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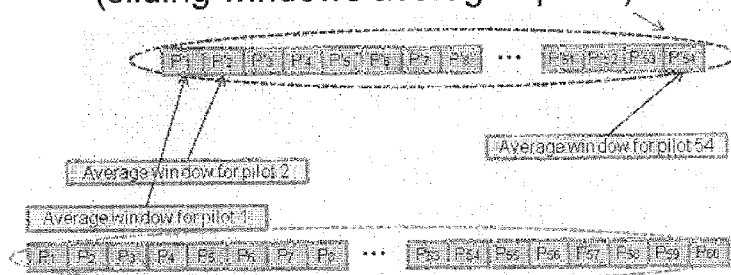
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- (54) **Title:** TIMING ERROR ESTIMATE OF UL SYNCHRONIZATION

Interference removed pilots for TOE
(sliding windows averaged pilots)



Received demodulated pilots for
desired user

Figure 4

(57) **Abstract:** The specification and drawings present a new method, apparatus and software related product (e.g., a computer readable memory) for a timing offset/error estimate (TOE) method, e.g., for a LTE UL receiver. This may especially be beneficial for the MU-MIMO and/or CoMP with MAAS applications, where the conventional methods do not work properly due to a strong interference among users (UEs) sharing the same radio resource. Two approaches (separately or in combination) may be used to improve TOE quality. First, the timing offset/error may be calculated using phase difference for pilot pairs with non-adjacent pilots/carriers having a larger separation between subcarriers than for pilot pairs with adjacent subcarriers. Second, a modified pilot sequence for timing offset estimate may be created using sliding an averaging window. This can effectively remove interference which is critical for the MU-MIMO and CoMP applications.

Description**Title****TIMING ERROR ESTIMATE OF UL SYNCHRONIZATION****Technical Field**

The exemplary and non-limiting embodiments of this invention relate generally to wireless communications and more specifically to a timing error estimate method, e.g., for a LTE UL receiver, especially for MU-MIMO and/or CoMP with MAAS.

Background Art

This section is intended to provide a background or context to the invention that is recited in the claims. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived, implemented or described. Therefore, unless otherwise indicated herein, what is described in this section is not prior art to the description and claims in this application and is not admitted to be prior art by inclusion in this section.

The following abbreviations that may be found in the specification and/or the drawing figures are defined as follows:

3GPP	third generation partnership project
AWGN	additive white Gaussian noise
CoMP	coordinated multiple point
CP	cyclical prefix
DFT	discrete Fourier transform
DL	downlink
DMRS	demodulate reference signal;
DRAN	density radio access network;
DS	data symbol
DSP	digital signal processor
E-UTRA	evolved universal terrestrial radio access
eNB or eNodeB	evolved node B /base station in an E-UTRAN system
E-UTRAN	evolved UTRAN (LTE)
FFT	fast Fourier transform
FO	frequency offset
LTE	long term evolution

	LTE-A	long term evolution advanced
	MAAS	multiple antenna aperture system
	MIMO	multiple input multiple output
	MU-MIMO	multiple-user multiple input multiple output
5	OFDM	orthogonal frequency division multiplexing
	PUSCH	physical uplink shared channel
	RB	resource block
	RS	reference symbol
	SC-FDMA	single carrier frequency division multiplexing access
10	SNR	signal to noise ratio
	TO	timing offset
	TOE	timing offset estimate
	UE	user equipment (e.g. mobile terminal)
	UL	uplink
15	UTRAN	universal terrestrial radio access network

In LTE system, timing synchronization between UE and eNB depends on the timing offset estimate of UL receiver in the eNB, where timing error of each UE is estimated and an associated adjustment command may be sent from the eNB to the UE. Therefore the timing error estimate quality directly affects the synchronization between the UE and eNB, which ultimately affects system performance. Conventional methods for timing error estimate can work in normal operation where received desired user signal power dominates. However, in case of UL MU-MIMO and/or CoMP with MAAS, the conventional methods may not work properly any more due to strong interference among users assigned the same radio resource.

It has been observed in tests for CoMP with MAAS that the UE and eNB can no longer keep synchronization in time, so that the communication between the UE and eNB may be disconnected due to a timing error estimate in the UL receiver.

Summary:

According to a first embodiment of the invention, a method, comprising: demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and sliding in the network element an averaging window through the demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component

caused by other user equipments using predetermined rules, the averaging window having a length comprising multiple pilots.

According to a second embodiment of the invention, an apparatus comprising: at least one processor and a memory storing a set of computer instructions, in which the processor and the memory storing the computer instructions are configured to cause the apparatus to:
5 demodulate a group of pilots received uplink by the apparatus from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and slide an averaging window through the demodulated pilots of the group of the demodulated pilots to determine a
10 modified group of demodulated pilots having a removed interference component caused by other user equipments using predetermined rules, the averaging window having a length comprising multiple pilots.

According to a third embodiment of the invention, a computer program product comprising a non-transitory computer readable medium bearing computer program code
15 embodied herein for use with a computer, the computer program code comprising: code for demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and code for sliding in the network element an averaging window through the demodulated pilots of the
20 group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other user equipments using

According to a fourth embodiment of the invention, a method, comprising:
demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot
25 corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and calculating in the network element timing offsets in the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency
30 subcarriers of the plurality of frequency subcarriers.

According to a fifth embodiment of the invention, an apparatus comprising: at least one processor and a memory storing a set of computer instructions, in which the processor and the memory storing the computer instructions are configured to cause the apparatus to:
demodulate a group of pilots received uplink in the apparatus from a user equipment served
35 by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and calculate timing offsets in

the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency subcarriers of the plurality of frequency subcarriers.

5 According to a sixth embodiment of the invention, a computer program product comprising a non-transitory computer readable medium bearing computer program code embodied herein for use with a computer, the computer program code comprising: code for demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot
10 corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and code for calculating in the network element timing offsets in the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency
15 subcarriers of the plurality of frequency subcarriers.

Brief Description of the Drawings:

For a better understanding of the nature and objects of the present invention, reference is made to the following detailed description taken in conjunction with the following
20 drawings, in which:

Figure 1 is a diagram depicting a time-frequency domain LTE UL signal structure for PUSCH in the UE transmitter;

Figures 2a-2b are diagrams demonstrating pilot pairs which may be user for a TOE using adjacent pilot pairs with lag 1 for a conventional approach (Figure 2a) and using pilot
25 pairs with larger separation, e.g., separated by 2 subcarriers with lag 2 (Figure 2b) according to an exemplary embodiment of the invention;

Figure 3 is a diagram of a phase ramp (useful signal) vs. a length of lag according to an exemplary embodiment of the invention;

Figure 4 is an a diagram illustrating how the pilots are formed by a sliding an averaging
30 window in case of 60 assigned pilots/subcarriers with a window size of 6 pilots/subcarriers according to exemplary embodiment of the invention;

Figures 5a-5b and 6a-6b show TOE simulation results (TO samples vs. desired user SNR) for a first embodiment of the invention;

Figures 6a-6b show TOE simulation results (TO samples vs. desired user SNR) for a
35 second embodiment of the invention;

Figure 7 is a flow chart demonstrating implementation of exemplary embodiments of

the invention by an eNB; and

Figure 8 is a block diagram of wireless devices for practicing exemplary embodiments of the invention.

5 **Detailed Description**

In LTE system, the timing synchronization between UE and serving eNB is achieved by timing error estimate conducted in the eNB UL receiver and associated adjustment commands are sent from the eNB to the UE. Therefore the timing error estimate quality
10 directly affects the synchronization between the UE and eNB, which ultimately affects system performance.

It is known that timing error in OFDM system only causes received frequency domain signal phase rotation that depends on a subcarrier index, given the timing error magnitude is within a CP interval. Conventionally, the timing offset estimate may be calculated based on a
15 phase difference of demodulated pilot (or RS) pairs between adjacent subcarriers. This method may not work in the presence of a strong interference among users and can result in detachment of the UE from the serving eNB.

