, in this case, is a general network server (and not a server on a single mobile device).

1. Message (31), "New TOA and MD id". This is a message after processing (under the frames of this example) a "Probe Request" frame or frames from clients mentioned in "Follow MD" list. This message initiates a TOA based client position location thread (12, 22). The results of this thread for a frame from MD with id are: MD coordinates, time of sending frame by client T0 and accuracy estimations. A client (20) having mobile position location capability uses the results by itself. This is shown by self returning block (22). The server (10) will prepare client position results for sending (13) to clients without this capability. This can be placing results to some Data Base or simple sending to a designated receiver.

2. Message (32), “New TOA, waveform and MD id”. This is a message after processing (under the frames of this example) of a frame from clients mentioned in “TOAD demanded” list. This message initiates TOAD determination (14) and a TOAD based client position location thread (15). The results of this thread for a frame from MD with id are: MD coordinates, time of sending frame by client T0 and accuracy estimations. Server (10) will prepare client position results for sending (16). This can be placing the results to some Data Base or simple sending to a designated receiver.

3. Message (33), “AP id, TOA, waveform”. This message is send by an AP after processing of a frame from some other AP. The processing results will be used for APs time synchronization improvement. This message initiates block (17), which determines TOAD for all pairs of APs that received the frame. The determined TOADs are sent to block (18). Block (18) will gather a sufficient amount of TOADs for solving equations for Time Corrections and will solve them. The exact procedure of gathering sufficient amount of TOADs is not significant in the current example, as it depends on many factors and can be supported by some additional software. Block (18) will produce Time Corrections for the APs and accuracy estimations. Server (10)will prepare these results for sending (19). This can be placing the results in a Time Synchronization History Data Base and/or sending a message (110) to the appropriate APs with Time Corrections for those APs.

As mentioned above, the example is limited to the client position location system task. Messages (31, 32, 33) can be updated by those hosting any or all accessible results of the proposed method (ideal/abstract and actually received waveforms of frames or/and portions thereof or/and their representations or/and representations of their portions). Each such message will initiate a thread providing information for any/all additional system tasks like:

- analysis and improvement of functionality of network APs;
- analysis and improvement of functionality of network clients;
- analysis and improvement of functionality of the network system;
- analysis and improvement of functionality of the network system infrastructure;

Operation of a system according to other embodiments of the invention includes:

- storing an original waveform stream or/and waveform representation in a time-indexed buffer;
- reconstructing at least a portion of an ideal waveform based on the received packet;
- analyzing and/or selecting an "optimal" segment or part of the reconstructed waveform/waveform representation, for use of the selected part or segment in comparison with the previously stored original waveform/waveform representation;
- (optionally) analyzing and/or choosing an optimal method of comparison or set of methods for comparing the waveform representation with the original waveform;
- comparison between the received (stored) and original (ideal) waveform/waveform representation; and
- (optionally) analyzing the results from the previous step for use in TOA and/or TOAD calculation (location application), signal quality analysis, determining of changes occurring in the network, causes and wireless interfaces maintenance operation (e.g., signal quality control, improving of SNR, load balancing, etc...).

- partial or/and complete reconstructing of abstract/ideal waveforms and/or waveform representations (Continuous or/and Discrete Transform, Wavelet

Transform, etc) in Base Band Frequency (BF) or/and Intermediate Frequency (IF) or/and Radio Frequency (RF);

- analyzing and selecting a “optimal” portion of the frame or waveform, depending on predicted comparison/analysis method used by the next steps;
- searching in the input RF and/or IF and/or BF signal streams of a wireless network device for actually received waveforms or/and waveform parts or/and waveform representations or/and representations of waveform parts;
- analyzing and choosing an optimal methodology or set of methodologies for searching in the signal stream of the wireless device for previously selected waveform/ or parts of a waveform/ pattern/ waveform representation, etc...
- using, for comparison or/and independently, the abstract/ideal or/and found actually received waveforms of network frames or/and waveform parts or/and waveform representations or/and representations of waveform parts;
- complex analyses of the differences between the real waveform and the reconstructed/ideal waveform, in order to find and determine the causes of changes occurring and to develop ways to minimize them or their use.

This use may include: determining Time of Arrival (TOA) of the waveforms of a network frame; determining Time of Arrival Differences (TOAD) of the waveforms of a network frame at different points of reception; mutual analyses of abstract/ideal waveforms and actually received waveforms or/and their representations for: analysis and improvement of functionality of network Access Points (AP); analysis and improvement of functionality of network clients; analysis and improvement of time synchronization of network components; analysis and improvement of functionality of the network system; analysis and improvement of functionality of a network system infrastructure; a wireless network system capable of using all the above, generally, and, in particular, for determining client position location and/or Access Points time synchronization improvement.

Another use of the present invention is to improve quality of signal. The actual received signal is compared with the abstract/ideal signal and one can determine the way in which the environment influenced the packet. This information can be sent to the controller managing the receiver to permit the receiver to decode later packets in such a way as to counteract the effects of the environment, or to the server, which can move the client to a different access point.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made. It will further be appreciated that the invention is not limited to what has been described hereinabove merely by way of example. Rather, the invention is limited solely by the claims which follow.

## CLAIMS

1. A method for locating a waveform in a received signal, the method including:

buffering an original waveform stream in a time-indexed buffer;

reconstructing an ideal waveform based on a waveform in said received waveform stream;

selecting a portion of said reconstructed waveform, for use in comparison with said buffered original waveform; and

comparing said buffered waveforms with a reconstructed waveform in order to locate said original waveform stream.

