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APPARATUS AND METHOD FOR DETERMINING SIGNAL AND/OR SYMBOL TIMING IN A WIRELESS COMMUNICATION SIGNAL

5 The invention relates to determining signal timing in a wireless communications signal. The invention also relates to determining symbol timing in a wireless MIMO (Multiple input, Multiple output) wireless communications signal. The invention has particular, but not exclusive, application in MIMO-OFDM (Orthogonal Frequency Division Multiplexed) systems.

10 In packet radio systems, packets which are transmitted over a wireless communications link typically consist of a preamble portion and a data payload portion. A wireless receiver device configured to receive and decode the signal uses the preamble portion to determine signal (frame/packet) timing to facilitate processing of the data payload.

15 A principal objective of frame and symbol timing is to determine when the desired frame/packet commences and when a data symbol in the data payload of that frame/packet commences. Any error in timing in this detection process will give rise to a phase rotation of the signal (sub)carriers. This phase rotation
20 is largest on the edges of the frequency band. Wireless communications devices usually offer some tolerance for symbol timing errors by introducing a cyclic prefix to extend the symbol. For example, in OFDM systems, the timing error should be small enough to keep the channel impulse response within the cyclic prefix so that orthogonality between subcarriers is maintained. If a timing
25 error is a larger than the cyclic prefix, Inter Symbol Interference (ISI) will occur. In OFDM systems a guard interval (GI), copied from the last part of the symbol, is inserted before the symbol as a cyclic prefix. Therefore, in order to reduce ISI and phase rotation, the estimated timing of the start of the symbol should be
30 possible.



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Figure 1A illustrates wireless signal components 10, 12 transmitted respectively by antennas 14, 16. Signal component 10 comprises preamble 16. Signal component 12 comprises preamble 18, shifted by a cyclic shift interval with respect to preamble 16 of signal component 10. The cyclic shift may be a shift of the same or similar signals being transmitted through different spatial streams respectively by antennas 14, 16 and is introduced to prevent unintentional beamforming in the signal. This cyclic shift makes the individual signal components 10, 12 appear to be multipath signals.

Typically, timing estimation for a wireless signal is achieved by correlating the signal with a predetermined preamble sequence and detecting correlation via crossing of a threshold. The preamble sequences can be considered synchronisation signals that are pre-pended to the packet prior to transmission. For an OFDM configuration according to IEEE 802.11a/g/n standard, for example, the preamble called L-STF (Legacy Short Training Field) in IEEE 802.11n consists of ten identical predetermined short training symbols used for synchronisation. The IEEE 802.11n standard also defines the L-LTF (Legacy Long Training Field) in the preamble, comprising long training symbols following the L-STF symbols.

In a multipath environment, such typical preamble correlation is spread over several output samples so that any peak detected by signal cross-correlation is smaller than would be detected in a non-multipath environment. In general, the transmitted signal traverses multiple paths to the receiver resulting in an interference pattern that obscures the results of the correlation process. The correlation process for the multipath environment exhibits a multipath delay profile and results in multiple attenuated decaying peaks at a receiver rather than one strong peak. A single, constant threshold value – as discussed above – used to distinguish correlation peaks from noise is inadequate to achieve desired performance levels. A constant threshold value optimised for Additional White Gaussian Noise (AWGN) increases the occurrence of missed events since the threshold must be set at a relatively high level that is greater than the

result of the plural, more attenuated correlation events in a multipath environment. A smaller threshold used for correlation detection detects weaker correlation peaks but also increases the occurrence of timing errors.

- 5 Figure 1B illustrates the concept that cross-correlation of the respective signal components 10, 12 with the predetermined preamble sequence returns two, individual cross-correlation peaks 20, 22, spaced in time along the time axis 24. The shift between the cross-correlation peaks 20, 22 corresponds with the cyclic shift interval.

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In a MIMO system, a MIMO radio transmission environment intensifies multipath interference. In a MIMO-OFDM system according to IEEE 802.11n, preamble sequences are transmitted over multiple channels. In addition to cyclic shift, the signals sent by multiple antennas are transmitted through
 15 multiple channels and summed up at the receiver antennas, which make the multipath interference even worse. Multipath interferences eventually obscure the frame and symbol timing.