A new method, apparatus, and software related product (e.g., a computer readable memory) are presented for a timing error estimate method, e.g., for a LTE UL receiver. The
20 embodiments described herein may be especially beneficial for the MU-MIMO and/or CoMP with MAAS applications, where the conventional methods do not work properly due to a strong interference among users (UEs) sharing the same radio resource. It is critical to make UL MU-MIMO and CoMP work and keep UEs synchronized with eNBs. Two approaches (separately or in combination) may be used to improve timing offset estimate quality. First, the
25 timing offset/error may be calculated using phase difference for pilot pairs with non-adjacent pilots/carriers having a larger separation between subcarriers than for pilot pairs with adjacent subcarriers. This can effectively reduce noise power and result in a better performance in all cases of interest. Second, a modified pilot sequence for timing offset estimate may be created using sliding window average (or sliding an averaging window). This can effectively remove
30 interference which is critical for the MU-MIMO and CoMP applications. The embodiments described herein can be applied to any OFDM system where there is a need to calculate timing offset estimate.

For example, according to a **first embodiment**, a network element (e.g., eNB) may receive from a UE in UL and demodulate a group of pilots to provide a group of demodulated
35 pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers.

After demodulating, the network element can calculate timing offsets/errors in the demodulated group of pilots or in a modified group of demodulated pilots (as described further herein) using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more (e.g., 5, 6 or 7) frequency subcarriers of the plurality of frequency subcarriers. Then an average timing offset can be calculated by averaging over the calculated timing offsets when the pairs being separated by two or more frequency subcarriers, which could be followed by signaling, by the network element (eNB) to the UE, an adjustment command based at least on the calculated average timing offset.

It is further shown herein that a noise component in the timing offset calculated using phase differences for pairs of the demodulated pilots is inversely proportional a lag equals to a number of the two or more frequency subcarriers separating pilots in the pairs of the demodulated pilots.

According to a **second embodiment**, first (like in the first embodiment), the network element (e.g., eNB) may receive from a UE in UL and demodulate a group of pilots to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers.

Then, however, before calculate timing offsets/errors, the network element (eNB) can perform sliding an averaging window (based on coordinated pilot orthogonality) through demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other UEs using predetermined rules, the averaging window having a length comprising multiple pilots (e.g., six or twelve pilots).

It is noted that for this embodiment the network element (eNB) may be engaged in a MU MIMO operation and/or in a CoMP operation where the UE can share at least one common radio resource with other UEs served by the network element/eNB, so that the other UEs may create the interference component in the demodulated pilots which is removed using the sliding of the averaging window. The modified group of demodulated pilots will comprise less pilots than the group of demodulated pilots by a number of pilots having a total length equals to the length of the averaging window.

Creation of the modified group of demodulated pilots may be followed by the calculation of the timing offsets/errors for this modified demodulated group of pilots (with removed interference component) using phase differences for pairs of the demodulated pilots comprised in the modified group of demodulated pilots, where the demodulated pilots in corresponding pairs may be separated by one or more frequency subcarriers of the plurality of frequency subcarriers (i.e., having lag of one or more) as further explained herein.

In the following further explanations pertinent to embodiments described herein are provided.

In order to understand the impact of timing offset on the received LTE UL signal, let us review some DFT (discrete Fourier transform) properties. Let x_l and X_k be a time domain signal and an associated frequency domain signal respectively, where $k, l = 0, 1, 2, \dots, N-1$ represent time domain sample and frequency domain subcarrier index respectively, and N is a system DFT size. When the time domain signal x_l is cyclically shifted by τ samples (where x_l is periodical signal with the period N), the frequency domain signal is given by:

$$\begin{aligned} DFT(x_{l-\tau})|_k &= \frac{1}{\sqrt{N}} \sum_{l=0}^{N-1} x_{l-\tau} e^{-j\frac{2\pi}{N}kl} = \frac{1}{\sqrt{N}} \sum_{m=-\tau}^{N-1-\tau} x_m e^{-j\frac{2\pi}{N}k(m+\tau)} \\ &= e^{-j\frac{2\pi}{N}k\tau} \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} x_m e^{-j\frac{2\pi}{N}km} \\ &= e^{-j\frac{2\pi}{N}k\tau} DFT(x_m) = e^{-j\frac{2\pi}{N}k\tau} X_k \end{aligned} \quad (1).$$

This implies that the impact of timing offset on LTE UL signal is a pure frequency domain phase rotation or a subcarrier dependent phase rotation, given the timing offset is within a CP (Cyclic Prefix) interval. Therefore, a TOE (timing offset estimate) can be calculated based on the received pilots or DMRS (demodulation reference signal).

Figure 1 depicts a frequency domain LTE UL signal structure for PUSCH (physical uplink shared channel) at mobile (UE) transmitter, where one RB (resource block) pair within one subframe (of 1 ms) is illustrated. Each RB consists of 12 subcarriers (15 MHz each) in a frequency domain and seven SC-FDMA (single carrier frequency division multiplexing access) symbols in a time domain and partitioned into DSs (data symbols) and pilots. DMRS or pilots (as known to both transmitter and receiver) are located in the middle of the RB in the time domain. In other words, the middle SC-FDMA symbol in the RB is a DMRS that occupies all subcarriers used by the mobile user (UE) for the PUSCH. As shown above, any TO (timing offset) will cause received frequency domain DMRS phase rotation or phase ramp across subcarriers as illustrated in Figure 1. Consequently, the TOE can be calculated based on the phase ramp of received DMRS or pilots.

The LTE UL timing offset estimate for a single UE according to **the first embodiment** described herein can be calculated as follows. In a conventional approach, the TOE at the UL receiver can be based on the phase difference of demodulated pilots of adjacent subcarriers. Let R_k be a frequency domain received pilot on subcarrier k . Without loss of generality, in case of timing offset τ samples with an AWGN (additive white Gaussian noise), R_k can be

represented as follows:

$$R_k = c_k e^{-j\frac{2\pi}{N}tk} + n \quad k = 0, 1, 2, \dots, N_{sc} - 1 \quad (2),$$

where c_k is a pilot sequence on k th subcarrier, which is known to the UL receiver (e.g., in the eNB); n is the AWGN and N_{sc} is a number of subcarriers of the UE used for the PUSCH (N is a system DFT size). A demodulated pilot P_k may be obtained by multiplying R_k by a conjugated pilot sequence, resulting (since $c_k c_k^* = 1$) as follows:

$$P_k = R_k c_k^* = e^{-j\frac{2\pi}{N}tk} + n', \quad k = 0, 1, 2, \dots, N_{sc} - 1 \quad (3)$$

where $n' = c_k^* n$. Therefore, the TOE based on adjacent subcarrier phase difference may be calculated as

$$\tilde{\tau}_1 = \frac{N}{2\pi} (\angle P_{k-1} - \angle P_k) = \frac{N}{2\pi} \angle (P_{k-1} P_k^*) = \frac{N}{2\pi} \left(\angle e^{j\frac{2\pi}{N}\tau} + n'' \right) = \tau + \frac{N}{2\pi} n'' = \tau + \tilde{n} \quad (4),$$

where n'' is a modified AWGN term. Then a final TOE value may be determined as an average of all $\tilde{\tau}_1$ of adjacent pilot pairs.

Furthermore, according to **the first embodiment** described herein, in order to improve TOE performance, especially in case of low SNR (signal to noise ratio), the phase difference can be calculated using pilot pairs with larger separation or lag, as shown in the Figure 2b for $N_{sc} = 12$. The conventional approach using TOE (see Equation 4) based on adjacent pilot pairs with lag 1 is demonstrated in Figure 2a, while the new TOE approach according to **the first embodiment** using pilot pairs separated by 2 subcarriers with lag 2 is illustrated in Figure 2b.