2. The method according to claim 1, wherein said reconstruction includes creating a representation of said original waveform; and

said step of comparing includes comparing said representation with a representation of said original.

3. The method according to claims 1 or 2, (optionally) analyzing and/or choosing an optimal method of comparison or set of methods for comparing the waveform representation with the original waveform;

4. The method according to any of the preceding claims, further comprising calculating Time of Arrival (TOA) or Time of Arrival Differences (TOAD) of said waveform.

5. The method according to claim 4, further comprising transmitting said TOA or TOAD to an access point (AP) for adjusting time synchronization of said AP or calculating location of an element in the network.

6. The method according to claim 4, further comprising transmitting said TOA or TOAD to a server for adjusting time synchronization of an AP coupled to said server or for calculating location of an element in the network.

7. A method for calculating TOA of a wireless network frame received from a wireless mobile device at a device capable of calculating TOA in a wireless telecommunication network, the method comprising:

storing, with a time stamp, on at least one frequency (RF, IF and/or BF) in a buffer, a digitized input data stream signal carrying the received frame from the mobile device;

reconstructing at least a portion of a waveform of said received frame; and

comparing at least a portion of said reconstructed waveform with said stored data streams so as to identify a TOA of said received frame.

8. The method according to claim 1, further comprising utilizing said TOA to determine location of said mobile device.

9. The method according to any of claims 7-8, wherein said step of reconstructing includes:

using an algorithm of a wireless standard used to send the frame to construct a waveform for at least a portion of decoded contents in the received network frame, performing said reconstruction to one of said frequencies stored in said buffer;

comparing said reconstructed waveform with said data stream signal stored in said buffer to find a match; and

identifying a time stamp on said matching data stream signal.

10. The method according to any of claims 7-9, wherein said step of reconstructing includes performing the reconstruction utilizing a simplified reconstruction algorithm.

11. A system for calculating Time of Arrival (TOA) of a wireless network frame from a wireless mobile device in a wireless telecommunication network, the device comprising:

at least one analog to digital converter (ADC) in a frequency range of said network;

a buffer coupled to each said ADC for storing a digitized input data stream signal with a time stamp carrying the wireless network frame from the mobile device;

a reconstructor for reconstructing a waveform of said wireless network frame;

a comparator for comparing said reconstructed waveform with said stored data streams and calculating a TOA of said received frame.

12. A system for locating a waveform in a received signal, the system comprising:

a plurality of Access Points (AP) capable of two way communication with a plurality of mobile devices;

a time-indexed buffer for buffering an original waveform stream received from one of said access points;

a reconstructor for reconstructing an ideal waveform based on a waveform in said received waveform stream;

a selector for selecting a portion of said reconstructed waveform, for use in comparison with said buffered original waveform; and

a comparator for comparing said buffered waveforms with a reconstructed waveform in order to locate said original waveform stream.

13. The system according to claim 12, further comprising a location server (LS) which communicates with the APs throughout the network for determining location of one of said mobile devices.