- Referring again to Figure 1, the preamble 18 of signal component 12 is
 20 cyclically shifted forward a few samples within one symbol which makes the received signals through the different spatial streams of antennas 14, 16 appear to be multipath signals. In addition to cyclic shift, the signal sent by multiple antennas are transmitted through multiple channels (or sub-channels) and summed up at the receiver antennas. That is, each, individual antenna may
 25 detect a signal stream of a sub-channel it is not supposed to.

- Furthermore, in WLAN standards, the symbols of the OFDM preamble have relatively poor (high) cross-correlation properties, thereby increasing the chances of timing estimation errors. Normally the correlation peak of a L-STF
 30 preamble symbol is used to determine the symbol timing and the last correlation peak is used to decide the frame timing. Because of poor cross-correlation properties between L-STF and the following preamble, L-LTF, it is difficult to

distinguish the last correlation peak of the L-STF symbol. In a MIMO environment in which multipath interferences are intensified, such cross-correlation is even poorer so that the frame and symbol timing is easily missed.

5 Therefore, a summary of problems which can lead to decreased performance in the synchronisation process may be summarised as follows:

- the poor cross-correlation property between the L-STF and L-LTF preamble training symbols can make it difficult to determine frame/packet timing.
- a more complicated packet format for the MIMO standard 802.11n requires a
10 cyclic shift to be introduced to the multiple spatial stream signal components, thereby causing multiple correlation peaks.
- MIMO channel environments are much worse than single channel environments when it comes to multipath interference.

15 These problems bring challenges to time synchronisation. Conventional methods using correlation and threshold detection may not be able to overcome these problems, thereby leading to a significant number of frame/packet and symbol timing errors and, hence, loss of entire packets from the transmitted signals.

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The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

A first apparatus and method for signal and symbol timing determination in a
25 wireless communications signal distinguishes different preamble symbols and frame/packet timing by comparing an auto-correlation of a signal and an energy characteristic of the signal which acts as a threshold. In some apparatuses, the energy characteristic is derived from the power or the energy of the signal. This first apparatus and method may provide more reliable performance in signal
30 timing acquisition.

A second apparatus and method is proposed for the determination of symbol timing in a wireless communications MIMO signal. The apparatus and method performs first and second cross correlations on the communications signal with a known symbol. The first cross correlation is performed at a first time and the
5 second cross correlation is performed at a second time shifted from the first time by a cyclic shift interval. The apparatus and method then determines a combined cross correlation from the first and second cross correlations. Such an apparatus and method may take advantage of the cyclic shift interval conventionally inserted in different MIMO signal components for the plural
10 MIMO spatial streams. Some apparatuses utilise a correlation combiner to enforce a correlation peak at symbol timing and hence makes the symbol timing more readily detectable.

The invention will now be described, by way of example only, and with
15 reference to the accompanying drawings in which:
Figure 1 is a schematic diagram illustrating the cyclic shift interval in the preamble of respective components of a wireless data signal transmitted over different spatial streams;
Figure 2 is a block diagram illustrating an apparatus for estimating signal and
20 symbol timing in the wireless data signal components of Figure 1;
Figure 3 is a block diagram illustrating a process flow for the estimation of signal and symbol timing in the apparatus of Figure 2;
Figure 4 is a signal waveform diagram representing two symbols in a wireless data signal, and timing relations between the symbol; and
25 Figure 5 is a signal waveform diagram representing signals derived by the apparatus of Figure 2 and the manner in which signal and symbol timing can be derived from the signal.