It can be shown that the TOE using pilot pairs with a larger subcarrier separation (e.g., for the lag > 1) can provide a better receiver performance. For example, let us assume that the TOE is based on the phase difference of pilot pairs separated by L subcarriers ($L > 1$), so that the

TOE can be calculated as follows:

$$\tilde{\tau}_L = \frac{N}{2\pi L} (\angle P_{k-L} - \angle P_k) = \frac{N}{2\pi L} \angle (P_{k-L} P_k^*) = \frac{N}{2\pi L} \left(\angle e^{j\frac{2\pi}{N}L\tau} + n'' \right) = \tau + \frac{N}{2\pi L} n'' = \tau + \frac{1}{L} \tilde{n} \quad (5).$$

Compared with Equation 4 for $\tilde{\tau}_1$ above, we can see that the effective noise for $\tilde{\tau}_L$ is reduced

by a factor of L . This implies that the TOE with a larger subcarrier separation will be more accurate due to a less effective noise or equivalently a larger effective SNR, as illustrated in Figure 3, where the useful signal for the TOE is a phase ramp or a phase difference across subcarriers, which is a linear function of subcarrier index or the lag for pilot pairs. Clearly, the useful signal of the pilot pair with lag 7 is much stronger than that of the pilot pair with lag 1.

Moreover, intuitively, one may want to use pilot pairs with the largest possible lag for timing offset estimate to maximize the effective SNR per pilot pair. However, the number of pilot pairs would decrease as the lag increases for a given N_{sc} , which is the total number of subcarriers of the UE. This implies less benefits from averaging for the final TOE. Also, there is another restriction on the selection of lags. To avoid phase ambiguity in the TOE calculation, the lag L must satisfy the following condition:

$$-\pi < \frac{2\pi}{N} L \tau < \pi \quad \text{or} \quad -0.5N < L \tau < 0.5N \quad (6).$$

For example for a 10MHz system with $N = 1024$, to support timing offset estimate up to 70 samples, the largest lag cannot be greater than 7.

Then, if a particular lag selection for the TOE is $L = 5, 6$ and 7 , the final TOE may be calculated as an average of all possible pilot pairs associated with $\tilde{\tau}_5$, $\tilde{\tau}_6$ and $\tilde{\tau}_7$ which are given by:

$$\tilde{\tau}_5 = \frac{1}{(N_{sc} - 5)} \frac{N}{10\pi} \sum_{5 \leq k \leq N_{sc}-1} \angle(P_{k-5} P_k^*) \quad (7a)$$

$$\tilde{\tau}_6 = \frac{1}{(N_{sc} - 6)} \frac{N}{12\pi} \sum_{6 \leq k \leq N_{sc}-1} \angle(P_{k-6} P_k^*) \quad (7b)$$

$$\tilde{\tau}_7 = \frac{1}{(N_{sc} - 7)} \frac{N}{14\pi} \sum_{7 \leq k \leq N_{sc}-1} \angle(P_{k-7} P_k^*) \quad (7c)$$

and then the average TOE can be determined as an average:

$$\hat{\tau} = \frac{1}{3} (\tilde{\tau}_5 + \tilde{\tau}_6 + \tilde{\tau}_7) \quad (8),$$

where $\hat{\tau}$ is a final estimated timing offset.

According to **the second embodiment** described herein, the LTE UL timing offset estimate for a multi-UE case with CoMP and/or MIMO operation can be calculated as follows. In this scenario, multiple users may share the same radio resource or RBs. Consequently, received pilots can be represented as:

$$R_k = \sum_{u=1}^M g_u c_k(u) e^{-j2\pi\tau_u \frac{k}{N}} + n \quad k = 0, 1, 2, \dots, N_{sc} - 1 \quad (9),$$

Where M is a number of users sharing the same radio resource, g_u is a channel gain of k th subcarrier, $c_k(u)$ is a pilot on a subcarrier k of the user (UE) u , τ_u is a timing offset of the user u , N_{sc} is a number of subcarriers of the PUSCH for the desired UE and n is a corresponding AWGN. The TOE for the desired user based on the method described above for a single UE can suffer a significant performance loss due to a strong interference among the multiple users.

In this case, it is essential to suppress the interference for the TOE calculation. By exploiting orthogonality of the LTE UL pilot sequences, especially for the UL MIMO and UL CoMP with coordinated pilot operation, we can virtually remove the multi-user interferences in the received DMRS. Without loss of generality, let user 1 be a desired UE. Then demodulated pilots of the user 1 may be determined by multiplying R_k by conjugated pilot sequence of user 1, resulting (since $c_k(1)c_k^*(1) = 1$) as follows:

$$P_k = R_k c_k^*(1) = g_1 e^{-j2\pi\tau_1 \frac{k}{N}} + \sum_{u=2}^M g_u c_k(u) c_k^*(1) e^{-j2\pi\tau_u \frac{k}{N}} + n', \quad k = 0, 1, 2, \dots, N_{sc} - 1 \quad (10),$$

where $n' = c_k^*(1)n$. A set of new (modified group of) demodulated pilots, denoted by P'_k , may be calculated by sliding window average (or averaging window) on P_k . For a proper window size W , e.g., $W = 6$ or 12 , LTE UL pilot sequences may be designed so that

$$\frac{1}{W} \sum_{w=1}^W c_{k+w}(u) c_{k+w}^*(v) = \begin{cases} 1 & u = v \\ 0 & u \neq v \end{cases} \quad (11)$$

for the subcarrier index k such that $k + W \leq N_{sc} - 1$. Therefore, a group of new calculated pilots is less by W in length than the original received demodulated group of pilots. The new calculated pilots for the user 1 do not contain interference from other users. Then P'_k can be calculated as follows ("0" indicates that there is no interference term and n'' is an average over W pilots):

$$P'_k = \frac{1}{W} \sum_{w=1}^W P_{k+w} = g_1 \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau_1 \frac{k+w}{N}} + 0 + n'', \quad k = 0, 1, 2, \dots, N_{sc} - W - 1 \quad (12)$$

Figure 4 illustrates how the new pilots are formed by a sliding window average

(averaging window) in case of 60 assigned subcarriers or equivalently 5 RBs and a window size of 6, where received 60 pilots are demodulated by the DMRS sequence of the desired user, then 6 of consecutive pilots are continuously selected and averaged to form a set of new modified pilots having $60 - 6 = 54$ pilots/subcarriers in length. Then the TOE can be calculated using the new 54 pilots.

In the following, we will show how the TOE can be calculated using the new pilots. For simplicity and without loss of generality, we can write

$$P'_k = \frac{1}{W} \sum_{w=1}^W P_{k+w} = \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau \frac{k+w}{N}} + n \quad k = 0, 1, 2, \dots, N_{sc} - W - 1 \quad (13),$$

where τ represents a TO of the desired user. Then the TOE can be calculated based on the phase difference between adjacent subcarriers of the new pilots (similar to Equation 4 for the **first embodiment**), as follows:

$$\begin{aligned} \tilde{\tau}_1 &= \frac{N}{2\pi} (\angle P'_{k-1} - \angle P'_k) = \frac{N}{2\pi} \left(\angle \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau \frac{k-1+w}{N}} - \angle \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau \frac{k+w}{N}} \right) + n' \\ &= \frac{N}{2\pi} \frac{1}{W} \sum_{w=1}^W 2\pi\tau \left(\frac{k+w}{N} - \frac{k-1+w}{N} \right) + \frac{N}{2\pi} n' \\ &= \tau \frac{1}{W} \sum_{w=1}^W 1 + \frac{N}{2\pi} n' \\ &= \tau + \tilde{n} \end{aligned} \quad (14),$$

where n' is a modified AWGN term. Similarly, we can calculate the TOE using pilot pairs with larger subcarrier separation, or lags, to reduce the effective noise, as described for the single UE according to the **first embodiment**, as follows:

$$\begin{aligned} \tilde{\tau}_L &= \frac{N}{2\pi L} (\angle P'_{k-L} - \angle P'_k) = \frac{N}{2\pi L} \left(\angle \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau \frac{k-L+w}{N}} - \angle \frac{1}{W} \sum_{w=1}^W e^{-j2\pi\tau \frac{k+w}{N}} \right) + n' \\ &= \frac{N}{2\pi L} \frac{1}{W} \sum_{w=1}^W 2\pi\tau \left(\frac{k+w}{N} - \frac{k-L+w}{N} \right) + \frac{N}{2\pi L} n' \\ &= \tau \frac{1}{W} \sum_{w=1}^W 1 + \frac{N}{2\pi L} n' \\ &= \tau + \frac{1}{L} \tilde{n} \end{aligned} \quad (15).$$