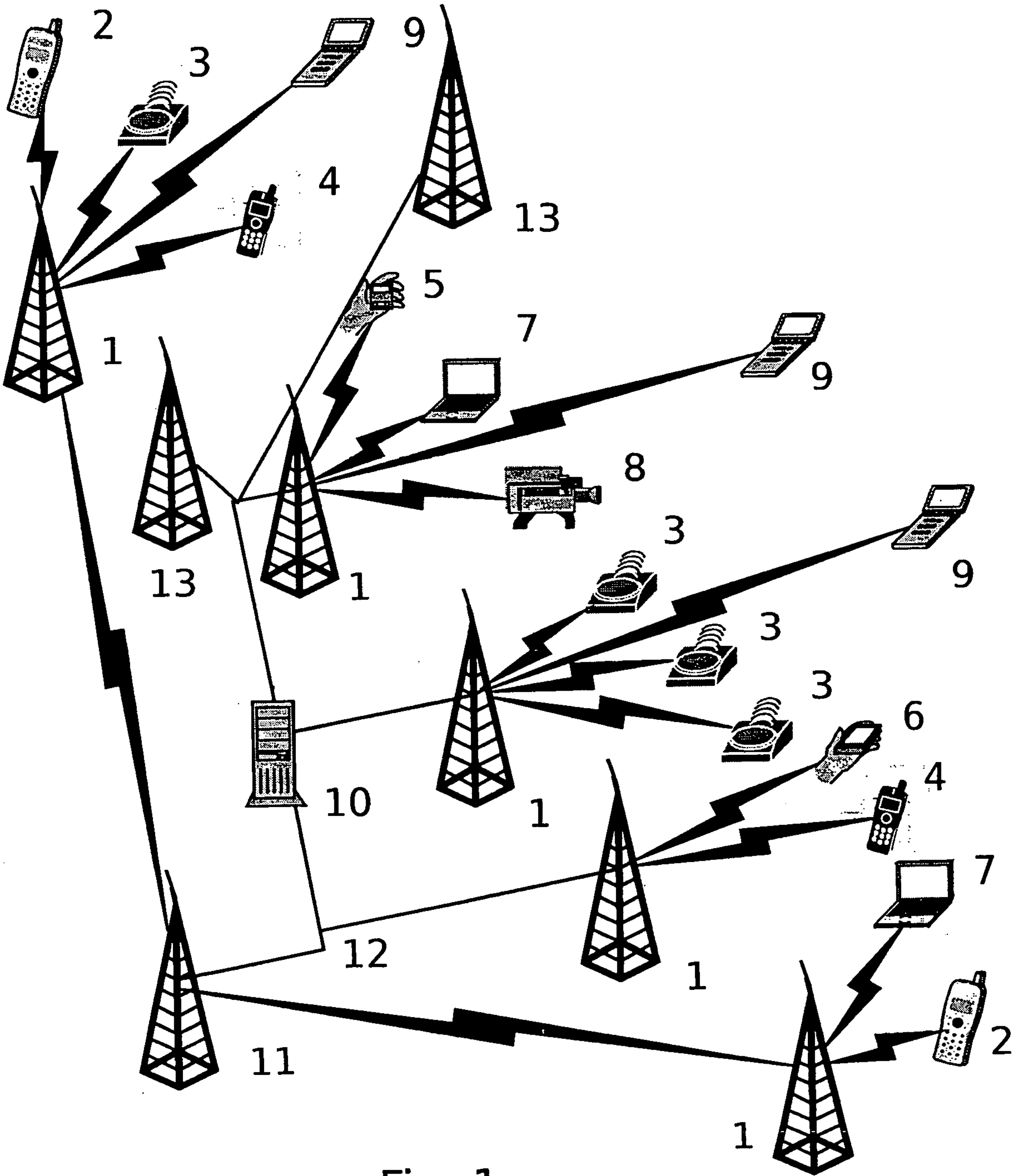


Fig. 1

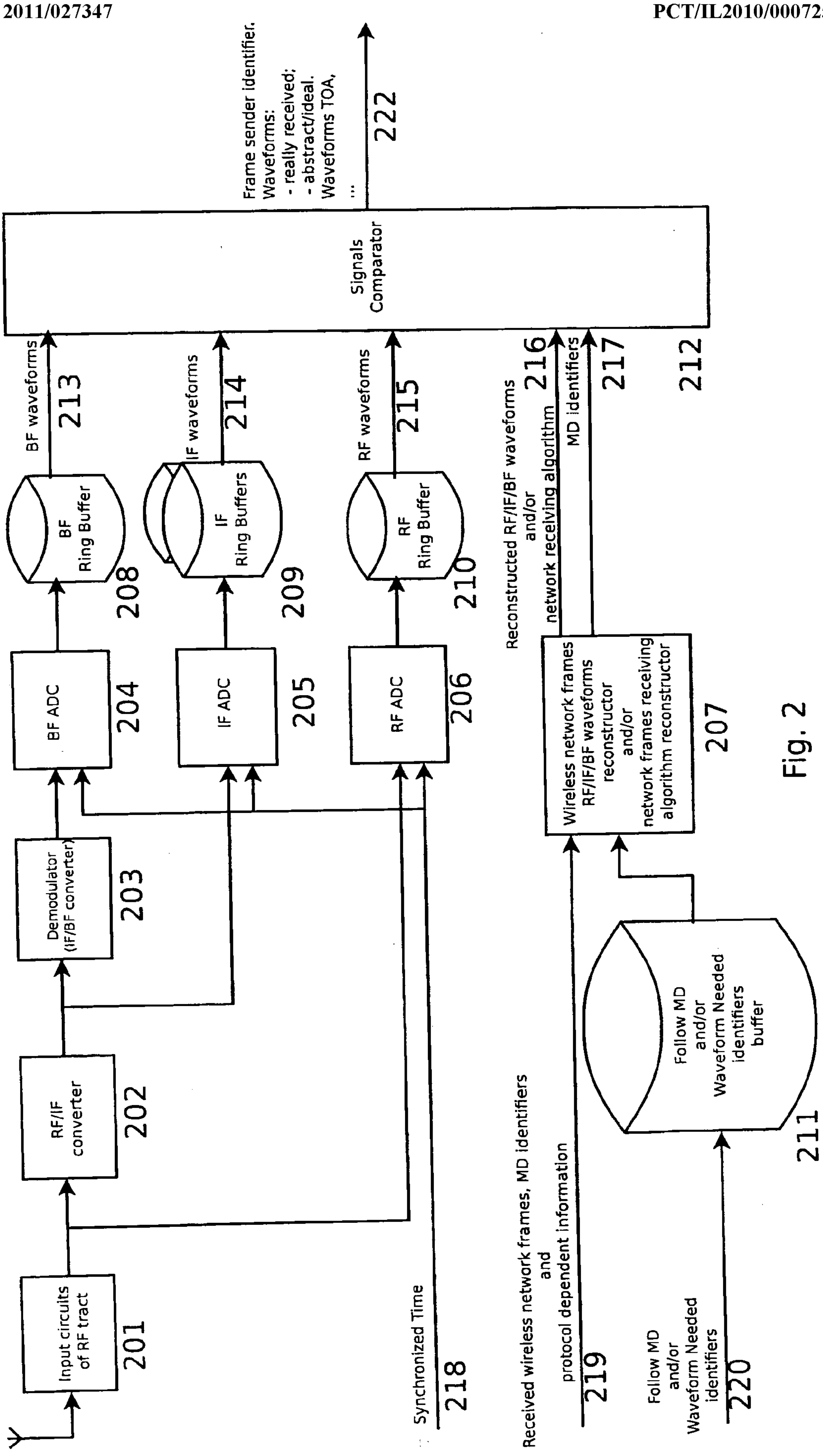
Input circuits of RF tract
201
RF/IF converter
202
Demodulator (IF/BF converter)
203
BF ADC
204
IF ADC
205
RF ADC
206
BF Ring Buffer
208
IF Ring Buffers
209
RF Ring Buffer
210
BF waveforms
213
IF waveforms
214
RF waveforms
215
Signals Comparator
212
Reconstructed RF/IF/BF waveforms and/or network receiving algorithm
216
MD identifiers
217
Wireless network frames RF/IF/BF waveforms reconstructor and/or network frames receiving algorithm reconstructor
207
Follow MD and/or Waveform Needed identifiers buffer
211
Synchronized Time
218
Received wireless network frames, MD identifiers and protocol dependent information
219
Follow MD and/or Waveform Needed identifiers
220
Frame sender identifier. Waveforms:
- really received;
- abstract/ideal.
Waveforms TOA,
...
222

