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**APPARATUS AND METHOD FOR FRAME DETECTION AND/OR
FREQUENCY OFFSET DETECTION IN A RECEIVED WIRELESS
COMMUNICATIONS SIGNAL**

- 5 The invention relates to an apparatus and method for frame detection and/or frequency offset detection in a received wireless communications signal.

Differential phase shift keying (DPSK) modulation schemes are widely used in wireless communications. For example, Differential Quadrature Phase Shift Keying (DQPSK) is employed in WLAN systems. 8DPSK is used in the
10 Bluetooth Medium Rate system. $\pi/4$ DQPSK is proposed for use in IS-54 and IS-136 TDMA systems, the Bluetooth Medium Rate system, PHS, Inter-vehicle communication (IVC) and Road-to-vehicle communication (RVC) system, Terrestrial Trunked Radio (TETRA) system, and satellite communication system, and so on.

- 15 Frame detection and frequency estimation modules are two important modules in wireless communication systems. The implementation of frame detection methods is for the purpose of finding the correct starting point of a data frame to ensure any forward error correction (FEC) decoder (e.g. Turbo or Viterbi decoder) in a receiver performs correctly. The performance of block decoding
20 schemes such as Turbo decoding and Viterbi decoding is sensitive to a correct determination of the correct coding block size and position.

Frequency offset estimation and correction methods are used in wireless communication systems to compensate for frequency offset of the received signal caused by clock drift and Doppler shift. If the frequency offset is
25 excessive and suitable compensation is not provided, the performance of the demodulator at the receiver will be degraded and the original signal data may not be recoverable.



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A common structure for a frame of a wireless communications signal is illustrated in Figure 1. A frame 10 comprises preamble (PR) portion 12 and unique word (UW) portion 14 in each frame. The frame 10 also comprises data payload portion 16, subjected to encoding which, in the example of Figure 1, is Turbo encoding. Timing estimation and synchronization is effected by the receiver during the period of preamble 12 portion, while UW portion 14 is used for frame detection and frequency offset estimation.

The k^{th} received symbol of frame 10 can be represented by:

$$r(k) = (I_k + jQ_k)e^{j[2\pi(f+\Delta f)kT_s + \Delta\psi]} \quad (1)$$

Where f is the carrier frequency, Δf is the frequency offset, $\Delta\psi$ is the carrier phase difference between transmitter and receiver and T_s is the symbol interval.

A receiver apparatus usually comprises a demodulator module (not shown) for demodulating the received symbol with local carrier $e^{j2\pi f t}$ which yields a representation of the demodulated k^{th} symbol as follows:

$$d(k) = (I_k + jQ_k)e^{j[2\pi\Delta f kT_s + \Delta\psi]} \quad (2)$$

Likewise, the $(k-1)^{\text{th}}$ demodulated symbol is defined by:

$$d(k-1) = (I_{k-1} + jQ_{k-1})e^{j[2\pi\Delta f (k-1)T_s + \Delta\psi]} \quad (3)$$

Differential demodulation of the signal comprises complex multiplication of $d(k)$ and the conjugate of $d(k-1)$ yields the following result:

$$\begin{aligned} d(k) \times d^*(k-1) &= (I_k + jQ_k)e^{j[2\pi\Delta f kT_s + \Delta\psi]} \times (I_{k-1} + jQ_{k-1})^* e^{-j[2\pi\Delta f (k-1)T_s + \Delta\psi]} \\ &= (I_k + jQ_k) \times (I_{k-1} + jQ_{k-1})^* \times e^{j2\pi\Delta f T_s} \end{aligned} \quad (4)$$

The differential modulation scheme determines the relationship between the adjacent symbols as being:

$$(I_k + jQ_k) = (I_{k-1} + jQ_{k-1})e^{j\Delta\phi_k} \quad (5)$$

Where $\Delta\phi_k$ is a difference between absolute phases of two consecutive symbols k and k-1, which is determined by the modulated signal at symbol k. Hence:

$$d(k) \times d^*(k-1) = (|I_{k-1}|^2 + |Q_{k-1}|^2) \times e^{j2\pi\Delta f T_s} \times e^{j\Delta\phi_k} \quad (6)$$