As for the single UE case described in the first embodiment, the effective noise is

reduced by L times if one uses pilot pairs with large separation L . For example, in case of $L = 6$ and 7 , the final TOE may be calculated as an average of all possible pilot pairs associated

with $\tilde{\tau}_5$, $\tilde{\tau}_6$ and $\tilde{\tau}_7$ which are given by:

$$\tilde{\tau}_5 = \frac{1}{(N_{sc} - 5)} \frac{N}{10\pi} \sum_{5 \leq k \leq N_{sc}-1} \angle(P'_{k-5} P'^{*}_k) \quad (16a)$$

$$\tilde{\tau}_6 = \frac{1}{(N_{sc} - 6)} \frac{N}{12\pi} \sum_{6 \leq k \leq N_{sc}-1} \angle(P'_{k-6} P'^{*}_k) \quad (16b)$$

$$\tilde{\tau}_7 = \frac{1}{(N_{sc} - 7)} \frac{N}{14\pi} \sum_{7 \leq k \leq N_{sc}-1} \angle(P'_{k-7} P'^{*}_k) \quad (16c),$$

and then the average TOE can be determined (as in the first embodiment, see Equation 8) as an average:

$$\hat{\tau} = \frac{1}{3} (\tilde{\tau}_5 + \tilde{\tau}_6 + \tilde{\tau}_7) \quad (17).$$

Figures 5a-5b and 6a-6b show TOE simulation results (TO samples vs. desired user SNR). Figures 5a illustrates single UE TOE simulation results using a convention approach (using adjacent pilot pairs) and Figure 5b illustrates single UE TOE simulation results using the new method for the **first embodiment** for lags 5, 6 and 7 in case of the AWGN channel. As expected, the new TOE method (as shown in Figure 5b) outperforms conventional one (as shown in Figure 5a) in terms of both mean value and estimate error variance. Note, that a solid line is an actual timing offset, a line with * represents a mean value of the estimated timing offset, dotted and dash-dotted lines indicate standard deviation of the estimated timing offset around a mean value, respectively.

Furthermore, as demonstrated in Figures 6a-6b, in case of two users with MIMO or CoMP, the conventional method fails (as shown in Figure 6a) while sliding window approach with lag 5, 6 and 7 works perfectly (as shown in Figure 6b), where the interference is completely averaged out.

Figure 7 shows an exemplary flow chart demonstrating implementation of embodiments of the invention by a network element (e.g., eNB). It is noted that the order of steps shown in Figure 7 is not absolutely required, so in principle, the various steps may be performed out of the illustrated order. Also certain steps may be skipped, different steps may be added or substituted, or selected steps or groups of steps may be performed in a separate application.

In a method according to the exemplary embodiment shown in Figure 7, in a first step **40**, the eNB (network element) demodulates a group of pilots received UL in a UE served by the eNB to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers.

5 In a next step **42**, the eNB performs sliding an averaging window through the demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other UEs using predetermined rules (e.g., the averaging window may have a length of six pilots or twelve pilots).

10 In a next step **44**, the eNB calculates timing offsets in the group of demodulated pilots or in the modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots (according to **the first embodiment** if step **42** is not performed) or in the modified group of demodulated pilots (according to **the second embodiment** if step **42** is performed), the demodulated pilots in the
15 pairs being separated by one or more frequency subcarriers (for the modified group of demodulated pilots) or by two or more frequency subcarriers (for the modified group of demodulated pilots) of the plurality of frequency subcarriers

In a next step **46**, the eNB calculates an average timing offset by averaging over the calculated timing offsets. In a next step **48**, the eNB signals to the UE an adjustment command
20 based at least on the calculated average timing offset.

Figure 8 shows an example of a block diagram demonstrating wireless devices (e.g., in LTE) including a network element (e.g., eNB) **80** comprised in a network **100**, and a UE **82** communicating with the eNB **80**, according to an embodiment of the invention. Figure 8 is a simplified block diagram of various electronic devices that are suitable for practicing the
25 exemplary embodiments of this invention, and a specific manner in which components of an electronic device are configured to cause that electronic device to operate. The UE **82** may be a mobile phone, a camera mobile phone, a wireless video phone, a portable device or a wireless computer, etc.

The eNB **80** may comprise, e.g., at least one transmitter **80a**, at least one receiver **80b**,
30 at least one processor **80c** at least one memory **80d** and a TOE application module **80e**. The transmitter **80a** and the receiver **80b** may be configured to provide a wireless communication with the UE **82** (and others not shown in Figure 8), e.g., through a corresponding link **81**, according to the embodiments of the invention. The transmitter **80a** and the receiver **80b** may be generally means for transmitting/receiving and may be implemented as a transceiver, or a
35 structural equivalence thereof. It is further noted that the same requirements and considerations are applied to transmitter and receiver of the UE **82**.

Various embodiments of the at least one memory **80d** (e.g., computer readable memory) may include any data storage technology type which is suitable to the local technical environment, including but not limited to semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory, removable memory, disc memory, flash memory, DRAM, SRAM, EEPROM and the like. Various embodiments of the processor **80c** include but are not limited to general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and multi-core processors. Similar embodiments are applicable to memories and processors in other wireless devices such as UE **82** shown in Figure 8.

The TOE application module **80e** may provide various instructions for performing steps **40-48** shown in Figure 7 (according to the **first or second embodiments** described herein). The module **80e** may be implemented as an application computer program stored in the memory **80d**, but in general it may be implemented as software, firmware and/or hardware module or a combination thereof. In particular, in the case of software or firmware, one embodiment may be implemented using a software related product such as a computer readable memory (e.g., non-transitory computer readable memory), computer readable medium or a computer readable storage structure comprising computer readable instructions (e.g., program instructions) using a computer program code (i.e., the software or firmware) thereon to be executed by a computer processor. Furthermore, the module **80e** may be implemented as a separate block or may be combined with any other module/block of the device **80**, or it may be split into several blocks according to their functionality.

The UE **82** may have similar components as the eNB **80**, as shown in Figure 8, so that the above discussion about components of the eNB **80** is fully applicable to the components of the UE **82**.

It is noted that various non-limiting embodiments described herein may be used separately, combined or selectively combined for specific applications.

Further, some of the various features of the above non-limiting embodiments may be used to advantage without the corresponding use of other described features. The foregoing description should therefore be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the scope of the invention, and the appended claims are intended to cover such modifications and arrangements.

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CLAIMS:

What is claimed is:

- 5 1. A method, comprising:
 demodulating a group of pilots received uplink in a network element from a user
equipment served by the network element to provide a group of demodulated pilots, each pilot
corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and
 sliding in the network element an averaging window through the demodulated pilots of
10 the group of the demodulated pilots to determine a modified group of demodulated pilots
having a removed interference component caused by other user equipments using
predetermined rules, the averaging window having a length comprising multiple pilots.
- 15 2. The method of claim 1, further comprising:
 calculating in the network element timing offsets in the demodulated group of pilots
using phase differences for pairs of the demodulated pilots comprised in the modified group of
demodulated pilots, the demodulated pilots in the pairs the pairs being separated by one or
more frequency subcarriers of the plurality of frequency subcarriers.
- 20 3. The method of claim 2, further comprising:
 calculating in the network element an average timing offset by averaging over the
calculated timing offsets; and
 signaling, by the network element to the user equipment, an adjustment command
based at least on the calculated average timing offset.
- 25 4. The method of claim 2, wherein the demodulated pilots in the pairs being separated by
two or more frequency subcarriers.
- 30 5. The method of claim 2, wherein the demodulated pilots in the corresponding pairs
being separated by five, six or seven frequency subcarriers of the plurality of frequency
subcarriers.