Fig. 2

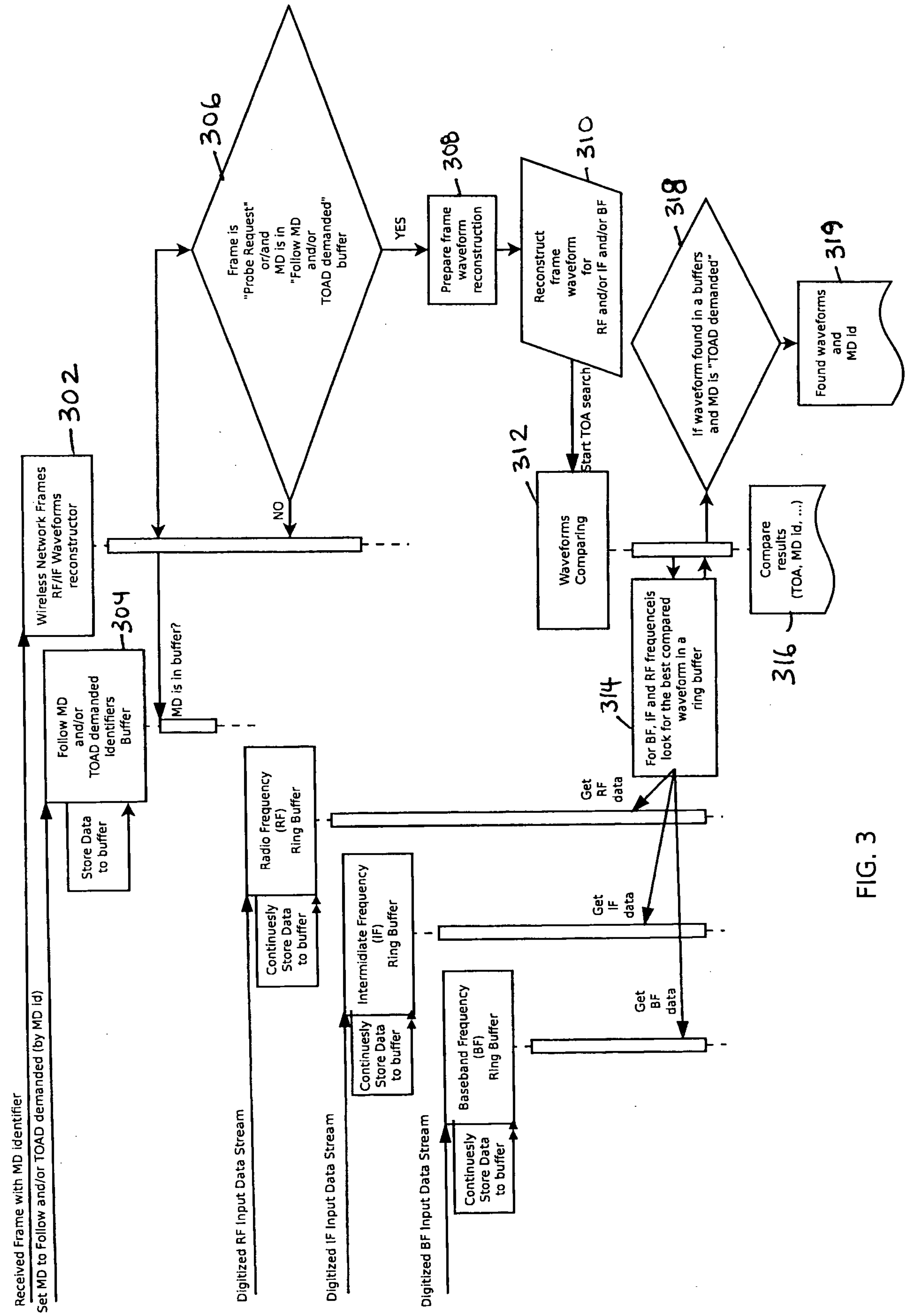
Received Frame with MD identifier
Set MD to Follow and/or TOAD demanded (by MD id)
Wireless Network Frames RF/IF Waveforms reconstructor
302
Follow MD and/or TOAD demanded Identifiers Buffer
304
Store Data to buffer
MD is in buffer?
Frame is "Probe Request" or/and MD is in "Follow MD and/or TOAD demanded" buffer
306
NO
YES
Prepare frame waveform reconstruction
308
Reconstruct frame waveform for RF and/or IF and/or BF
310
Start TOA search
Waveforms Comparing
312
For BF, IF and RF frequenceis look for the best compared waveform in a ring buffer
314
Compare results (TOA, MD Id, ...)
316
If waveform found in a buffers and MD is "TOAD demanded"
318
Found waveforms and MD Id
319
Digitized RF Input Data Stream
Radio Frequency (RF) Ring Buffer
Continuesly Store Data to buffer
Digitized IF Input Data Stream
Intermidiate Frequency (IF) Ring Buffer
Continuesly Store Data to buffer
Digitized BF Input Data Stream
Baseband Frequency (BF) Ring Buffer
Continuesly Store Data to buffer
Get RF data
Get IF data
Get BF data