With reference to Figure 2 an apparatus for signal and symbol timing will now
30 be described. The apparatus of Figure 2 comprises a receiver apparatus 30 for receiving MIMO signals, optionally MIMO-OFDM signals although apparatuses for signal timing are not restricted to MIMO or MIMO-OFDM signals. In the

example of Figure 2, the apparatus 30 is configured to communicate over n spatial streams and comprises antennas 32a,..., 32n each of which is respectively connected to RF analogue signal processors 34a,..., 34n which are in turn respectively connected to analogue-to-digital converters 36a,...36n. The
 5 respective signals output by analogue-to-digital converters 36a,..., 36n are fed individually to CFO remover module 44, CFO estimation module 38, and packet detection module 40, described in commonly-assigned co-pending Singapore Patent Application No. 200700004-5 incorporated by reference in its entirety. Additionally, outputs from the CFO estimation module 38 are fed to CFO
 10 remover module 44 and packet detection module 40. The output of packet detection module 40 is supplied to the symbol timing module 42. The output of symbol timing module 42 is supplied to window control module 46 as an input. Also input to window control module 46, is the output(s) of CFO remover module 44. The outputs of window control module 46 are fed to Fast Fourier
 15 Transform (FFT) module 48 as an input. The output of FFT module 48 is supplied to demodulator 50 which in turn outputs decoded bitstream 52.

Operation of packet detection module 40 and symbol timing module 42 is described in greater detail with reference to Figure 3. Initially, received MIMO
 20 signal components from the multiple input antennas 32a,..., 32n are sampled at over-sampling rate by apparatus 30 and saved into a buffer in the packet detection module. At step 62, apparatus 30 calculates the signal energy R . The energy of the signal samples is measured and accumulated over a window duration of T_W . If the sample interval is T , $T_W=WT$; i.e. W samples in the
 25 window are processed to calculate the signal energy $R(d)$ of the received signals, determined by:

$$R(d) = \sum_{a=1}^{Att} \sum_{m=0}^{W-1} |r_a(d+m)|^2 \quad (1)$$

30 where W is window length, representing the number of samples used to compute the signal energy within the window, d is a time index corresponding to

the first sample in the window of W samples, m the sample index of the window, r_a is the signal energy of a sample of input signal chain a and Att is the number of signal chains corresponding to the antennas 32a,...32n. Thus, the signal energy is accumulated for each spatial stream of the MIMO signal over a first sliding window length of W samples.

The calculation of $R(d)$ can be implemented by the following simplified iterative computation:

$$R(d+1) = R(d) + |r(d+W)|^2 - |r(d)|^2 \quad (2)$$

Where $r(d+W)$ is the received signal sample, $r(d)$ is buffered sample at index d , and W is integration window length.

At step 64, apparatus 30 determines whether or not the calculated signal energy R satisfies a threshold criterion. In one example, the threshold criterion which must be satisfied is that the calculated signal energy is greater than a predetermined minimum threshold amount. In parallel with the calculation of signal energy at steps 62 and 64, apparatus 30 also performs an auto-correlation of the received signal. The auto-correlation of the received signal samples r is calculated as follows:

$$AC(d) = \sum_{a=1}^{Att} \sum_{m=0}^{W-1} (r_a^*(d+m) r_a(d+m+D)) \quad (3)$$

where D is the number of delay samples in the delay of the auto-correlation and W is the number of samples over the length of the correlation window. The auto-correlation is accumulated for each spatial stream of the MIMO signal over a second sliding window length. The window slides along in time as the receiver apparatus 30 searches for the L-STF symbols of the preamble.

The L-STF symbols of the preamble are illustrated in Figure 4. If we denote T as a sample interval, then the delay time $T_d = DT$ and the length of the integration window $D_W = WT$. A predetermined duration of the second sliding window length is set to correspond with a duration of a symbol. For
 5 packet/frame detection, the delay time T_d is set to one short symbol length, i.e., 800ns and the integration window length T_W is also set to one short symbol length; i.e. 800ns.

If apparatus 30 determines that the calculated signal energy R satisfies the
 10 threshold criterion in step 64 of Figure 3, a scaling factor μ is applied to R by a multiplier (not shown) in packet detection module 40. In the present example the output of the multiplier $\mu \cdot R$ defines an energy characteristic of the signal. (In another example, the energy characteristic is defined by the product of μ and the calculated signal power which can be calculated as an alternative to the
 15 signal energy as described above.) At step 68, apparatus 30 calculates an absolute magnitude value of the auto-correlation defined by Equation 3. Apparatus 30 then utilises a comparator (not shown) to compare the absolute value of the auto-correlation with the energy characteristic $\mu \cdot R$ and determines the signal timing in dependence of the comparison. In the example of Figure 3,
 20 signal timing is detected when the absolute value of the auto-correlation exceeds the calculated value of the energy characteristic. That is, it indicates that a desired signal is received and a desired frame has started. (This is discussed further below with reference to Figure 5.) Detection of the signal timing (packet/frame timing) by apparatus 30 is depicted at step 70.