The phase offset of the received signal resulting from the frequency offset is expressed as:

$$e^{j2\pi\Delta f T_s} = \frac{d(k) \times d^*(k-1) \times e^{-j\Delta\phi_k}}{|I_{k-1}|^2 + |Q_{k-1}|^2} \quad (7)$$

Common frame detection and frequency estimation systems are implemented by correlating the received signal with a known UW pattern, details of which are available to the receiver. Assuming the known UW symbols are mapped into phase $\Delta\phi_k'$. The next step is for the output signals from the differential demodulator to be correlated with $e^{-j\Delta\phi_k'}$ in a correlator. The correlator output signal is defined by:

$$SUM = \sum_{k=1}^L \left(A_k e^{j2\pi\Delta f T_s} e^{j\Delta\phi_k} e^{-j\Delta\phi_k'} \right) = \sum_{k=1}^L \left(A_k e^{j2\pi\Delta f T_s} e^{j(\Delta\phi_k - \Delta\phi_k')} \right) = e^{j2\pi\Delta f T_s} \times \sum_{k=1}^L \left(A_k e^{j(\Delta\phi_k - \Delta\phi_k')} \right) \quad (8)$$

Here $A_k = |I_{k-1}|^2 + |Q_{k-1}|^2$ represents the energy of symbol k, L is the correlation length and $\Delta\phi_k - \Delta\phi_k'$ $k = 1, \dots, L$ are a set of phase differences between the

received symbols and the known UW symbols.

After correlation, the demodulator checks the amplitude of the correlation result SUM from the following:

$$AMP = \left| e^{j2\pi\Delta f T_s} \times \sum_{k=1}^L \left(A_k e^{j(\Delta\phi_k - \Delta\phi_k')} \right) \right| = \left| \sum_{k=1}^L \left(A_k e^{j(\Delta\phi_k - \Delta\phi_k')} \right) \right| \quad (9)$$

- 5 Meanwhile, the differential demodulator outputs are also used to estimate the signal energy. The estimated signal energy A is expressed as follows:

$$A = \sum_{k=1}^L \left| A_k e^{j2\pi\Delta f T_s} e^{j(\Delta\phi_k - \Delta\phi_k')} \right| = \sum_{k=1}^L A_k \quad (10)$$

- The correlation output AMP will be compared with the estimated energy A. If the received L symbols are matched with the known UW symbols, these two results should be very close. Moreover, a determination of the frequency offset can be obtained from the correlator output SUM by calculating the phase of SUM.

- As it is clear from this analysis, known frame detection and frequency estimation methods require many complex multiplication operations. The resulting calculations require complex hardware and software for implementation.

- The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims. An apparatus and method according to the independent claims offers significant advantages over known systems. For instance, by introduction of a phase detector module into the apparatus, the complexity of the hardware and/or software for frame detection and/or frequency estimation for the wireless communications receiver may be greatly simplified. Frame detection can be performed by a manipulation of the received signals which correspond to subtraction operations in the real domain

instead of the complex multiplication signal processing algorithms required in known systems as detailed above. Also, by introduction of phase detection, differential demodulation of the signal can be performed by real subtraction.

The present invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 is a block diagram illustrating a structure for a frame of a wireless communications signal;

Figure 2 is a block diagram illustrating a first apparatus for frame detection and/or frequency offset detection in a received wireless communications signal;

Figure 3 is a block diagram representing a signal processing operation of the apparatus of Figure 2;

Figure 4 is a block diagram illustrating an alternative structure for a frame of a wireless communications signal;

Figure 5 is a block diagram illustrating a second apparatus for frame detection and/or frequency offset detection of a wireless communications signal; and

Figure 6 is a block diagram representing a signal processing operation of the apparatus of Figure 5.