FIG. 3

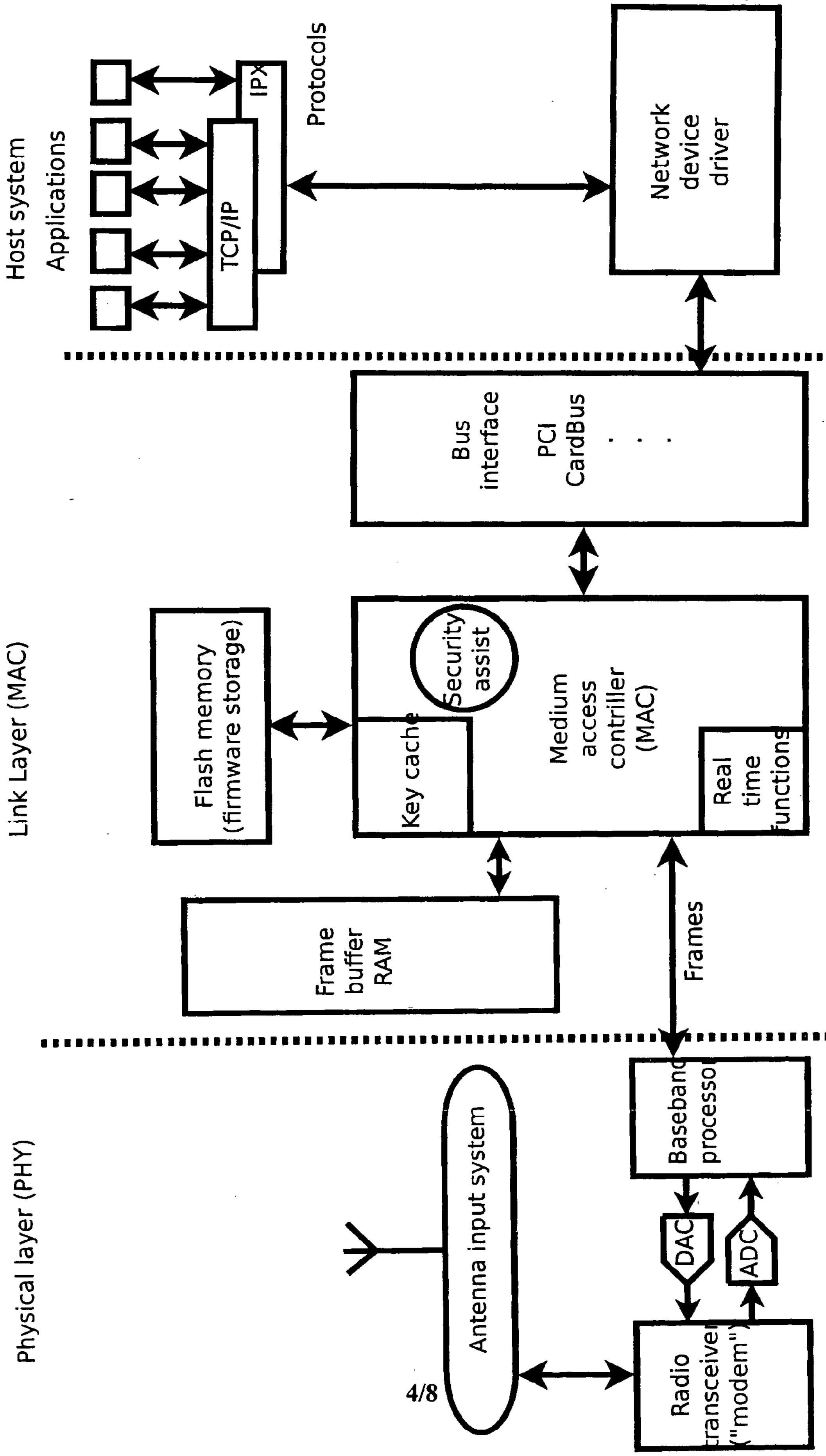


FIG. 4
Prior Art

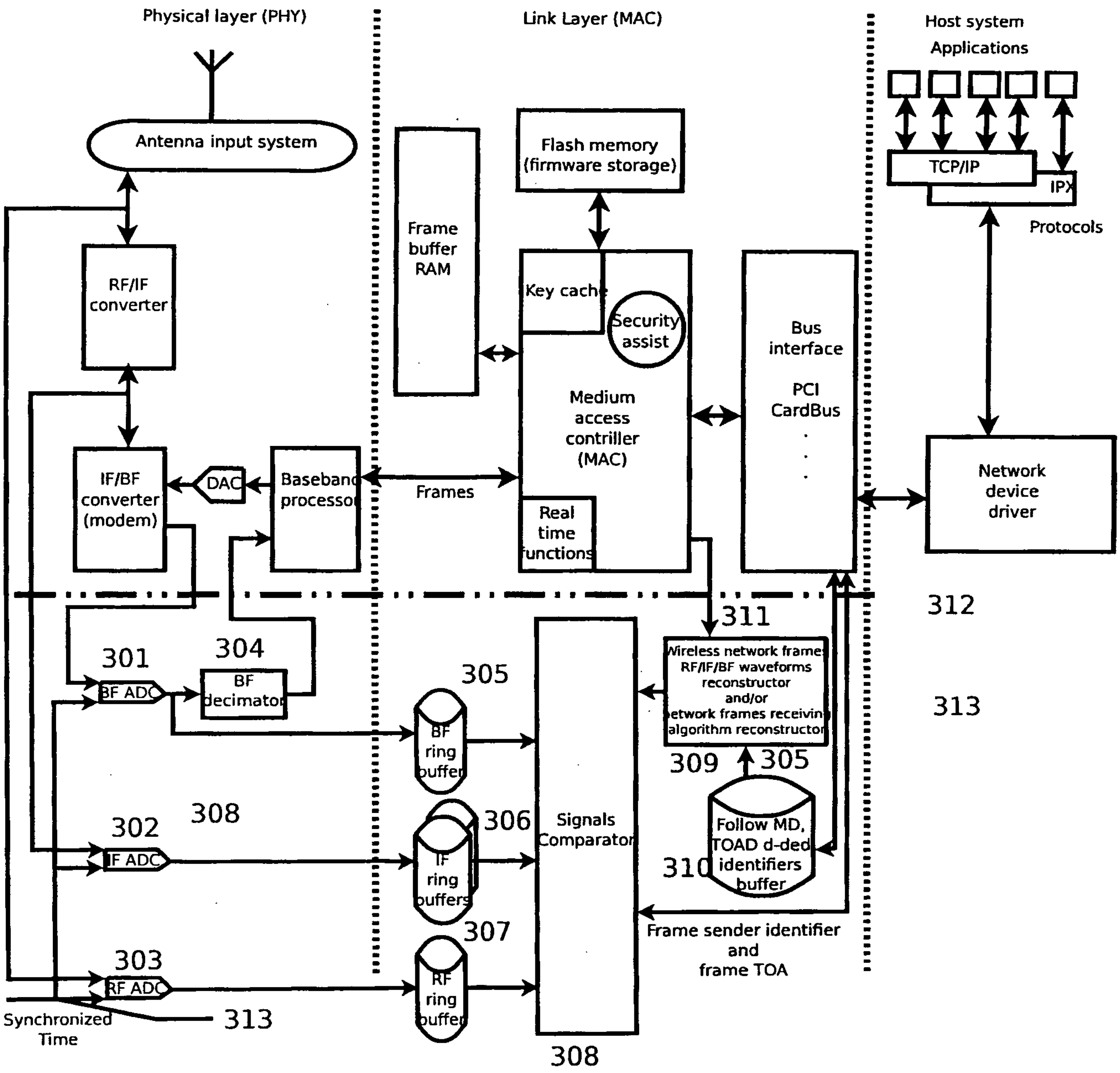
Physical layer (PHY)
Link Layer (MAC)
Host system
Applications
Antenna input system
Flash memory (firmware storage)
TCP/IP
IPX
Protocols
Frame buffer RAM
RF/IF converter
Key cache
Security assist
Bus interface
PCI CardBus
Medium access contriller (MAC)
Network device driver
IF/BF converter (modem)
DAC
Baseband processor
Frames
Real time functions
312
311
301
304
BF ADC
BF decimator
305
Wireless network frames RF/IF/BF waveforms reconstructor and/or network frames receiving algorithm reconstructor
313
BF ring buffer
309
305
302
308
306
Signals Comparator
Follow MD, TOAD d-ded identifiers buffer
IF ADC
IF ring buffers
310
307
Frame sender identifier and frame TOA
303
RF ADC
RF ring buffer
Synchronized Time
313
308

FIG. 5

New Frame Received and completely decoded 1

**Actually Received Signals Buffering** 2

Time Synchronization Signals: PPS+ADC Time Synchronization Series = All ADC Synchronization + Input Data Buffers Time Indexing
RF Data Stream: Time Series = Very High Frequency Data
IF Data Stream: Time Series = Intermediate Frequency Data
BF Data Stream: Time Series = Base Band Frequency Data
Each time series sampling rate is not less than Nyquist frequency which depends from a particular wireless standard.