25 Therefore, it will be seen that apparatus 30 determines the signal timing by performing an auto-correlation of the signal, determining whether an energy characteristic of the signal satisfies a threshold criterion and, upon this determination, compares the auto-correlation with the energy characteristic.
 30 The signal timing is determined from the comparison.

As mentioned above, this example depicts an apparatus for signal timing in a MIMO system but the disclosed method is equally applicable in non-MIMO systems.

- 5 The scale factor μ is selected to provide a sufficient margin relative to the instantaneous noise level in the signals. That is, a scale factor for the scale value is a pre-determined value selected to mitigate effects of noise in the signal. If we consider the signals received at apparatus 30 to consist of a desired signal component s and noise or interference component n , then $r = s +$
 10 n . Auto-correlation of the received signal components leads to:

$$AC = AC_s + AC_n,$$

- where AC_s is the auto-correlation of the desired signal s , and AC_n is the auto-
 15 correlation of the noise component.

- Generally, $|AC_s|$, is much larger than $|AC_n|$. Indeed, in a noise-free or relatively noise-free signal environment, $|AC_s|$ is normally close to the signal energy characteristic R . The absolute value of the auto-correlation of the noise
 20 component $|AC_n|$ can possibly cause false detection of the signal timing. In the condition where $|AC| > \mu * R$, μ is selected to make $\mu * R > |AC_n|$. When the received signal does not contain the desired signal, $|AC| = |AC_n| < \mu * R$. When the received signal contains a desired signal, $|AC| = |AC_s| + |AC_n| > \mu * R$.

- 25 For simplicity, the absolute value of the auto-correlation, $|AC|$ can be replaced with $|real(AC)| + |imag(AC)|$.

- Normally, packet/frame detection by apparatus 30 can be finished within three short symbols; i.e. within $2.4\mu s$. If the absolute value of the auto-correlation
 30 does not exceed the threshold over the first preamble, the packet is considered to be lost.

Apparatus 30 is also configured to determine symbol timing in a MIMO wireless signal. Upon detection at block 68 that the absolute value of the auto-correlation exceeds the energy characteristic, apparatus 30 calculates at step
 5 70 of Figure 3 the cross-correlation of received signal samples and the stored L-STF preamble as follows:

$$XC(d) = \sum_{a=1}^{At} \sum_{m=0}^{W-1} (r_a^*(d+m)s(m)) \quad (4)$$

10 where $s(m)$ represents the stored L-STF preamble.

Normally, the peak of the cross-correlation will indicate the start of a symbol. However, in MIMO systems, and in particular MIMO-OFDM systems, matters become more complicated because the cyclic shift is introduced to a preamble
 15 symbol of each spatial stream in order to prevent unintentional beamforming which results in multiple cross-correlation peaks. In order to reduce the multipath effect caused by cyclic shift, the cross-correlation can be combined as follows:

$$20 \quad XCC(d) = XC(d) + XC(d - c) \quad (5)$$

where $XC(d)$ is a first cross correlation for the communications signal with the known symbol stored in the apparatus 30 and $XC(d - c)$ is a second correlation for the communications signal performed at a second time, the second time
 25 being shifted from the first time by the shift interval. Thus, the cross correlation is a combined cross correlation. In the example of Equation 5, the combined cross correlation is obtained from a summation of the first and second cross correlations.

Combining the cross-correlation provides for an addition of two peaks thereby resulting in a single peak. This therefore increases the peak value at the correct symbol timing and distinguishes this peak from other peaks in the signal. By searching the peak within a sliding window of 400ns (one L-STF symbol length) the timing of L-STF symbols can be determined.