Referring now to Figure 2, a first apparatus for frame detection and/or frequency offset detection is described. The apparatus 30 comprises analogue-to-digital converter (ADC) 34, digital down converter (DDC) 36, low pass filters (LPFs) 38, 40 for the in-phase I and quadrature Q components respectively (although, alternatively, a single, complex LPF could be provided instead), time estimation module 42, module 46 with sub-modules for implementing phase detection 46a, differential demodulation 46b, frame detection 46c and frequency estimation and correction 46d. The apparatus 30 also comprises turbo decoder module 48. In operation, ADC 34 receives a demodulated $\pi/4$ DQPSK modulated signal 32 from a digital receiver (not shown). Digitisation of signal 32 is performed by ADC 34 at an intermediate frequency (IF). DDC 36 allows recovery of the baseband signal and LPFs 38, 40 perform out-of-band noise rejection. Time estimation module 42 receives output signals from the LPFs 38,

40 and outputs signals to module 46. Module 46 performs signal manipulation of the input signals as will be described below prior to transmitting a soft decision output signal to turbo decoder 48 which generates a hard decision output after a pre-determined number of decoding iterations. Turbo decoder 48
 5 decodes the data portion 16 of frame 10 of Figure 1 and outputs the recovered bit stream 50.

Phase detector module 46a receives I and Q signals from time estimation module 42 and calculates the absolute phase of these I and Q signals.

The k^{th} received symbol received at phase detector module 46a from time
 10 estimation module 42 is expressed as:

$$d(k) = (I_k + jQ_k)e^{j[2\pi\Delta f k T_s + \Delta\psi]} = A_k e^{j[2\pi\Delta f k T_s + \Delta\psi + \phi_k]} \quad (11)$$

Where Δf is the frequency offset, $\Delta\psi$ is the carrier phase difference between transmitter and receiver (carrier phase offset), ϕ_k is the absolute phase of the modulated signal at symbol k, and T_s is the symbol interval. Then phase
 15 detector 46a takes the phase in equation (11) of the k^{th} received symbol i.e.:

$$\varphi_k = 2\pi\Delta f k T_s + \Delta\psi + \phi_k \quad (12)$$

After differential demodulation in module 46b, the phase difference between the k^{th} and the $(k-1)^{\text{th}}$ received symbols is defined by:

$$\Delta\varphi_k = 2\pi\Delta f k T_s + \Delta\psi + \phi_k - 2\pi\Delta f (k-1)T_s + \Delta\psi + \phi_{k-1} = 2\pi\Delta f T_s + \Delta\phi_k \quad (13)$$

20 Where $\Delta\phi_k$, defining a difference between the absolute phases of the symbols, is determined by the modulated signal at symbol k. Thus, the phase detector 46a determines a phase difference result $\Delta\varphi_k$ from first and second received symbols of the wireless communications signal. In the apparatus of Figure 2,

the phase difference result is obtained by differential demodulation of two consecutive symbols $k-1$ and k . Phases of each of the symbols are determined by phase detector 46a and compared to obtain the phase difference result.

Following from equation (13), the phase offset of the k^{th} symbol resulting from the frequency offset is expressed as:

$$2\pi\Delta f T_s = \Delta\phi_k - \Delta\phi'_k \quad (14)$$

Referring now to Figure 3, a block diagram representing a signal processing algorithm of the apparatus of Figure 2 is described. Initially the known UW symbols (or a property thereof) which are used for frame detection and/or frequency estimation in the apparatus of Figure 2 are stored in buffer 66. Then, mapper 68 maps the known UW (or UW property) into the phases $\Delta\phi'_k$ for $k=1, \dots, L$ (where L is the number of samples of the UW, up to the full length of the UW symbol). That is, mapper 68 maps a property of the known UW data symbol stored in buffer 66 to a known phase result $\Delta\phi'_k$ 70. Then, comparator 72 compares (e.g. subtracts) the known phase result $\Delta\phi'_k$ 70 from phase difference result $\Delta\phi_k$ 64 output by the differential detector 46b. The comparison result obtained from this subtraction is fed to two branches as signal 72a and signal 72b as illustrated in Figure 3. As will now be described, the apparatus detects a frame of the received signal in dependence of the comparison result 72a, 72b.

