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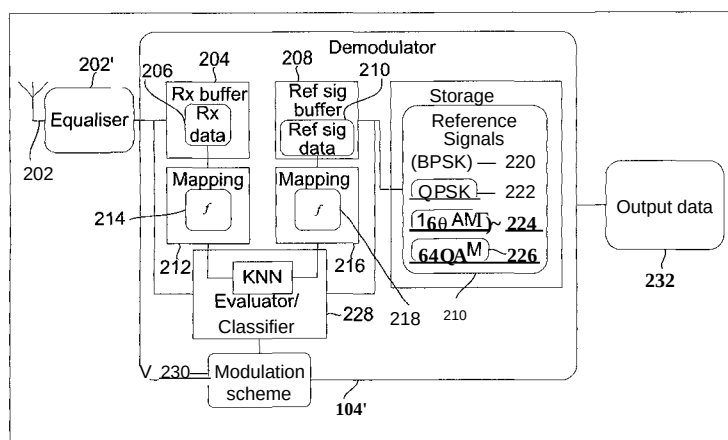
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(54) Title: AUTOMATIC DIGITAL MODULATION CLASSIFICATION USING GENETIC PROGRAMMING WITH K-NEAREST NEIGHBOR



200

Figure 2

(57) Abstract: Embodiments of the present invention relate to a signal processing system and method for automatically recognising a modulation scheme used by a received signal.

AUTOMATIC DIGITAL MODULATION CLASSIFICATION USING GENETIC PROGRAMMING WITH K- NEAREST NEIGHBORField of the invention

Embodiments of the present invention relate to signal processing systems and methods.

5 Background to the invention

Many modulation techniques exist for communications. Examples include BPSK, QPSK and QAM. Knowledge of the modulation technique used by a transmission system is essential for demodulating the received signal. Techniques have been developed that support automatic recognition of modulation techniques. Such
10 automatic recognition is known as Automatic modulation classification (AMC). Automatic modulation classification is an intermediate step between signal detection and demodulation.

Existing AMC techniques are computationally complex, which limits their applicability. Furthermore, existing AMC techniques perform poorly when seeking to distinguish
15 between variants of the same modulation technique such as, for example, 16QAM and 64QAM.

Summary of invention

Accordingly, embodiments of the present invention provide a signal processing method comprising the steps of

20 mapping a received modulated signal according to a first mapping function onto a first classification space to produce mapped received modulated signal data; said first mapping function being arranged to map a first type of received modulated signal into a corresponding first region of said first classification space and a second type of modulated signal into a corresponding second region of said first classification space;

25 determining whether or not the mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the first classification space; and

classifying the received modulated signal according to said determining as either the first type of received modulated signal or the second type of received modulation
30 signal.

Advantageously, embodiments of the present invention support rapid automatic modulation classification, with increased accuracy as well as an ability to distinguish between variants of the same modulation technique.

Embodiments of the present invention provide a signal processor comprising:

5 a mapper for mapping a received modulated signal according to a first mapping function onto a first classification space to produce mapped received modulated signal data; said first mapping function being arranged to map a first type of received modulated signal into a corresponding first region of said first classification space and a second type of modulated signal into a corresponding
10 second region of said first classification space;

 a correlator to determine whether or not the mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the first classification space; and

 a classifier arranged to classify the received modulated signal according to
15 said determining as either the first type of received modulated signal or the second type of received modulation signal.

Embodiments of the present invention provide a signal processor wherein:

 said mapper is adapted for mapping the received modulated signal, according to a second mapping function, onto a second classification space to produce second
20 mapped received modulated signal data; said second mapping function being arranged to map a third type of received modulated signal into a corresponding first region of said second classification space and a fourth type of modulated signal into a corresponding second region of said second classification space;

 said correlator being adapted to determine whether or not the second
25 mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the second classification space; and

 said classifier being adapted to classify the received modulated signal according to said determining as either the third type of received modulated signal or the fourth type of received modulation signal.

Embodiments of the present invention provide a signal processor wherein the first mapping function is arranged to map data associated with the first type of modulation into a cluster of data points in the first modulation classification space.

Embodiments of the present invention provide a signal processor wherein the first mapping function comprises at least one of

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] j \right) \right]} + \left| \sin \left[\cos^{-1} (c_{63}) \right] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] \right) \right]} + \left| \sin \left[\cos^{-1} (c_{63}) \right] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] \right) \right]} + \sin \left[\cos^{-1} (c_{63}) \right];$$

$$f_1 = -\cos \cos^{-1} [\ln (c_{63})];$$

$$10 \quad f_1 = \left[\ln \left(\sqrt{c_{63}} \right) \right];$$

$$f_1 = \ln (c_{63}); \text{ Or}$$

$$f_1 = c_{63}$$

where

$$c_{40} = M_{40} - 3M_{20}^2,$$

$$15 \quad c_{41} = M_{40} - 3M_{20}M_{21},$$

$$c_{42} = M_{42} - M_{20}M_{20}^* - 2M_{21}^2,$$

$$c_{63} = M_{63} - 9M_{21}M_{42} + 12M_{21}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}$$

where

M_{pq} represents the moment of the received signal data, $y(n)$, or the reference

signal data 210, that is

$M_{pq} = E \left[\left(y(n) \right)^{p-q} \left(y^*(n) \right)^q \right]$, where $E[\cdot]$ is the expectation operator and $(\cdot)^*$ is the complex conjugate.