Thus, it can be seen that the apparatus 30 is configured to determine a combined cross-correlation from the first and second cross-correlations and determine symbol timing from the combined cross-correlation. This is an important feature and is provided independently. Accordingly, one apparatus and method for determining symbol timing in a wireless MIMO communication signal, the signal having first and second signal components comprising known (preamble) symbols, a known (preamble) symbol of the second signal component being shifted by a shift interval with respect to a known symbol of the first signal component, is configured to perform, at a first time, a first cross correlation of the communications signal with a known symbol stored in the apparatus; perform, at a second time, a second cross correlation of the communications signal with the known symbol, the second time being shifted from the first time by the shift interval; determine a combined cross-correlation from the first and second cross-correlation; and determine symbol timing from a combined cross-correlation.

The performance of Equation 5 is implemented by apparatus 30 in block 73 of Figure 3.

Once the peak timing is detected, apparatus 30 monitors the peak of the combined cross-correlation in a third sliding window in block 75a. The third sliding window may be set to correspond with a duration of the known L-STF symbol stored in the apparatus.

Apparatus 30 is also configured to detect the end of the L-STF preamble. From this, the start of the L-LTF preamble can be detected. In wireless LAN

standards, L-STF and L-LTF preamble symbols have a relatively poor (high) cross-correlation property, which can cause a false determination of the L-STF preamble. (The cross-correlation of the two different symbols, generally, provides a low output as opposed to a cross-correlation of two symbols which are similar or the same which provides a high output.) In wireless LAN standards, a high correlation between L-STF and L-LTF symbols is not desired. As such, apparatus 30 makes use of this poor cross-correlation property in order to detect the end of the L-STF preamble. As the peak searching algorithm of steps 71, 73 and 75 of Figure 3 detect the combined cross-correlation peak within the third sliding window, when the L-LTF preamble enters the sliding window, a similar peak is generated due to poor cross-correlation properties between the L-LTF preamble in the wireless signal and the non L-STF preamble stored in the apparatus. This may lead to a false determination of peak timing. The problem may be further exacerbated in a MIMO environment.

In order to overcome this, apparatus 30 extends the algorithms already discussed in Figure 3 in order to determine the end of the L-STF preamble based on a second cross-over between the absolute value of the auto-correlation of the received signals $|AC|$ with the energy characteristic $\mu.R$. In block 72 of Figure 3, a determination is made that the absolute value of the auto-correlation calculated in step 66 falls below the threshold of the energy characteristic $\mu.R$. As such, this is the converse operation from the detection of the signal timing whether the packet/frame is detected in steps 68, 70 of Figure 3. That is, the end of the L-STF preamble symbol is detected when the absolute value of the auto-correlation becomes smaller rather than greater than the energy characteristic $\mu.R$. This cross-over enables the peak searching module 75b of symbol timing module 42 in Figure 2 to output a signal asserting the L-STF preamble to the window control function block 46 of Figure 2. Determination of the end of the L-STF symbol timing is indicated as step 74 of Figure 3.

Turning now to Figure 5, the signal waveforms of the signals derived by the apparatus 30 to facilitate the signal and symbol timing is now discussed. As shown in Figure 5, three signals are derived and illustrated:

- 5 the energy characteristic $\mu.R$ 92 (which represents an absolute scalar value); an absolute value of the auto-correlation 94 calculated in step 66 of Figure 3; and an absolute value of the combined cross correlation 96 calculated in steps 71 and 73 of Figure 3.
- 10 Energy characteristic 92 in the sample window of Figure 5 comprises a few small signal perturbations for the first 70 samples (the t-axis of Figure 5) or so of the window before rising sharply to a plateau within about 100 microseconds. Minor variations about this plateau in this energy characteristic are derived over the next 250 samples or so. The auto-correlation 94 exhibits only a gradual
15 increase from about 60 samples up to about 150 samples when it also increases to a plateau. At point 98 of Figure 5, the absolute value of the auto-correlation crosses over (i.e. becomes greater than) the energy characteristic 92. At this point, the signal timing of the packet/frame is asserted and the packet is detected. This clearly illustrates the signal processing algorithm
20 defined in steps 62, 64, 66 68 and 70 of Figure 3. Figure 5 also illustrates at point 100 the instant where the value of the auto-correlation 94 falls below the magnitude of the energy characteristic 92. At this point, and as illustrated in step 72, 75b and 74 of Figure 3, the end of the L-STF preamble symbol and the beginning of the L-LTF preamble symbol is indicated. Thus, when the L-STF
25 preamble is complete, the auto-correlation value decreases very quickly so that a distinction between the L-STF and L-LTF preamble symbols may be made within several samples of the wireless communication signal as sampled by our analogue-to-digital converters 36a,...,36n.
- 30 Because the combined cross-correlation 96 peak occurs for each L-STF short symbol, this enables the apparatus to detect fine symbol timing. The determination that the absolute value of the auto-correlation has fallen below