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6. The method of claim 1, wherein a noise component in the timing offset is inversely proportional a lag equals to a number of the two or more frequency subcarriers separating demodulated pilots in the pairs of the demodulated pilots.

5 7. The method of claim 1, wherein the averaging window has a length of six pilots or twelve pilots.

8. The method of claim 1, wherein the network element is engaged in a multiple-user multiple input multiple output operation or in a coordinated multiple point operation where the
10 user equipment share at least one common radio resource with the other user equipments, so that the other user equipments create the interference component in the demodulated pilots which is removed using said sliding of the averaging window.

9. The method of claim 1, wherein the modified group of demodulated pilots comprises
15 less pilots than the group of demodulated pilots by a number of pilots having a total duration equals to a duration of the averaging window.

10. The method of claim 1, wherein the sliding of the averaging window is based on coordinated pilot orthogonality.
20

11. The method of claim 1, wherein the network element comprises an eNB.

12. An apparatus comprising:
at least one processor and a memory storing a set of computer instructions, in which
25 the processor and the memory storing the computer instructions are configured to cause the apparatus to:
demodulate a group of pilots received uplink by the apparatus from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and
30 slide an averaging window through the demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other user equipments using predetermined rules, the averaging window having a length comprising multiple pilots.

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13. The apparatus of claim 12, wherein the computer instructions are configured to cause the apparatus to:

calculate timing offsets in the demodulated group of pilots using phase differences for pairs of the demodulated pilots comprised in the modified group of demodulated pilots, the demodulated pilots in the pairs the pairs being separated by one or more frequency subcarriers of the plurality of frequency subcarriers.

14. The apparatus of claim 13, wherein the computer instructions are configured to cause the apparatus to:

calculate an average timing offset by averaging over the calculated timing offsets; and signal to the user equipment an adjustment command based at least on the calculated average timing offset.

15. The apparatus of claim 12, wherein the demodulated pilots in the pairs being separated by two or more frequency subcarriers.

16. The apparatus of claim 12, wherein the averaging window has a length of six pilots or twelve pilots.

17. The apparatus of claim 12, wherein the apparatus is engaged in a multiple-user multiple input multiple output operation or in a coordinated multiple point operation where the user equipment share at least one common radio resource with the other user equipments, so that the other user equipments create the interference component in the demodulated pilots which is removed using said sliding of the averaging window.

18. The apparatus of claim 12, wherein the sliding of the averaging window is based on coordinated pilot orthogonality.

19. The apparatus of claim 12, wherein the apparatus comprises an eNB.

20. A computer program product comprising a non-transitory computer readable medium bearing computer program code embodied herein for use with a computer, the computer program code comprising:

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code for demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and
code for sliding in the network element an averaging window through the demodulated
5 pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other user equipments using

21. A method, comprising:

demodulating a group of pilots received uplink in a network element from a user
10 equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and
calculating in the network element timing offsets in the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the
demodulated pilots comprised in the group of demodulated pilots or in the modified group of
15 demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency subcarriers of the plurality of frequency subcarriers.

22. The method of claim 21, further comprising:

calculating in the network element an average timing offset by averaging over the
20 calculated timing offsets when the t demodulated pilots in the pairs being separated by two or more frequency subcarriers; and
signaling, by the network element to the user equipment, an adjustment command based at least on the calculated average timing offset.

25 23. The method of claim 21, wherein the network element comprises an eNB.

24. The method of claim 21, wherein the demodulated pilots in the pairs being separated by five, six or seven frequency subcarriers of the plurality of frequency subcarriers.

30 25. The method of claim 21, wherein a noise component in the timing offset is inversely proportional a lag equals to a number of the two or more frequency subcarriers separating pilots in the pairs of the demodulated pilots.

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26. The method of claim 21, wherein after demodulating the group of pilots but before calculating the timing offsets, the method comprises:

sliding an averaging window through demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other user equipments using predetermined rules, the averaging window having a length comprising multiple pilots, so that

said calculating of the timing offsets is performed in the modified demodulated group of pilots using phase differences for pairs of the demodulated pilots comprised in the modified group of demodulated pilots.

27. The method of claim 26, wherein the averaging window has a length of six pilots or twelve pilots.

28. The method of claim 26, wherein the network element is engaged in a multiple-user multiple input multiple output operation or in a coordinated multiple point operation where the user equipment share at least one common radio resource with the other user equipments, so that the other user equipments create the interference component in the demodulated pilots which is removed using said sliding of the averaging window.

29. The method of claim 26, wherein the modified group of demodulated pilots comprises less pilots than the group of demodulated pilots by a number of pilots having a total duration equals to a duration of the averaging window.

30. The method of claim 26, wherein the sliding of the averaging window is based on coordinated pilot orthogonality.

31. An apparatus comprising:

at least one processor and a memory storing a set of computer instructions, in which the processor and the memory storing the computer instructions are configured to cause the apparatus to:

demodulate a group of pilots received uplink in the apparatus from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and

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calculate timing offsets in the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency subcarriers of the plurality of frequency subcarriers.

32. The apparatus of claim 31, wherein the computer instructions are configured to cause the apparatus to:

calculate an average timing offset by averaging over the calculated timing offsets when the t demodulated pilots in the pairs being separated by two or more frequency subcarriers; and

signal to the user equipment an adjustment command based at least on the calculated average timing offset.

33. The apparatus of claim 31, wherein the apparatus comprises an eNB.

34. The apparatus of claim 31, wherein the demodulated pilots in the pairs being separated by five, six or seven frequency subcarriers of the plurality of frequency subcarriers.

35. The apparatus of claim 31, wherein after demodulating the group of pilots but before calculating the timing offsets, the computer instructions are configured to cause the apparatus to:

slide an averaging window through demodulated pilots of the group of the demodulated pilots to determine a modified group of demodulated pilots having a removed interference component caused by other user equipments using predetermined rules, the averaging window having a length comprising multiple pilots, so that

said calculating of the timing offsets is performed in the modified demodulated group of pilots using phase differences for pairs of the demodulated pilots comprised in the modified group of demodulated pilots.

36. The apparatus of claim 35, wherein the averaging window has a length of six pilots or twelve pilots.

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37. The apparatus of claim 35, wherein the apparatus is engaged in a multiple-user multiple input multiple output operation or in a coordinated multiple point operation where the user equipment share at least one common radio resource with the other user equipments, so that the other user equipments create the interference component in the demodulated pilots which is removed using said sliding of the averaging window.

38. The apparatus of claim 35, wherein the modified group of demodulated pilots comprises less pilots than the group of demodulated pilots by a number of pilots having a total duration equals to a duration of the averaging window.

39. The apparatus of claim 35, wherein the sliding of the averaging window is based on coordinated pilot orthogonality.

40. A computer program product comprising a non-transitory computer readable medium bearing computer program code embodied herein for use with a computer, the computer program code comprising:

code for demodulating a group of pilots received uplink in a network element from a user equipment served by the network element to provide a group of demodulated pilots, each pilot corresponding to one frequency subcarrier of a plurality of frequency subcarriers; and

code for calculating in the network element timing offsets in the group of demodulated pilots or in a modified group of demodulated pilots using phase differences for pairs of the demodulated pilots comprised in the group of demodulated pilots or in the modified group of demodulated pilots, the demodulated pilots in the pairs being separated by two or more frequency subcarriers of the plurality of frequency subcarriers.