Embodiments of the present invention provide a signal processor wherein the second mapping function is arranged to map data associated with the second type of modulation into a cluster of data points in the second modulation classification space.

Embodiments of the present invention provide a signal processor wherein the second mapping function comprises

$$f_2 = \left| c_{40} - \cos(-c_{42}) \right|^{-1} \sin^{-1} \left[\sin^{-1} \left(\sin \left[\cos^{-1} \left(\ln \left[\ln \left(\cos[c_{42}] \right) \right] \right) \right] \right) \right]$$

Embodiments of the present invention provide a signal processor wherein said determining comprises determining the modulation classification of a predetermined number of neighbours in at least one of the first and second modulation classification spaces to the mapped received modulated signal.

Embodiments of the present invention provide a signal processor further a demodulator arranged to demodulate the received modulated signal according to said classifying.

Embodiments of the present invention provide a demodulator for demodulating a received modulated signal, the demodulator comprising a processor as described above for classifying the received modulated signal and means adapted to demodulate the received modulated signal according to said classifying.

Embodiments of the present invention provide a signal processor comprising

a mapper arranged to map a received modulated signal according to a first mapping function onto a first QAM classification space to produce mapped received modulated signal data; said first mapping function being arranged to map a first QAM type of received modulated signal into a corresponding first region of said first QAM classification space and a second QAM type of modulated signal into a corresponding second region of said first QAM classification space;

a correlator arranged to determine whether or not the mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the first classification space; and

a classifier arranged to classify the received modulated signal according to said determining as either the first QAM type of received modulated signal or the second QAM type of received modulation signal.

Embodiments of the present invention provide a signal processor wherein the first mapping function is adapted to map at least one cumulant, representing one or more than one feature of the received signal, into the first QAM classification space.

Embodiments of the present invention provide a signal processor where the first mapping function is

$$f_2 = |c_{40} - \cos(-c_{42})| - \sin^{-1} \left[\sin^{-1} \left(\sin \left[\cos^{-1} \left(\ln \left[\ln (\cos [c_{42}]) \right] \right) \right] \right) \right]$$

where

$$c_{40} = M_{40} - 3M_{20}^2,$$

$$c_{41} = M_{40} - 3M_{20}M_{21},$$

$$c_{42} = M_{42} - M_{20}M_{20}^* - 2M_{21}^2,$$

$$c_{63} = M_{63} - 9M_{21}M_{42} + 12M_{21}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}$$

where

M_{pq} represents the moment of the received signal data, $y\{n\}$, given by

$M_{pq} = E \left[(y\{n\})^{p-q} (y^*(n))^q \right]$, where $E[.]$ is the expectation operator and $(.)^*$ is the complex conjugate.

Embodiments of the present invention provide a signal processor wherein first QAM type of received modulated signal or the second QAM type of received modulation signal are 16QAM and 64QAM respectively.

Brief description of the drawings

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

Figure 1 shows a communication system;

Figure 2 depicts a receiver;

Figure 3 illustrates a signal processing flowchart ;

Figure 4 shows a first feature reference space; and

5 Figure 5 shows a second feature reference space.

Detailed description of embodiments of the invention

Referring to figure 1, there is schematically shown a communication system 100 comprising a transmitter 102 and a receiver 104. The transmitter 102 and receiver 104 are adapted to transmit and receive respectively a modulated signal 106. The
10 modulated signal 106 is produced at the transmitter 102 according a modulation scheme employed by a modulator 102' of the transmitter 102. The modulated signal 106 is received and demodulated via a demodulator 104' of the receiver 104 according to the modulation scheme employed by the transmitter 102.

The signal 106 is conveyed between the transmitter 102 and receiver 104 via a
15 channel 108. The channel 108 has a transfer function, $H(\omega)$, that introduces imperfections 110 to the signal 106. The imperfections comprise at least one of noise, distortion, symbol spreading and, for example, in the case of the channel being a radio environment reflections and multi-path fading. The transmitter 102 receives input data 112 to be conveyed and creates the modulated signal 106
20 according to that input data and a selected modulation scheme. The receiver 104 detects and demodulates the modulated signal to produce received or output data 114, which is typically an accurate approximation to the input data 112 processed by the transmitter 102.