The comparison result output by comparator 72 is defined by:

$$\Delta\phi_k - \Delta\phi'_k = 2\pi\Delta f T_s + \Delta\phi_k - \Delta\phi'_k \quad \text{for } k=1, \dots, L. \quad (15)$$

The comparison result of Equation (15) is rounded to the range of $(-\pi, \pi)$. If the received symbols $k, k-1$ can be matched with the known UW symbols, e.g. $\Delta\phi'_k$ is exactly the same as $\Delta\phi_k$ for $k=1, \dots, L$, then, from Equation (15) the

mean of $\Delta\phi_k - \Delta\phi'_k$ for $k=1, \dots, L$ will approximate to the phase offset $2\pi\Delta fT_s$, and the corresponding variance will be near zero since the signal variances are caused only by noise. These approximations are defined by:

$$E[\Delta\phi_k - \Delta\phi'_k] = \frac{1}{L} \sum_{k=1}^L (\Delta\phi_k - \Delta\phi'_k) \quad (16)$$

$$\sigma^2 = \frac{1}{L} \sum_{k=1}^L [(\Delta\phi_k - \Delta\phi'_k) - E[(\Delta\phi_k - \Delta\phi'_k)]]^2 \quad (17)$$

Where $E[\]$ is the mathematical *expectation* of the comparison result.

As defined by Equation (16), the apparatus accumulates a mean of the comparison result from a comparison of a plurality of samples of the phase difference result $\Delta\phi_k$ with a plurality of samples of the known symbol phase result $\Delta\phi'_k$, the mean being accumulated over a window having a length corresponding to at least a part of the length of the known UW symbol (L samples). The apparatus detects a frame of the received signal if the mean of the comparison result satisfies a pre-determined criterion.

That is, if the received symbols are matched with the known UW symbols property (known symbol phase result 70), i.e. $\Delta\phi'_k$ 70 approximates with (i.e. is approximately equal to) $\Delta\phi_k$ for $k=1, \dots, L$. That is, one apparatus determines a phase offset component of the received signal resulting from frequency offset (from Equation 14), the pre-determined criterion being that the mean of the comparison result is equal or approximately equal to the phase offset component resulting from frequency offset. Therefore, the frame is detected when the mean of $\Delta\phi_k - \Delta\phi'_k$ 72a, 72b for $k=1, \dots, L$ has a direct relation with the phase offset $2\pi\Delta fT_s$, and the corresponding variance is small, (or very small, approximating to zero). On the other hand, if the received symbols cannot be matched with the known UW symbol, property $\Delta\phi'_k$ 70 is different from $\Delta\phi_k$ for

$k=1, \dots, L$. Therefore, the mean of $\Delta \phi_k - \Delta \phi'_k$ has no direct relation with the phase offset and the corresponding variance is large as the variances are caused by both noise and unmatched phase.

As can be seen from Equation (15), the mean of the comparison result
 5 approximates with the phase offset caused by the frequency offset when the known symbol phase result $\Delta \phi'_k$ is equal or approximately equal to the phase difference $\Delta \phi_k$ between the first and second received symbols.

Thus, a determination of the variance in Equation (17) is used to detect whether the received symbols correspond with the known UW or not. In other words,
 10 UW positioning or frame detection is performed by observing this variance and determining when it equates to a predetermined value. In this example, the predetermined value is equal or approximately equal to zero.

Further, the frequency offset can be obtained according to Equation (16). That is, frequency offset is determined from the mean of the comparison result. This
 15 feature is provided independently and offers a significant advantage over known systems discussed above as frequency offset can be detected by subtraction in the real domain.