Buffer size can vary from relatively small for actually received waveform search algorithm like "Reconstructed Simplified Algorithm" to the length capable to store a maximum frame length plus frame processing delay plus time needed for frame information contents based reconstructions.

Digitize corresponding Input Data Stream with appropriated sampling rate synchronized by Time Synchronization Signals(Time Synchronization Signals, RF or IF or BF analogue Data Streams)
Index digitized data using information from Time Synchronization Signals(Time Synchronization Signals)

**Select Ideal/Abstract Waveform reconstruction types and Actually Received Waveform Search Methods** 3

Frame Information Contents = From MAC controller of the same interface or from an external interface

Ideal/Abstract Waveform Reconstruction Type

Today known choice:

1. No reconstruction.
2. Simplified Reconstructed Algorithm.
3. Permanent predefined waveform samples extraction.
4. Permanent predefined waveform representations extraction
5. Informational contents dependent permanent predefined waveforms samples extraction.
6. Informational contents dependent permanent predefined waveforms representation extraction.
7. Informational contents dependent waveforms portions.
8. Informational contents dependent waveforms representations, whole waveform or partial.
9. Frame waveform, whole waveform or partial.
10. Frame waveform representation, whole waveform or partial.
11. Fractal/multifractal model.
12. Any combination of items 2 - 11.