Figure 2 depicts, in greater detail, an embodiment 200 of the receiver 104. The
25 receiver 104 can be coupled to or comprise an antenna 202. The signal received by the antenna 202 is fed to and processed by an equaliser 202'. The demodulator 104' comprises a receive data buffer 204 for storing receive signal data 206 representing the received signal 106, in an equalised baseband form, and a reference signal buffer 208 for storing reference signal data 210.

30 The demodulator 104' comprises a pair of processors 212 and 216 for evaluating respective functions that map input data to respective modulation classification

spaces. The modulation classification spaces will be described with reference to figures 4 and 5. The processors 212 and 216 are programmable such that the functions can be changed. Although the demodulator 104' has been described as having a pair of processors 212 and 216, one skilled in the art will appreciate that the processors can be merely functions that are run on the same hardware as opposed to being distinct processors or distinct cores.

The first processor 212 maps the receive signal data 206 into a respective modulation classification space using a respective mapping function 214. The second processor 216 maps the reference signal data 210 into a respective modulation classification space using a respective mapping function 218.

Embodiments of the respective mapping functions 214 and 218 are realised using the same function, f_p . Embodiments of the respective mapping functions 214 and 218 can be realised using at least one or more of the following functions taken jointly or severally in any and all combinations:

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh(|\cos[c_{41}]|) \right] \right) \right]} + \left| \sin [\cos^{-1}(c_{63})] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \tan \left[\tanh(\cos[c_{41}]) \right] \right]} + \left| \sin [\cos^{-1}(c_{63})] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \tan \left[\tanh(\cos[c_{41}]) \right] \right]} + \sin [\cos^{-1}(c_{63})];$$

$$f_1 = -\cos^{-1}[\ln(c_{63})];$$

$$f_1 = \left[\ln \left(\sqrt{c_{63}} \right) \right];$$

$$f_1 = \ln(c_{63}); \text{ or}$$

$$f_1 = c_{63}$$

where

$$c_{40} = M_{40} - 3M_{20}^2,$$

$$c_{41} = M_{40} - 3M_{20}M_{21},$$

$$c_{42} = M_{42} - M_{20}M_{20}^* - 2M_{21}^2,$$

$$c_{63} = M_{63} - 9M_{21}M_{42} + 12M_{21}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}$$

are cumulants of a signal of interest and where

- 5 M_{pq} represents the moment of the received signal data, $y(n)$, or the reference signal data 210, that is

$M_{pq} = E \left[(y(n))^{p-q} (y^*(n))^q \right]$, where $E[.]$ is the expectation operator and $(.)^*$ is the complex conjugate. For a complex value, $z = x + jy$, where x and y are real and $i = \sqrt{-1}$, one skilled in the art appreciates that

$$10 \quad \sin(x + jy) = \sin(x) \cosh(j) + i \cos(x) \sinh(y) \quad \text{and} \quad \sin^{-1}(z) = i \ln \left[iz + \sqrt{1 - z^2} \right]$$

$$\cos(x + jy) = \cos(x) \cosh(j) - i \sin(x) \sinh(j); \quad \text{and} \quad \cos^{-1}(z) = -i \ln \left[z + i \sqrt{1 - z^2} \right].$$

In the above, the signal-to-noise ratio (SNR) for the received signal 106 is assumed to be known. One skilled in the art can readily evaluate or estimate the SNR of the received signal using known techniques.

- 15 The reference signal data 210 is obtained from a number of previously determined reference classes 220 to 226. The present embodiment of the invention uses four reference classes. However, embodiments can be realised in which some other number of reference classes is used. The reference classes 220 to 226 comprise first to fourth reference classes that correspond to respective modulation schemes.
- 20 A preferred embodiment provides for the first reference class to be a BPSK reference class, the second reference class to be a QPSK reference class, the third reference class to be a 16QAM reference class and the fourth reference class to be a 64QAM reference class. Embodiments of the invention are not limited to such modulation schemes for the reference classes. Embodiments can be realised in which other
- 25 modulation schemes are used, such as, for example, at least one of 128QAM and 256QAM.

For a given SNR, each reference class 220 to 226 comprises a particular number of sets of data points. Embodiments of the present invention will be described in which a reference class comprises 50 sets of data samples or points for a given SNR. A set of data samples represents a reference signal, $y'(n)$, where $n=1,2,\dots,N$.

- 5 Preferred embodiments use $N=2048$, but other values of N can be used such as, for example, 512, 1024, 4096 or more. The accuracy of the classification of the modulation techniques increases with increasing N .