Equation 17 can be expressed alternatively as:

$$\sigma^2 = \frac{1}{L} \sum_{k=1}^L [(\Delta \phi_k - \Delta \phi'_k)]^2 - E^2[(\Delta \phi_k - \Delta \phi'_k)] \quad (18)$$

20 That is, the variance of the comparison result is determined from a variance comparison (the variance comparison being defined by the right-hand side of Equation 18) of a mean of the square of the comparison result

$(\frac{1}{L} \sum_{k=1}^L [(\Delta \phi_k - \Delta \phi'_k)]^2)$ and a square of the mean of the comparison result

$(E^2[(\Delta \phi_k - \Delta \phi'_k)])$, substituted from Equation (16).

The digital signal processing algorithm implemented by the apparatus 30 of Figure 2 and as expressed by Equation (18) is discussed with reference to Figure 3.

First, differential demodulator block 46b performs a differential demodulation on
 5 two received symbols (e.g. k and $(k-1)$) in block 62 to output a phase difference
 result $\Delta\phi_k$ 64. At the same time, 32 bits of unique word portion 14 of data frame
 10 are read into buffer 66. Mapper 68 then maps a property of the known UW
 data symbol to a known symbol phase result $\Delta\phi'_k$ 70. Phase difference result
 64 and known symbol phase result 70 are supplied to comparator 72 which
 10 applies a subtraction operation between phase difference result 64 and known
 symbol phase result 70 to provide a comparison result output 72a, 72b.

Comparison result signal 72a is fed to processing block 74 where the square of
 the comparison results are summed and averaged over L samples to provide a
 moving squared average 74a of the comparison result 72a. Signal 72b is
 15 supplied to processing block 76 where comparison results are summed and
 averaged over L samples to provide an accumulated mean 76a of the
 comparison result 72b. Accumulated mean 76a is then squared in block 78 and
 supplied to comparator 80, where the output of block 80 is subtracted from
 moving square average 74a to perform the signal manipulation defined by
 20 equation 18. The output of comparator 80 is a soft decision output which is
 compared against a threshold in block 84 thereby providing a hard decision
 output 86 as to whether the frame has been detected or not. That is, when the
 variance comparison satisfies a threshold criterion, the frame has been
 detected. Frame detection is therefore made in dependence of the comparison
 25 result 72a, 72b.

Thus it can be seen that the process of Figure 3 is greatly simplified when
 compared with known systems implementing complex multiplication. All
 complex multiplication operations for differential demodulation, frame detection,
 frequency offset estimation and correction in the prior art are replaced by

subtraction operations in the real domain. A minor offset must be made by introducing an extra cost for a phase detection module 46a. However, this requires minimal extra complexity and is implemented with a look up table (LUT) which requires minimal hardware resources. Therefore, the complexity of the digital receiver can be reduced significantly.

A second apparatus for frame detection and/or frequency offset in a received wireless communications signal is now discussed. The second apparatus utilises a data frame 110 as illustrated in Figure 4. Data frame 110 comprises preamble 112, unique word (UW) portion 114, and data payload portion 116. In the example of Figure 4, preamble 112 comprises 128 bits, the UW 114 comprises 16 bits and data payload portion 116 comprises up to 2,000 bits which have been subjected to convolutional encoding. In the data frame 110 of Figure 4, a 16-bit unique word is employed. In the comparison which will be effected as discussed below, it is also possible to use a part, say, 16-bits of preamble portion 112 in conjunction with UW portion 114 because a 16-bit UW may be too short on its own to provide reliable detection of the start of the frame.

The apparatus of Figure 5 comprises Hard Limiter 133, cascaded integrator-comb (CIC) filter 133, DDC 136, LPFs 138, 140, time estimation module 142, module 146 comprising phase detection sub-module 146a, differential demodulation sub-module 146b, frame detection sub-module 146c, and frequency estimation and correction sub-module 146d. The output signals of module 146 are passed to Viterbi decoder module 148 which outputs the recovered bit stream 150. Hard Limiter 133 receives signals 132 from the digital receiver (not shown).

Hard Limiter 133 converts the received analogue IF signal into a binary signal. CIC filter 134 performs decimation of the signal output by the Hard Limiter 133. The baseband signal is recovered by the DDC 136 and LPFs 138, 140 reject out-of-band noise before outputting filtered signals to time estimation module

142, which then outputs signals to module 146 which is now discussed.