Actually Received Waveform Search Methods

Today known choice is based on today known choice of reconstruction types:

1. Simplified Reconstructed Algorithm based signal search.
2. Signal pattern search.
3. Representation based/utilizing signal search.
4. Fractal/multifractal model based/utilizing signal search.
5. Any combination of items 1-5.

Analyze Frame Informational Contents and previous reconstructions results(Frame Informational Contents , Previous reconstructions results)
Choose Ideal/Abstract Waveform reconstruction type()
Choose Actually Received Waveform Search Method()

FIG. 6a

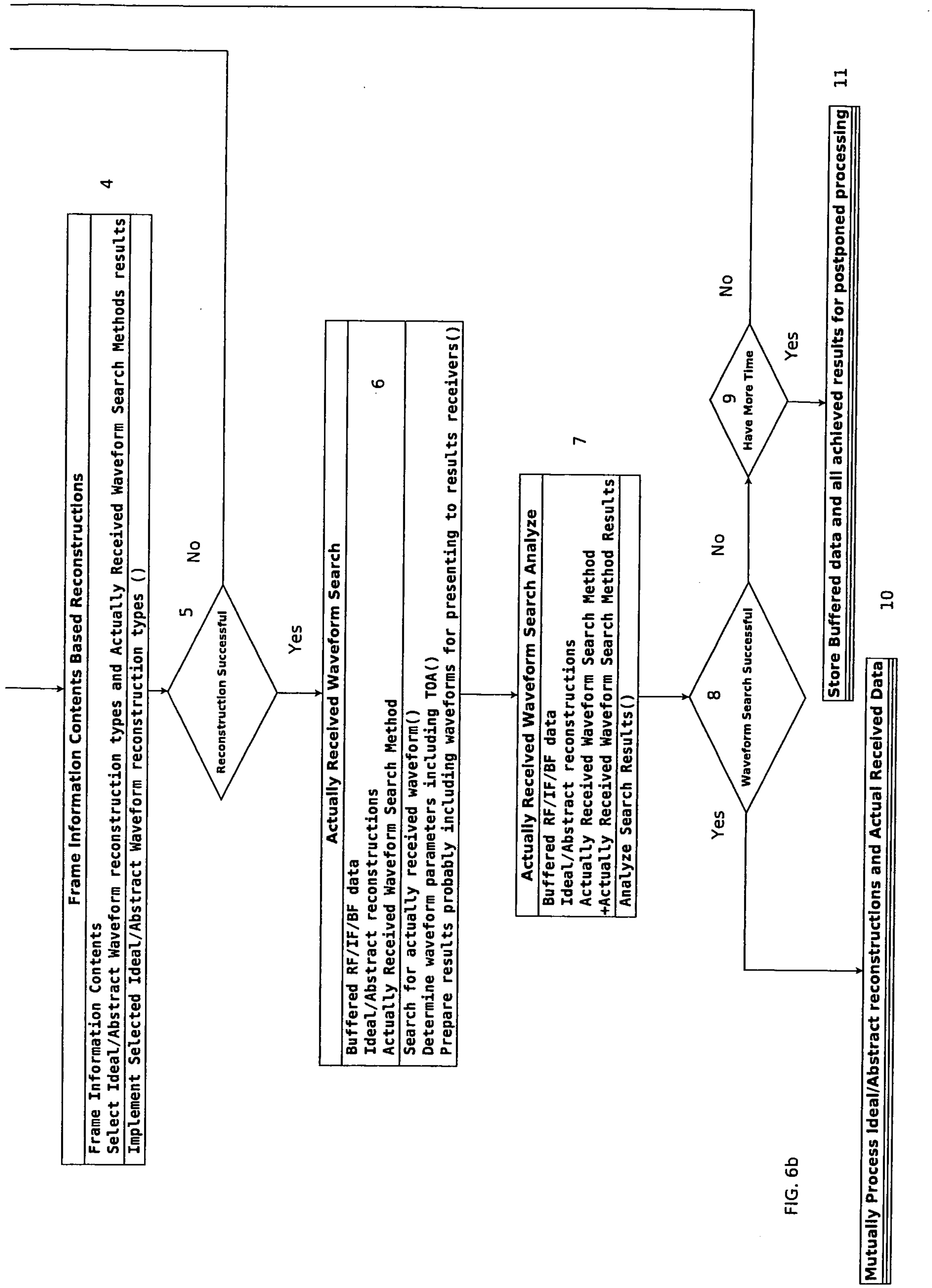
Frame Information Contents Based Reconstructions
Frame Information Contents
Select Ideal/Abstract Waveform reconstruction types and Actually Received Waveform Search Methods results
Implement Selected Ideal/Abstract Waveform reconstruction types ()
4
5
Reconstruction Successful
No
Yes
Actually Received Waveform Search
Buffered RF/IF/BF data
Ideal/Abstract reconstructions
Actually Received Waveform Search Method
Search for actually received waveform()
Determine waveform parameters including TOA()
Prepare results probably including waveforms for presenting to results receivers()
6
Actually Received Waveform Search Analyze
Buffered RF/IF/BF data
Ideal/Abstract reconstructions
Actually Received Waveform Search Method
+Actually Received Waveform Search Method Results
Analyze Search Results()
7
8
Waveform Search Successful
Yes
No
9
Have More Time
Yes
No
Store Buffered data and all achieved results for postponed processing
11
Mutually Process Ideal/Abstract reconstructions and Actual Received Data
10