A modulation scheme corresponding to a given reference class is represented within the modulation classification space by a respective cluster of data points within that space realised by calculating at least one function that maps, and preferably two functions that map, the data samples of corresponding sets into the modulation classification space. Preferred embodiments represent a given modulation scheme using 50 pairs of data points. Preferably, the first function is one of the functions, f_1 , given above. Preferably, the second function is given by

15
$$f_2 = |c_4 \mathbf{o} - \cos(-c_{42})| \cdot \sin^{-1} \left[\sin^{-1} \left(\sin \left[\cos^{-1} \left(\ln \left[\ln \left(\cos[c_{42}] \right) \right] \right) \right] \right) \right].$$

Again, for a complex value, $z = x + jy$, where x and y are real and $i = \sqrt{-1}$, one skilled in the art appreciates that

$$\sin(x + jy) = \sin(x) \cosh(j) + i \cos(x) \sinh(y) \text{ and } \sin^{-1}(z) = i \ln \left[iz + \sqrt{(1-z^2)} \right]$$

$$\cos(x + jy) = \cos(x) \cosh(j) - i \sin(x) \sinh(y) \text{ and } \cos^{-1}(z) = -i \ln \left[z + i \sqrt{1-z^2} \right].$$

20

In essence, f_1 and f_2 are evaluated for each set of $y'(n)$ and a given modulation scheme is represented in the modulation classification space by 50 pairs of values of f_1 and f_2 . Therefore, within the modulation classification space:

BPSK modulation or signals are represented by 50 pairs of values of f_1 and f_2 ;

- 25 QPSK modulation or signals are represented by 50 pairs of values of f_1 and f_2 ;

16QAM modulation or signals are represented by 50 pairs of values of f_1 and f_2 ; and

64QAM modulation or signals are represented by 50 pairs of values of f_1 and f_2 .

The sets of 50 pairs of values of f_1 and f_2 are known as reference sets for
5 respective modulation schemes. Although embodiments use 50 pairs of values of f_1 and f_2 , embodiments of the invention are not limited thereto. Embodiments can be realised that use some other number of pairs of values of f_1 and f_2 according, for example, to a desired or acceptable processing overhead and performance.

The demodulator 104' comprises an evaluator 228 that assesses the receive signal
10 data, following processing by at least one of f_1 and f_2 . The evaluator 228 is arranged to classify the receive signal according to perceived modulation class(es) using the reference sets, that is, by evaluating the mapping by at least one of f_1 and f_2 into the modulation classification space relative to the reference sets. The evaluation undertaken by the evaluator 228 is preferably based on a nearest
15 neighbour principle. According to one embodiment, the K nearest neighbours (KNN) of the reference sets to the mapping of the received signal via at least one of f_1 and f_2 into the modulation classification space is used as the basis for the classification of the modulation scheme of received signal. Firstly, the K nearest neighbours of the data of the reference sets are identified and then the modulation classes of those K
20 nearest neighbours are determined. If the predominant class is BPSK, the received signal is presumed to use BPSK and an output 230 to that effect is produced accordingly. If the predominant class is QPSK, the received signal is presumed to be QPSK and an output 230 to that effect is produced accordingly. If the predominant class is neither BPSK nor QPSK, then further processing is needed to narrow the
25 class to one of 16QAM and 64QAM. Embodiments of the present invention can be realised in which a broad range of values of K can be used. In particular, embodiments can be realised in which $K = 11$ to 29. Preferred embodiments of the present invention use an odd value of K. One skilled in the art will appreciate that determining the nearest neighbours can be realised by calculating distances such as,
30 for example, Euclidean distances. However, embodiments of the present invention are not limited thereto. Embodiments can be realised in which other measures or

distance measures can be used. For example, the nearest neighbours might be determined on the basis of a centroid or centre of mass.

The further processing takes the form of processing the received signal data 206 again using reference signal data for the remaining modulation classes that have not
 5 been ruled out. According to the present embodiment, a result of the processing by the evaluator 228 is that 16QAM and 64QAM cannot be ruled out, or, as a first pass, the evaluator 228 could not distinguish between, or could not distinguish with a desired level of confidence between, the remaining modulation classes. Consequently, the processing pipeline is used again, but with a second mapping
 10 function, given by f_2 and using only the reference sets for the remaining modulation classes, that is, 16QAM and 64QAM. Suitably, the evaluator 228 will then produce output data 230 indicating that the modulation scheme used by the received signal, or received signal data, corresponds to one of the remaining classes. In the present embodiment, the remaining classes are 16QAM and 64QAM, but could equally well
 15 be or comprise some other modulation class or classes.

Once the modulation class of the received signal 106 has been determined, demodulation can commence with a view to producing the original data transmitted by the transmitter in the form of output data 232.

Figure 3 shows a flowchart 300 of processing steps undertaken by embodiments. At
 20 step 302, data representing the received signal is obtained. Reference signal data is retrieved at step 304. One skilled in the art appreciates that steps 302 and 304 can be performed in any order. Furthermore, the reference signal data is used to create reference sets as described above using the two mapping functions. Embodiments can be realised in which the reference sets are created in advance and retrieved for
 25 use directly by the evaluator 228. Steps 306 and 308 process the data representing the received signal and the reference signal data to map them into a modulation classification space. Again the two steps 306 and 308 of mapping can be performed in any order. The evaluator 228 performs step 310 with a view to determining with which reference set the mapped received signal data most greatly corresponds, that
 30 is, determining whether or not there is a predominant modulation class. As described above, preferred embodiments undertake such determining on the basis of identifying the modulation class corresponding to the K nearest neighbours of the mapped received signal data.