Phase detection and differential demodulation sub-modules 146a, 146b operate in a similar fashion to the corresponding sub-modules in the apparatus of Figure 2. However, the operations of frame detection and frequency detection sub-modules 146c, 146d are different.

In order to reduce the complexity of the apparatus of Figure 2 and the signal processing algorithm of Figure 3 further, the squaring operation provided in blocks 74 and 78 of Figure 3 is approximated with an absolute value.

The phase comparison result can be alternatively expressed by $\gamma_k = \Delta\varphi_k - \Delta\phi_k$ and its mean as $\bar{\gamma} = \frac{1}{L} \sum_{k=1}^L \gamma_k$, Thus, equation (17) can be re-defined by:

$$\sigma_{\gamma}^2 = E(\gamma - \bar{\gamma})^2 = \frac{1}{L} \sum_{k=1}^L (\gamma_k - \bar{\gamma})^2 \quad (19)$$

That is, the apparatus determines the variance of the comparison result from an accumulation of a square of a comparison of the comparison result γ_k with a mean of the comparison result $\bar{\gamma}$, the variance being determined over an accumulation window length of samples L.

However, Equation (19) may be further simplified by, instead of the squaring operations in Equation (19) substituting the squared value with the absolute value. As a result, a new representation of the manipulated signals is defined by:

$$S = \frac{1}{L} \sum_{k=1}^L |\gamma_k - \bar{\gamma}| \quad (20)$$

Therefore, frame detection and frequency estimation is implemented by observing the value of S and by determining an absolute value of a comparison of the comparison result γ_k with a mean of the comparison result $\bar{\gamma}$, the mean of S being determined over the window length of samples L . The receiver apparatus detects the UW when the result of S in equation 20 is found to be below a pre-determined threshold. Meanwhile, the frequency offset $2\pi\Delta fT_s$ can be estimated as the value of $\bar{\gamma}$ in the event that UW detection is successfully achieved. That is, the frequency offset is again determined in the apparatus of Figure 5 from the mean of the comparison result.

The digital signal processing algorithm implemented by the apparatus 130 of Figure 5 is discussed with reference to Figure 6. Differential demodulator block 146b performs a differential demodulation on two received symbols (e.g. k and $(k-1)$) in block 162 to output a phase difference result $\Delta\phi_k$ 164. At the same time, 16 bits of the preamble portion 112 of data frame 130 and 16 bits of UW portion 114 are read into buffer 166. Mapper 168 then maps a property of the known data symbol (preamble and, optionally, unique word) to a known symbol phase result $\Delta\phi'_k$ 170. Phase difference result 164 and known symbol phase result 170 are supplied to comparator 172 which provides a subtraction operation to provide a comparison result output 172a, 172b γ_k . Comparison result signal 172b is fed to processing block 176 where comparison results are summed and averaged over L samples to provide an accumulated mean of the comparison result 172b. Comparison result signal 172a is supplied to processing block 174 where the signal manipulation defined by equation 20 is performed in conjunction with the output of block 176. The output block 174 is a soft decision output which is compared against a threshold in block 178 which provides a hard decision output 180 as to whether the frame has been detected or not.

It will therefore be seen that the additional advantage of the apparatus of Figures 5 and 6 is that this apparatus requires only addition and subtraction in the real domain.

5 It will be appreciated that the invention has been described by way of example only and variations and implementation are still embraced within the scope and spirit of the invention. It will also be appreciated that features of one aspect of the invention may be presented in combination with features of another aspect of the invention.