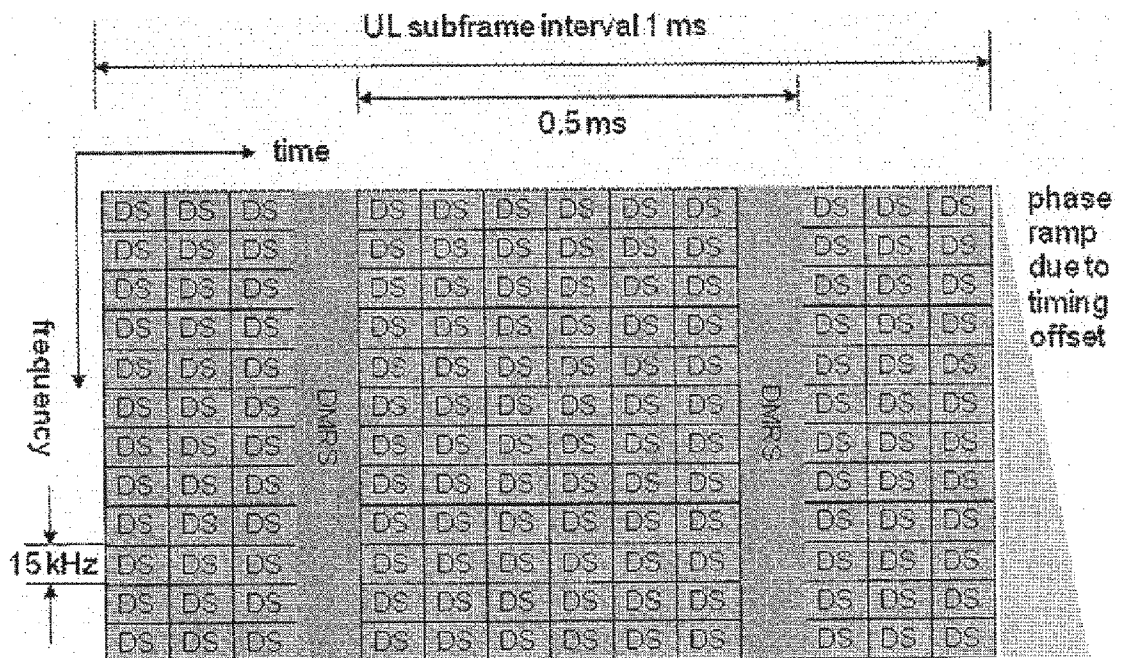


Figure 1

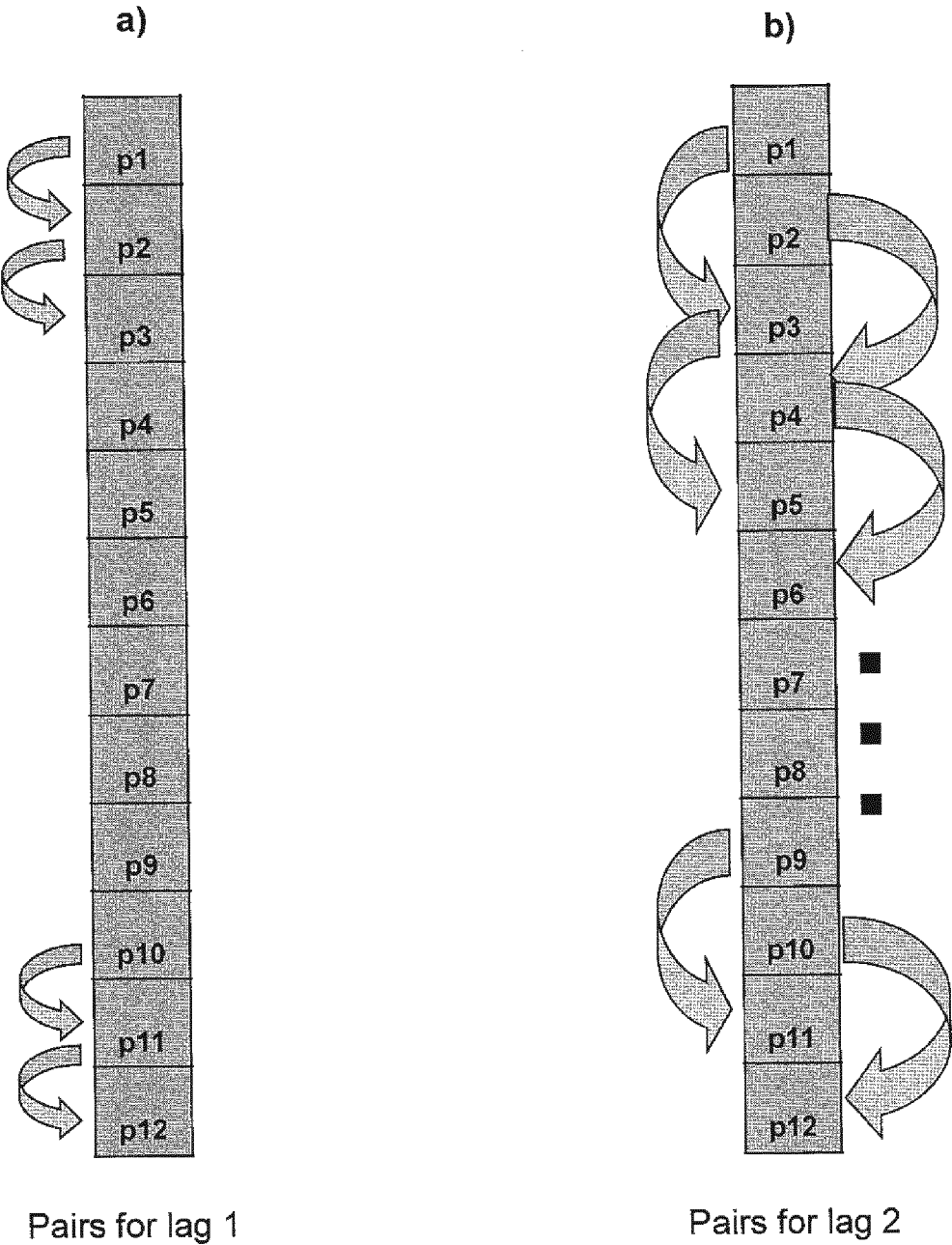


Figure 2

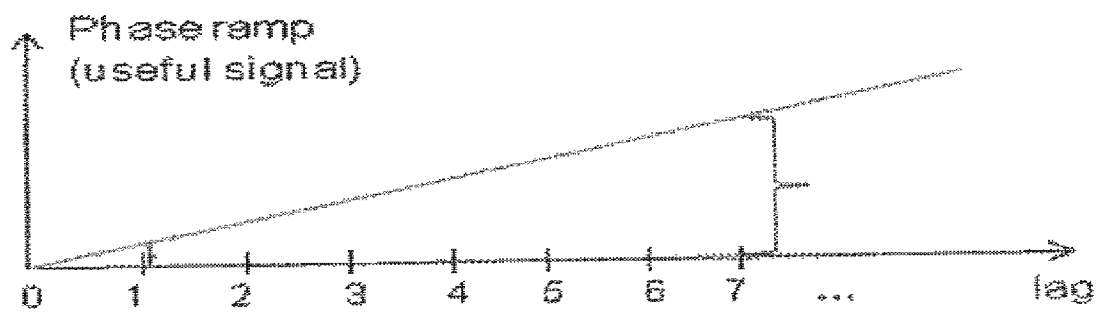
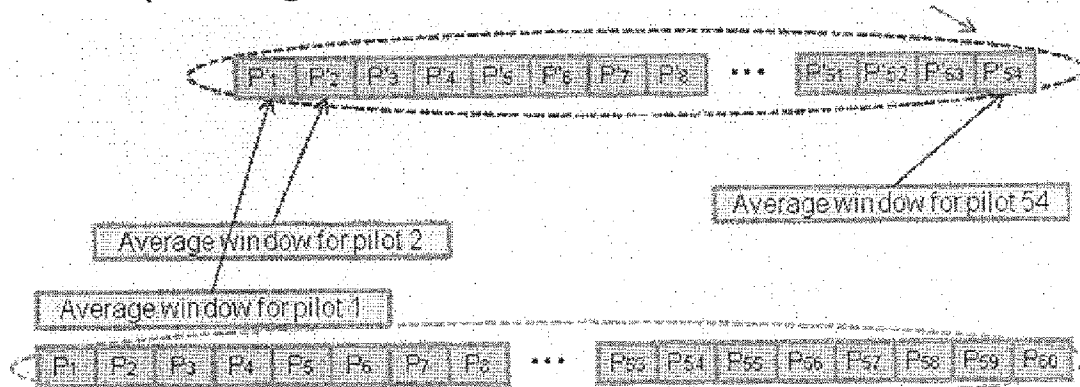