Again, embodiments of the present invention can be realised in which a broad range of values of K can be used. In particular, embodiments can be realised in which K= 11 to 29. Preferred embodiments of the present invention use an odd value of K. One skilled in the art will appreciate that determining the nearest neighbours can be realised by calculating distances such as, for example, Euclidean distances. However, embodiments of the present invention are not limited thereto. Embodiments can be realised in which other measures or distance measures can be used. For example, the nearest neighbours might be determined on the basis of a centroid or centre of mass.

- 10 A determination is made at step 314 regarding whether or not the predominant modulation class corresponds to at least one of a first modulation class and a second modulation class. In a preferred embodiment, the first and second modulation classes are BPSK and QPSK respectively. If the determination at step 314 is positive, an output of the predominant modulation class is given at step 316.
- 15 However, if the determination at step 314 is negative, control passes to step 318, where a subset of the reference signal data is used; the subset excluding reference signal data corresponding to the first and second reference signal data. Preferred embodiments provide reference signal data corresponding to four modulation schemes. Therefore, step 318 retrieves reference signal data for the third and fourth modulation classes. In preferred embodiments, the third and fourth modulation schemes or classes are 16QAM and 64QAM.
- 20

The reference signal data for the third and fourth modulation classes is processed at step 320 to map that data into a second modulation classification space. Similarly, the received signal data is mapped into the second modulation classification space at step 322. In preferred embodiments, the mapping is performed using the function

25

$$f_2 = \left| c_{40} - \cos(-c_{42}) \right| - \sin^{-1} \left[\sin^{-1} \left\{ \sin \left[\cos^{-1} (\ln[\ln(\cos[c_{42}])]) \right] \right\} \right]$$

described above. Again, for completeness, for a complex value, $z = x + jy$, where x and y are real and $i = \sqrt{-1}$, one skilled in the art appreciates that

$$\sin(x + jy) = \sin(x) \cosh(j) + i \cos(x) \sinh(y) \text{ and } \sin^{-1}(z) = i \ln \left[iz + \sqrt{(1-z^2)} \right]$$

30 $\cos(x + jy) = \cos(x) \cosh(j) - i \sin(x) \sinh(j); \text{ and } \cos^{-1}(z) = -i \ln \left[z + i \sqrt{1-z^2} \right].$

Steps 320 and 322 can be performed in any order.

An evaluation regarding whether or not the mapped received signal data has a sufficient degree of correlation with one of the reference sets corresponding to the third and fourth modulation classes is performed at step 324. In a preferred embodiment, the evaluation uses identifies the K nearest neighbours of reference sets to the mapping of the received signal data into the second modulation classification space. The modulation class of the K nearest neighbours is identified at step 326 and output at step 316.

Again, embodiments of the present invention can be realised in which a broad range of values of K can be used. In particular, embodiments can be realised in which K=11 to 29. Preferred embodiments of the present invention use an odd value of K. One skilled in the art will appreciate that determining the nearest neighbours can be realised by calculating distances such as, for example, Euclidean distances. However, embodiments of the present invention are not limited thereto. Embodiments can be realised in which other measures or distance measures can be used. For example, the nearest neighbours might be determined on the basis of a centroid or centre of mass.

Once the modulation class of the received signal has been identified, the signal can be processed, that is, preferably demodulated.

Referring to figure 4, there is shown an embodiment of a modulation classification space 400, also known as a reference feature space. One skilled in the art will appreciate that in general the data constituting the reference sets, that is, the outputs of the functions f_1 and f_2 are complex. Referring to figure 4, the complex numbers are plotted in the plane of the feature reference space. It can be appreciated that there are three clusters of reference sets; namely, a BPSK reference set 402, a QPSK reference set 404 and a cluster 406 representing reference sets for QAM, in particular, 16QAM, represented by the triangles, and 64QAM, represented by the circles. One skilled in the art can appreciate that mapping the received signal data onto the feature reference plane and determining the K nearest neighbours would be relatively straightforward if the KNN belonged to the BPSK reference set 402 or the QPSK reference set 404 thereby allowing modulation classification. However, if the KNN encompassed data from the cluster 406 representing significantly overlapping reference sets for QAM, it would not be possible to distinguish between the two modulation schemes of 16QAM and 64QAM.

In light of the above, embodiments of the present invention use a different feature reference space or modulation classification space to distinguish between the two types of QAM modulation. Referring to figure 5, there is shown a second feature reference space 500. The feature reference space 500 comprises two feature distributions 502 and 504, which correspond to respective modulation schemes. In the present embodiment, a first feature distribution 502 corresponds to 16QAM, represented by the triangles, and a second feature distribution 504 corresponds to 64QAM, represented by the circles. One skilled in the art can appreciate that the second modulation classification space, produced using a respective mapping function, allows 16QAM and 64QAM features to be distinguished.