Claims

1. Apparatus for detecting a frame of a received wireless communications signal, the apparatus comprising:
 - a phase detector configured to determine a phase difference result from
5 first and second received symbols of the wireless communications signal;
 - a mapper configured to map a property of a known data symbol stored in the apparatus to a known symbol phase result; and
 - a comparator configured to compare the phase difference result and the known symbol phase result and to provide a comparison result;
 - 10 the apparatus being configured to detect a frame of the received signal in dependence of the comparison result.
2. The apparatus of claim 1, wherein the apparatus is configured to accumulate a mean of the comparison result from a comparison of a plurality of
15 samples of the phase difference result and a plurality of samples of the known symbol phase result, the mean being accumulated over a window having a length corresponding to at least part of a length of the known symbol, and to detect a frame of the received signal if the mean of the comparison result satisfies a pre-determined criterion.
- 20 3. The apparatus of claim 2, wherein the apparatus is configured to determine a phase offset component of the received signal resulting from frequency offset of the received signal and to detect the frame when the mean of the comparison result satisfies the pre-determined criterion by being equal or
25 approximately equal to the phase offset component.
4. The apparatus of claim 3, wherein the apparatus is configured to determine that the mean of the comparison result approximates with the phase offset component when the known symbol phase result is equal or
30 approximately equal to a phase difference between the first and second received symbols.

5. The apparatus of any of claims 2 to 4, wherein the apparatus is configured to determine a variance of the comparison result and detect the frame of the received signal if the variance equates to a predetermined value.
- 5 6. The apparatus of claim 5, wherein the apparatus is configured to determine the variance of the comparison result from a variance comparison of a mean of the square of the comparison result and a square of the mean of the comparison result, the variance comparison being determined over the window length.
- 10 7. The apparatus of claim 6, wherein the apparatus is configured to detect the frame of the received signal from a determination that the variance comparison satisfies a threshold criterion.
- 15 8. The apparatus of claim 5, wherein the apparatus is configured to determine the variance of the comparison result from a square of a comparison of the comparison result with a mean of the comparison result, the variance being determined over the window length of samples L .
- 20 9. The apparatus of claim 2, configured to determine a mean absolute value of a comparison of the comparison result with the mean of the comparison result, the mean absolute value being determined over the window length, the apparatus being configured to detect the frame of the received wireless signal when the mean absolute value satisfies a threshold criterion.
- 25 10. The apparatus of any preceding claim, wherein the phase detector is configured to determine the phase difference result by performing a differential demodulation of the first and second symbols to determine a first phase of the first symbol and a second phase of the second symbol and comparing the first
- 30 and second phases.

11. The apparatus of claim 2, wherein the apparatus is configured to determine frequency offset in the received wireless communications signal from the mean of the comparison result.

5 12. Apparatus for detecting frequency offset in a received wireless communications signal, the apparatus comprising:

a phase detector configured to determine a phase difference result from first and second received symbols of the wireless communications signal;

10 a mapper configured to map a property of a known data symbol stored in the apparatus to a known symbol phase result; and

a comparator configured to compare the phase difference result and the known symbol phase result and to provide a comparison result;

15 the apparatus being configured to accumulate a mean of the comparison result from a comparison of a plurality of samples of each of the phase difference result and the known symbol phase result, the mean being accumulated over a window having a length corresponding to at least part of a length of the known symbol and to determine the frequency offset from the mean of the comparison result.

20 13. A method for detecting a frame of a received wireless communications signal, the method comprising:

configure a phase detector to determine a phase difference result from first and second received symbols of the wireless communications signal;

25 mapping a property of a known data symbol stored in the apparatus to a known symbol phase result; and

comparing the phase difference result and the known symbol phase result and to provide a comparison result;

and detecting a frame of the received signal in dependence of the comparison result.

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14. A method for detecting a frame of a received wireless communications signal using the apparatus of any of claims 1 to 11.

15. A method for detecting frequency offset in a received wireless communications signal, the apparatus comprising:

- 5 configuring a phase detector to determine a phase difference result from first and second received symbols of the wireless communications signal;
- mapping a property of a known data symbol stored in the apparatus to a known symbol phase result; and
- comparing the phase difference result and the known symbol phase result and to provide a comparison result;
- 10 accumulating a mean of the comparison result from a comparison of a plurality of samples of each of the phase difference result and the known symbol phase result, the mean being accumulated over a window having a length corresponding to at least part of a length of the known symbol and
- determining the frequency offset from the mean of the comparison result.