FIG. 6b

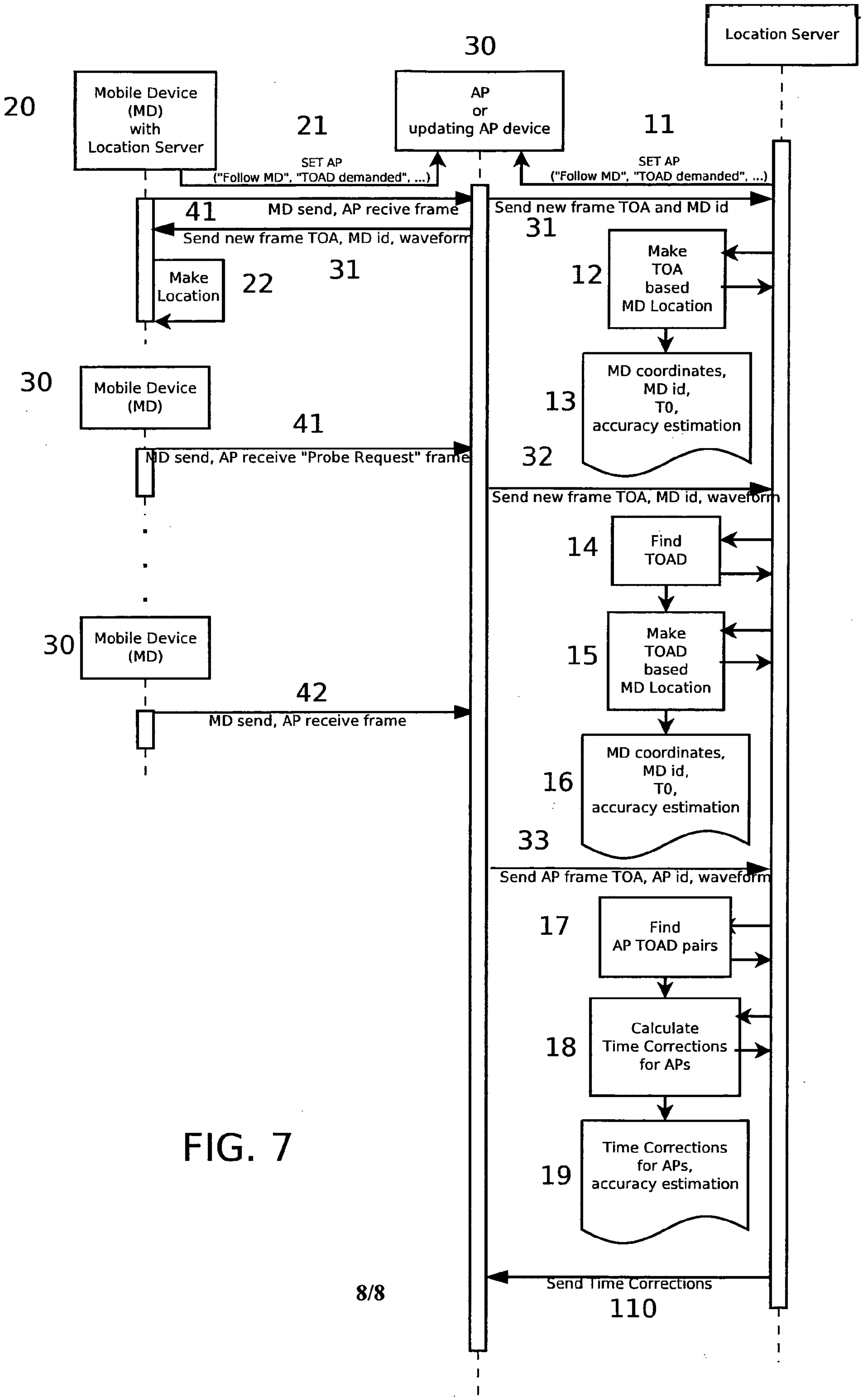
Location Server
30
AP
or
updating AP device
20
Mobile Device
(MD)
with
Location Server
21
SET AP
("Follow MD", "TOAD demanded", ...)
11
SET AP
("Follow MD", "TOAD demanded", ...)
41
MD send, AP recive frame
Send new frame TOA and MD id
Send new frame TOA, MD id, waveform
31
Make
Location
22
31
12
Make
TOA
based
MD Location
30
Mobile Device
(MD)
13
MD coordinates,
MD id,
T0,
accuracy estimation
41
MD send, AP receive "Probe Request" frame
32
Send new frame TOA, MD id, waveform
14
Find
TOAD
30
Mobile Device
(MD)
15
Make
TOAD
based
MD Location
42
MD send, AP receive frame
16
MD coordinates,
MD id,
T0,
accuracy estimation
33
Send AP frame TOA, AP id, waveform
17
Find
AP TOAD pairs
18
Calculate
Time Corrections
for APs
19
Time Corrections
for APs,
accuracy estimation
Send Time Corrections
110

FIG. 7