Figure 3

Interference removed pilots for TOE
(sliding windows averaged pilots)



Received demodulated pilots for
desired user

Figure 4

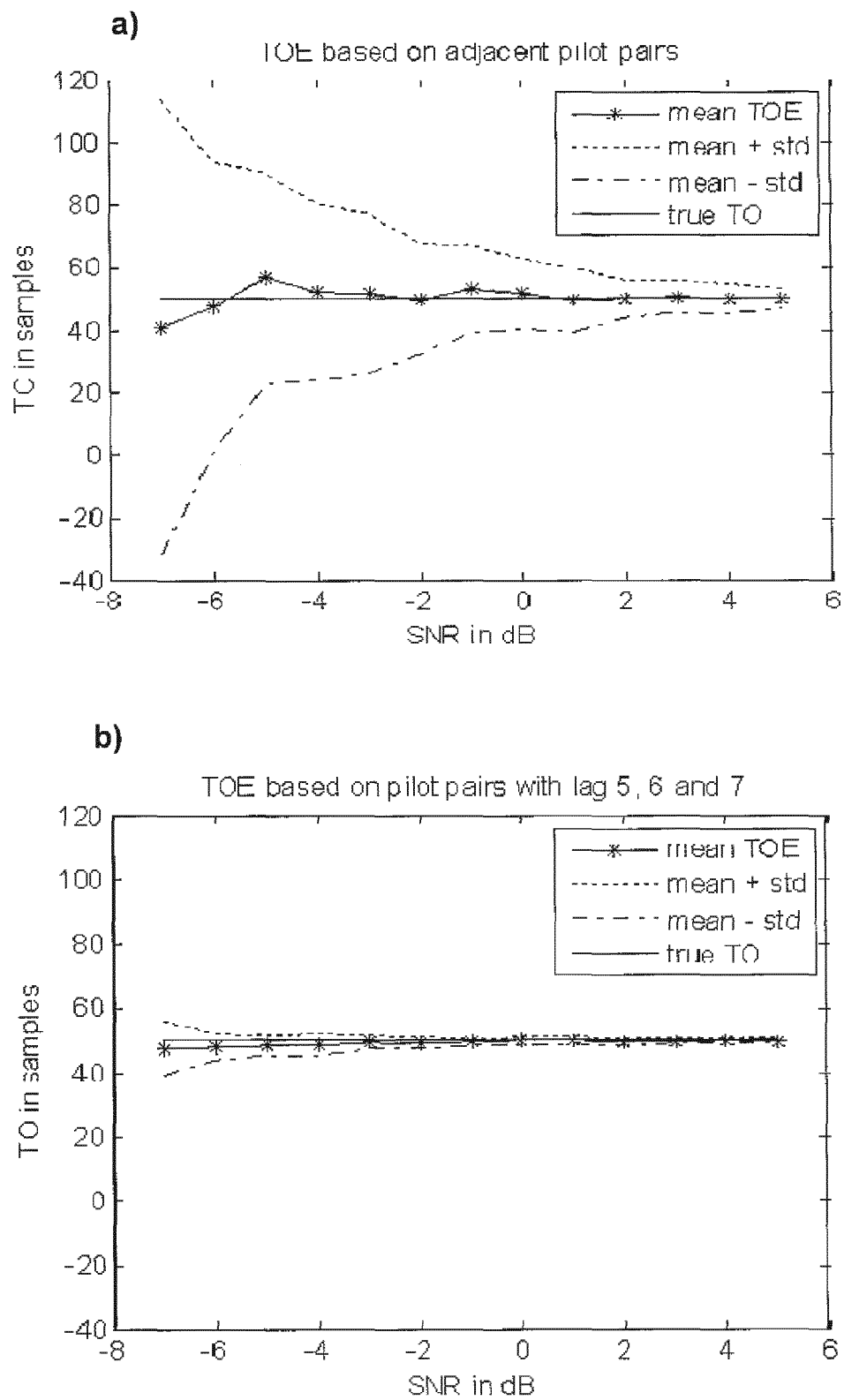


Figure 5

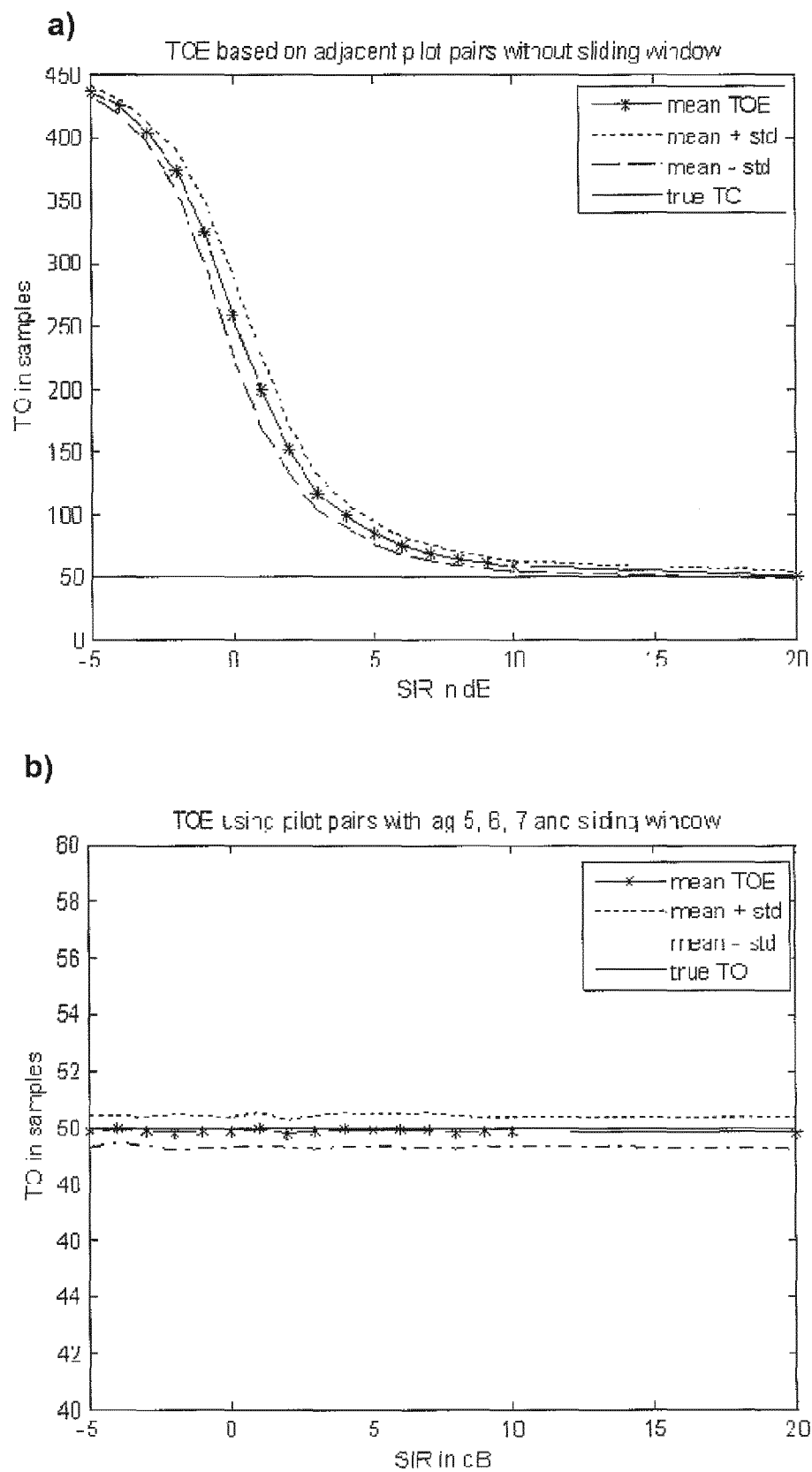


Figure 6

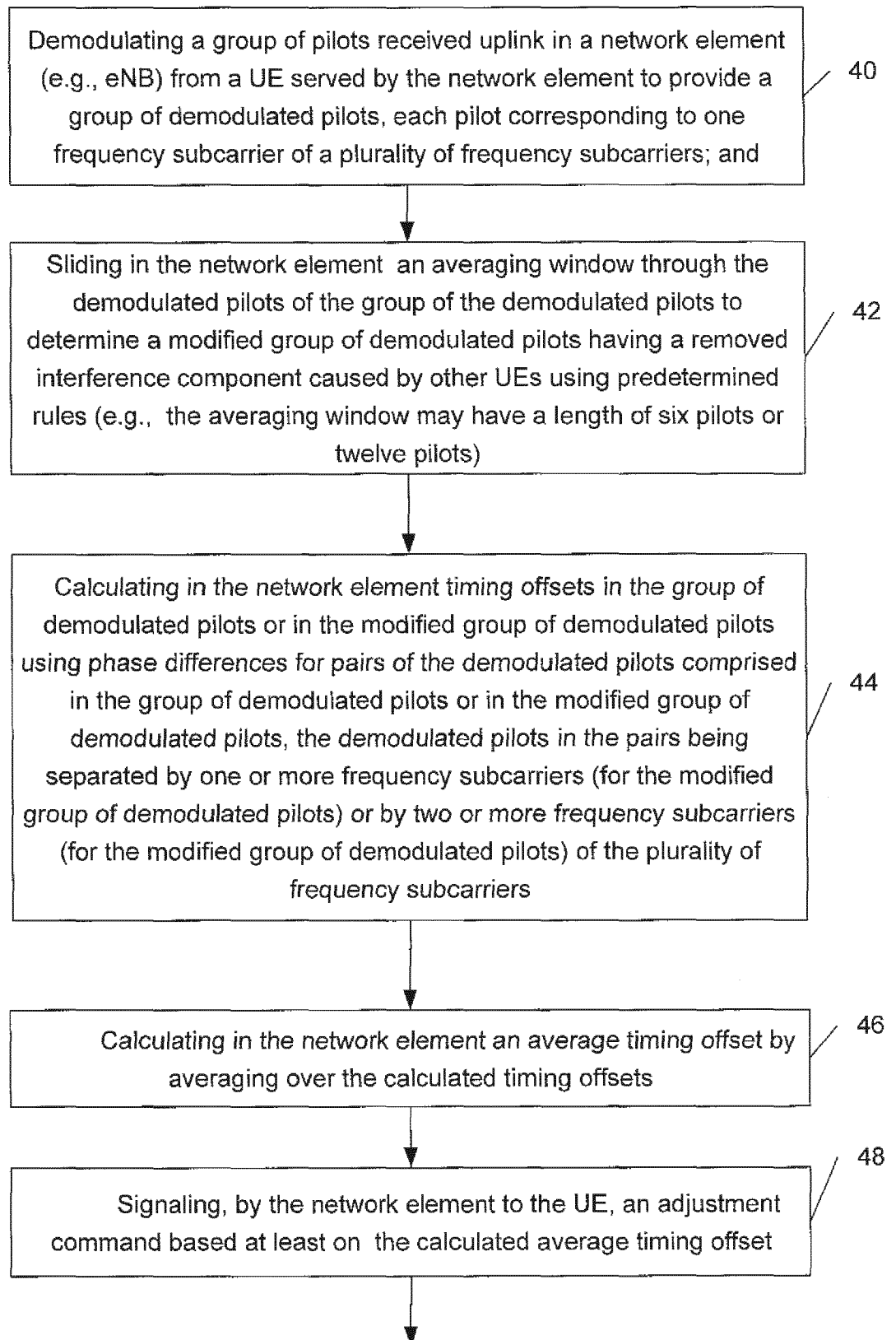


Figure 7

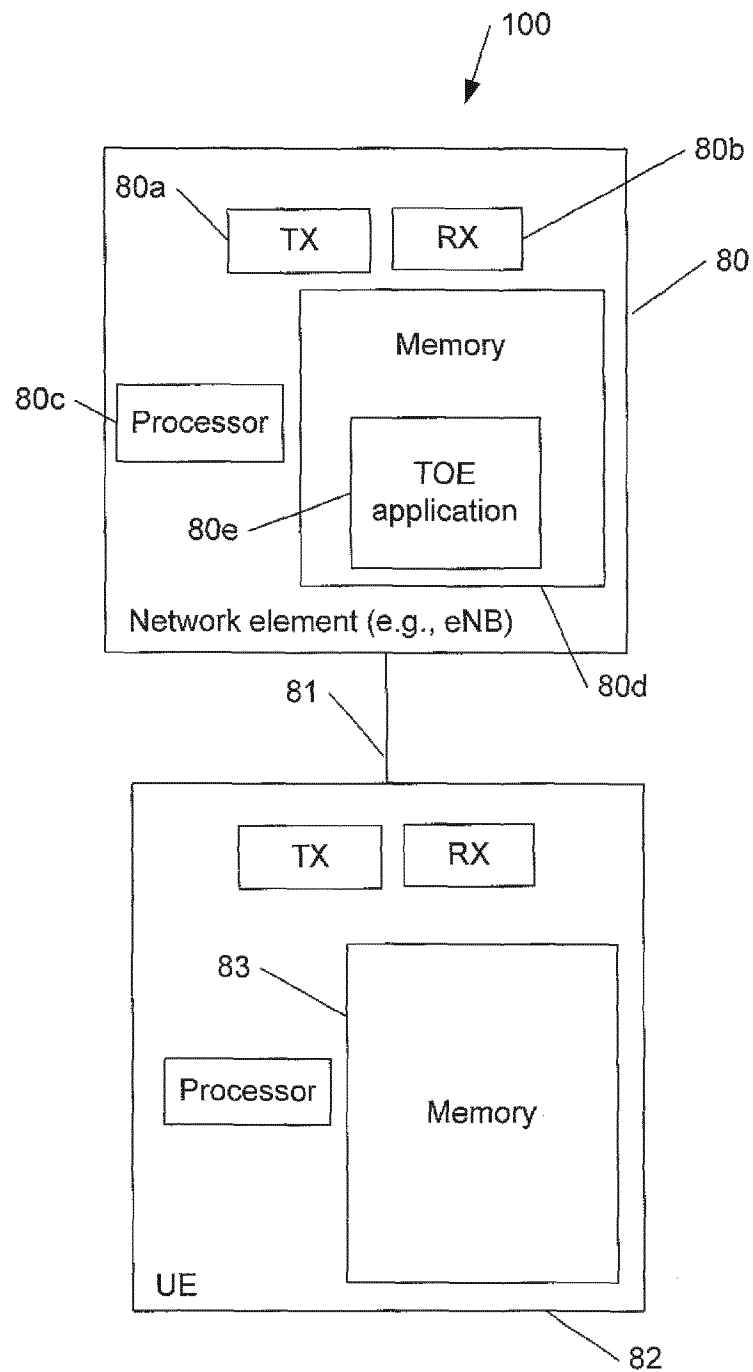


Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/076906

A. CLASSIFICATION OF SUBJECT MATTER INV. H04L27/26 ADD.		
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) H04L		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, COMPENDEX, INSPEC, IBM-TDB, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KIM D K ET AL: "A NEW JOINT ALGORITHM OF SYMBOL TIMING RECOVERY AND SAMPLING CLOCK ADJUSTMENT FOR OFDM SYSTEMS", IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 44, no. 3, 1 August 1998 (1998-08-01), pages 1142-1148, XP000851632, ISSN: 0098-3063, DOI: 10.1109/30.713247 page 1144, right-hand column figures 1, 3 -----	1,12, 20-40
<input style="width: 20px; height: 20px; margin-right: 5px;" type="checkbox"/> Further documents are listed in the continuation of Box C. <input style="width: 20px; height: 20px; margin-right: 5px;" type="checkbox"/> See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 6 March 2014	Date of mailing of the international search report 13/03/2014	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Farese, Luca	