Embodiments of the present invention are operable using one or more than one modulation scheme. The modulation schemes comprise at least two of BPSK, QPSK, and QAM. Embodiments can be realised using 16QAM and 64QAM. Other modulation schemes can be used to realised embodiments of the invention.

Embodiments of the present invention use the K nearest neighbour principle in distinguishing between modulation schemes. Embodiments of the present invention are operable with a broad range of values of K such as, for example, $K=1$ to 29. Preferably, K is odd. Furthermore, one skilled in the art will appreciate that determining the nearest neighbours can be realised by calculating distances such as, for example, Euclidean distances. However, embodiments of the present invention are not limited thereto. Embodiments can be realised in which other measures or distance measures can be used. For example, the nearest neighbours might be determined on the basis of a centroid or centre of mass.

Table 1 below illustrates the performance of embodiments of the present invention in the case of attempting to distinguish between four modulation classifications for different SNRs and different numbers of samples, N, for the reference signal data, $y'(n)$, where $n=1, 2, \dots, N$.

SNRs	N=512	N=2048
10 dB	94.7%	99.8%
20 dB	99.9%	100.0%

Table 1

The performance of the automatic modulation classifier according to embodiments of the present invention is impressive.

5 It will be appreciated that embodiments of the present invention can be realised in the form of hardware, software or a combination of hardware and software. Any such software may be stored in the form of volatile or non-volatile storage such as, for example, a storage device like a ROM, whether erasable or rewritable or not, or in the form of memory such as, for example, RAM, memory chips, device or integrated circuits or on an optically or magnetically readable medium such as, for example, a
10 CD, DVD, magnetic disk or magnetic tape or the like. It will be appreciated that the storage devices and storage media are embodiments of machine-readable storage that are suitable for storing a program or programs comprising instructions that, when executed, implement embodiments of the present invention. Accordingly, embodiments provide machine executable code for implementing a system, device or
15 method as described herein or as claimed herein and machine readable storage storing such a program. Still further, such programs may be conveyed electronically via any medium such as a communication signal carried over a wired or wireless connection and embodiments suitably encompass the same.

CLAIMS

1. A signal processing method, the method comprising the steps of

5 mapping a received modulated signal according to a first mapping function onto a first classification space to produce mapped received modulated signal data; said first mapping function being arranged to map a first type of received modulated signal into a corresponding first region of said first classification space and a second type of modulated signal into a corresponding second region of said first classification space;

10 determining whether or not the mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the first classification space; and

15 classifying the received modulated signal according to said determining as either the first type of received modulated signal or the second type of received modulation signal.

2. A signal processing method as claimed in any preceding claim, further comprising the steps of

20 mapping the received modulated signal according to a second mapping function onto a second classification space to produce second mapped received modulated signal data; said second mapping function being arranged to map a third type of received modulated signal into a corresponding first region of said second classification space and a fourth type of modulated signal into a corresponding second region of said second classification space;

25 determining whether or not the second mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the second classification space; and

classifying the received modulated signal according to said determining as either the third type of received modulated signal or the fourth type of received modulation signal.

3. A signal processing method as claimed in any preceding claim, wherein the first mapping function is arranged to map data associated with the first type of modulation into a cluster of data points in the first modulation classification space.

4. A signal processing method as claimed in any preceding claim, wherein the

5 first mapping function comprises at least one of

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] j \right) \right]} + \left| \sin \left[\cos^{-1} (c_{63}) \right] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] \right) \right]} + \left| \sin \left[\cos^{-1} (c_{63}) \right] \right|;$$

$$f_1 = \sqrt{\left[\cos^{-1} \left(\tan \left[\tanh (\cos [c_{41}]) \right] \right) \right]} + \sin \left[\cos^{-1} (c_{63}) \right];$$

$$f_1 = -\cos \cos^{-1} [\ln (c_{63})];$$

$$10 \quad f_1 = \left[\ln \left(\sqrt{c_{63}} \right) \right];$$

$$f_1 = \ln (c_{63}); \text{ or}$$

$$f_1 = c_{63}$$

where

$$c_{40} = M_{40} - 3M_{20}^2,$$

$$15 \quad c_{41} = M_{40} - 3M_{20}M_{21},$$

$$c_{42} = M_{42} - M_{20}M_{20}^* - 2M_{21}^2,$$

$$c_{63} = M_{63} - 9M_{21}M_{42} + 12M_{21}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}$$

where

M_{pq} represents the moment of the received signal data, $y(n)$, or the reference

20 signal data 210, that is

$M_{pq} = E \left[\left(y(n) \right)^{p-q} \left(y^*(n) \right)^q \right]$, where $E[\cdot]$ is the expectation operator and $(\cdot)^*$ is the complex conjugate.