the energy characteristic in step 72 of Figure 3 is used to determine coarse frame timing and indicate the end of the short training symbol preamble. The last short training symbol timing will be aligned with frame timings.

5 As is conventional, window control module 46 of Figure 2 extracts an OFDM symbol for Fast Fourier Transform (FFT) module 48 of Figure 2 to process and discard the guard interval (GI) based on correct symbol timing having been determined. As is well-known, exact symbol timing is not necessary for an OFDM signal as long as a start of an FFT window is within a guard interval and
10 after the multipath channel delay. Inter-Symbol Interference (ISI) may be reduced or even eliminated by removing the guard interval. Therefore, in order to avoid removing a part or sample of the desired signal when removing the guard interval, symbol timing is normally moved forward several samples as is conventional.

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It will be appreciated that the invention has been described by way of example only and modifications in detail may be made without departing from the spirit and scope of the invention. Features of one aspect of the invention may be presented in combination with features of another aspect of the invention.

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Claims

1. Apparatus for determining signal timing in a wireless communications signal, the apparatus being configured to:
 - 5 determine an auto-correlation of the signal;
 - determine whether an energy characteristic of the signal satisfies a threshold criterion and, upon said determination, compare the auto-correlation with the energy characteristic; and
 - determine the signal timing from the comparison.
- 10 2. Apparatus according to claim 1, wherein the apparatus is configured to determine the signal timing when the comparison returns that an absolute value of the auto-correlation is greater than a value of the energy characteristic.
- 15 3. Apparatus according to claim 1 or claim 2, wherein the energy characteristic is a scaled value of calculated signal energy or calculated signal power, a scale factor for the scaled value being a pre-determined value selected to mitigate effects of noise in the signal.
- 20 4. Apparatus according to any preceding claim, wherein the wireless communications signal is a MIMO wireless communications signal and the energy characteristic is accumulated for each spatial stream of the MIMO wireless communications signal over a first sliding window length.
- 25 5. Apparatus according to any preceding claim, wherein the wireless communications signal is a MIMO wireless communications signal and the auto-correlation is accumulated for each spatial stream of the MIMO signal over a second sliding window length.
- 30 6. Apparatus according to claim 5, wherein a predetermined duration of the second sliding window length is set to correspond with a duration of a symbol of the signal.

7. Apparatus according to any preceding claim, wherein the apparatus is further configured to detect an end of a known symbol in the signal from the comparison.

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8. Apparatus according to claim 7, wherein the apparatus is configured to detect the end of a known symbol in the signal when the absolute value of the auto-correlation falls below the value of the energy characteristic.

10 9. Apparatus according to any preceding claim, wherein the wireless communications signal is a MIMO wireless communications signal and the apparatus being further configured to determine symbol timing in the signal, the signal having first and second signal components comprising known symbols, a known symbol of the second signal component being shifted by a shift interval
15 with respect to a known symbol of the first signal component, and wherein the apparatus is configured to:

perform, at a first time, a first cross correlation of the communications signal with a known symbol stored in the apparatus;

perform, at a second time, a second cross correlation of the
20 communications signal with the known symbol, the second time being shifted from the first time by the shift interval;

determine a combined cross correlation from the first and second cross correlations; and

determine symbol timing from the combined cross correlation.