5. A signal processing method as claimed in any preceding claim, wherein the second mapping function is arranged to map data associated with the second type of modulation into a cluster of data points in the second modulation classification space.

6. A signal processing method as claimed in any preceding claim, wherein the second mapping function comprises

$$f_2 = \left| c_{40} - \cos(-c_{42}) \right|^{-1} \sin^{-1} \left[\sin^{-1} \left(\sin \left[\cos^{-1} \left(\ln \left[\ln \left(\cos[c_{42}] \right) \right] \right) \right] \right) \right]$$

7. A signal processing method as claimed in any preceding claim, wherein said determining comprises determining the modulation classification of a predetermined number of neighbours in at least one of the first and second modulation classification spaces to the mapped received modulated signal.

8. A signal processing method as claimed in any preceding claim, further comprising the step of demodulating the received modulated signal according to said classifying.

9. A method of demodulating a received modulated signal comprising the step of processing the received modulated signal using a method as claimed in any preceding claim and demodulating the received modulated signal according to said classifying.

10. A signal processing method, the method comprising the steps of

mapping a received modulated signal according to a first mapping function onto a first QAM classification space to produce mapped received modulated signal data; said first mapping function being arranged to map a first QAM type of received modulated signal into a corresponding first region of said first QAM classification space and a second QAM type of modulated signal into a corresponding second region of said first QAM classification space;

determining whether or not the mapped received modulated signal data has a sufficient degree of correlation with at least one of the first and second regions of the first classification space; and

classifying the received modulated signal according to said determining as either the first QAM type of received modulated signal or the second QAM type of received modulation signal.

11. A signal processing method as claimed in claim 10, wherein the first mapping function is adapted to map at least one cumulant, representing one or more than one feature of the received signal, into the first QAM classification space.

12. A signal processing method as claimed in claim 11, where the first mapping function is

$$f_2 = |c_{40} - \cos(-c_{42})| - \sin^{-1} \left[\sin^{-1} \left(\sin \left[\cos^{-1} \left(\ln \left[\ln (\cos [c_{42}]) \right] \right) \right] \right) \right]$$

10 where

$$c_{40} = M_{40} - 3M_{20}^2,$$

$$c_{41} = M_{40} - 3M_{20}M_{21},$$

$$c_{42} = M_{42} - M_{20}M_{20}^* - 2M_{21}^2,$$

$$c_{63} = M_{63} - 9M_{21}M_{42} + 12M_{21}^3 - 3M_{20}M_{43} - 3M_{22}M_{41} + 18M_{20}M_{21}M_{22}$$

15 where

M_{pq} represents the moment of the received signal data, $y(n)$, given by

$M_{pq} = E \left[(y(n))^p (y^*(n))^q \right]$, where $E[.]$ is the expectation operator and $(.)^*$ is the complex conjugate.

13. A method as claimed in any of claims 10 to 12, wherein first QAM type of received modulated signal or the second QAM type of received modulation signal are 16QAM and 64QAM respectively.

14. A signal detector, demodulator or apparatus comprising a processor arranged to implement a method as claimed in any preceding claim.