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10. Apparatus for determining symbol timing in a wireless MIMO communications signal having first and second signal components comprising known symbols, a known symbol of the second signal component being shifted by a shift interval with respect to a known symbol of the first signal component,
30 the apparatus being configured to:

perform, at a first time, a first cross correlation of the communications signal with a known symbol stored in the apparatus;

perform, at a second time, a second cross correlation of the communications signal with the known symbol, the second time being shifted from the first time by the shift interval;

5 determine a combined cross correlation from the first and second cross correlations; and

 determine symbol timing from the combined cross correlation.

11. Apparatus according to claim 9 or claim 10, wherein the apparatus is configured to determine the combined cross correlation from a summation of
10 the first and second cross correlations.

12. Apparatus according to any of claims 9 to 11, wherein the apparatus is configured to determine the symbol timing from a peak of the combined cross correlation, and to monitor the peak in a third sliding window.
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13. Apparatus according to claim 12, wherein a predetermined duration of the third sliding window is set to correspond with a duration of the known symbol stored in the apparatus.

20 14. A method for determining signal timing in a wireless communications signal, the method comprising:
 determining an auto-correlation of the signal;
 determining whether an energy characteristic of the signal satisfies a threshold criterion and, upon said determination, comparing the auto-correlation
25 with the energy characteristic; and
 determining the signal timing from the comparison.

15. The method of claim 14, wherein the method comprises determining the signal timing when the comparison returns that an absolute value of the auto-
30 correlation is greater than a value of the energy characteristic.

16. The method of claim 14 or claim 15, wherein the energy characteristic is a scaled value of calculated signal energy or calculated signal power, the method comprising applying a pre-determined scale factor for the scaled value selected to mitigate effects of noise in the signal.

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17. The method of any of claims 14 to 16, wherein the wireless communications signal is a MIMO wireless communications signal and the method comprises accumulating the energy characteristic for each spatial stream of the MIMO wireless communications signal over a first sliding window length.

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18. The method of any of claims 14 to 17, wherein the wireless communications signal is a MIMO wireless communications signal and the method comprises accumulating the auto-correlation for each spatial stream of the MIMO signal over a second sliding window length.

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19. The method of claim 18, the method comprising setting a predetermined duration of the second sliding window length to correspond with a duration of a symbol of the signal.

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20. The method of any of claims 14 to 19, the method further comprising detecting an end of a known symbol in the signal from the comparison.

21. The method of claim 20, wherein the method comprises detecting the end of a known symbol in the signal when the absolute value of the auto-correlation falls below the value of the energy characteristic.

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22. The method of any of claims 14 to 21, wherein the wireless communications signal is a MIMO wireless communications signal and the method further comprises determining symbol timing in the signal, the signal having first and second signal components comprising known symbols, a known symbol of the second signal component being shifted by a shift interval with

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respect to a known symbol of the first signal component, and the method comprising:

performing, at a first time, a first cross correlation of the communications signal with a known symbol stored in the apparatus;

5 performing, at a second time, a second cross correlation of the communications signal with the known symbol, the second time being shifted from the first time by the shift interval;

determining a combined cross correlation from the first and second cross correlations; and

10 determining symbol timing from the combined cross correlation.

23. A method for determining symbol timing in a wireless MIMO communications signal having first and second signal components comprising known symbols, a known symbol of the second signal component being shifted
15 by a shift interval with respect to a known symbol of the first signal component, the method comprising:

performing, at a first time, a first cross correlation of the communications signal with a known symbol stored in the apparatus;

performing, at a second time, a second cross correlation of the
20 communications signal with the known symbol, the second time being shifted from the first time by the shift interval;

determining a combined cross correlation from the first and second cross correlations; and

determining symbol timing from the combined cross correlation.
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24. The method of claim 22 or claim 23, the method comprising determining the combined cross correlation from a summation of the first and second cross correlations.

30 25. The method of any of claims 22 to 24, the method comprising determining the symbol timing from a peak of the combined cross correlation, and monitoring the peak in a third sliding window.

26. The method of claim 25, the method further comprising setting a predetermined duration of the third sliding window to correspond with a duration of the known symbol stored in the apparatus.