15. A method substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

16. A system substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

17. An apparatus substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

Figure 1

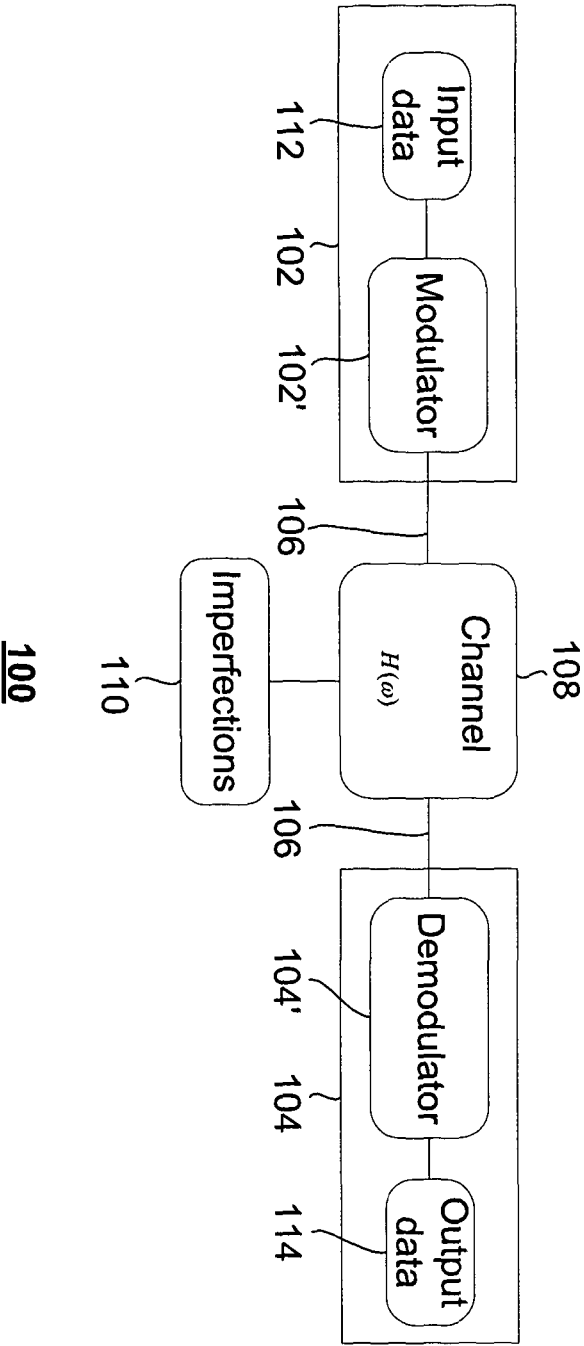
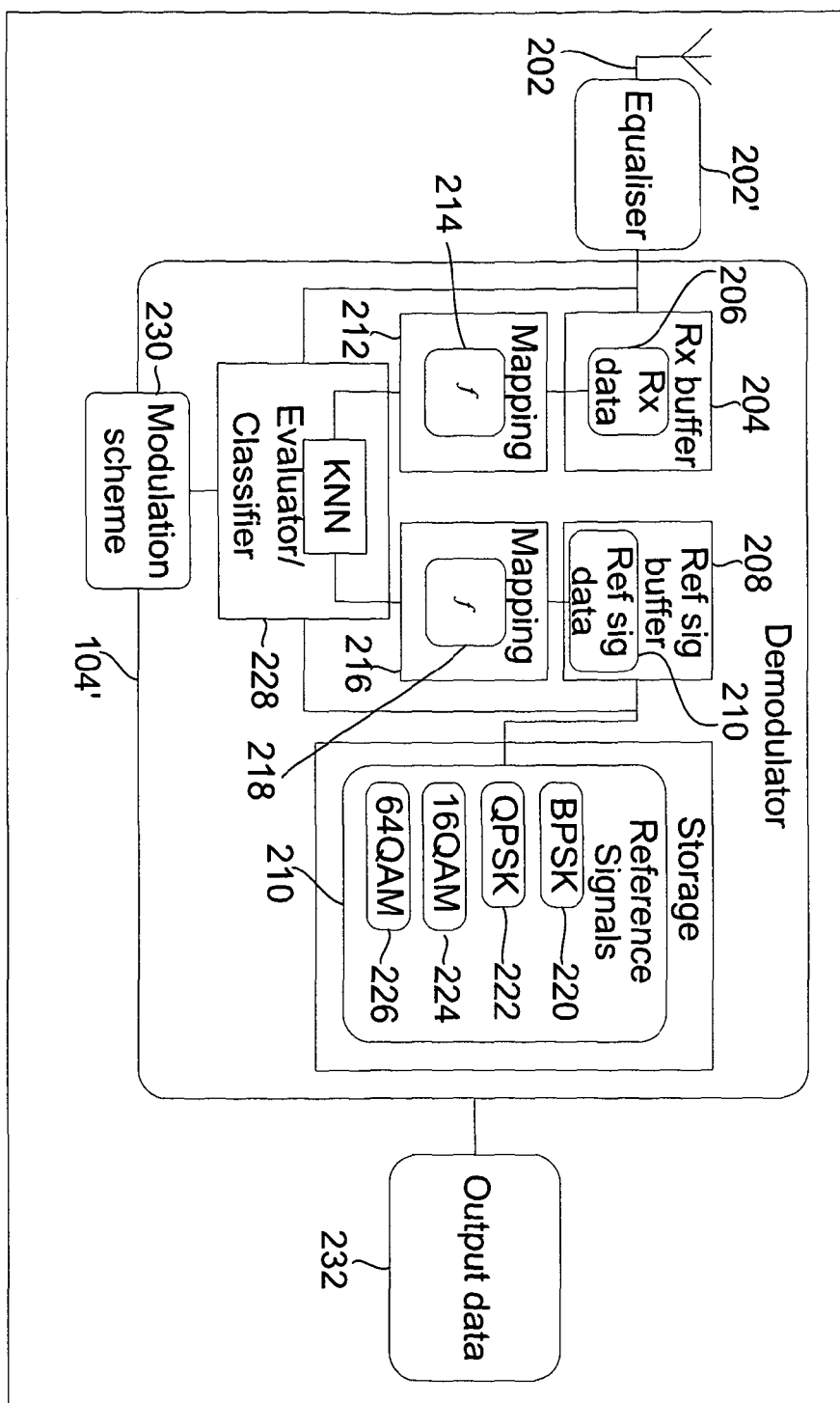


Figure 2



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Figure 3

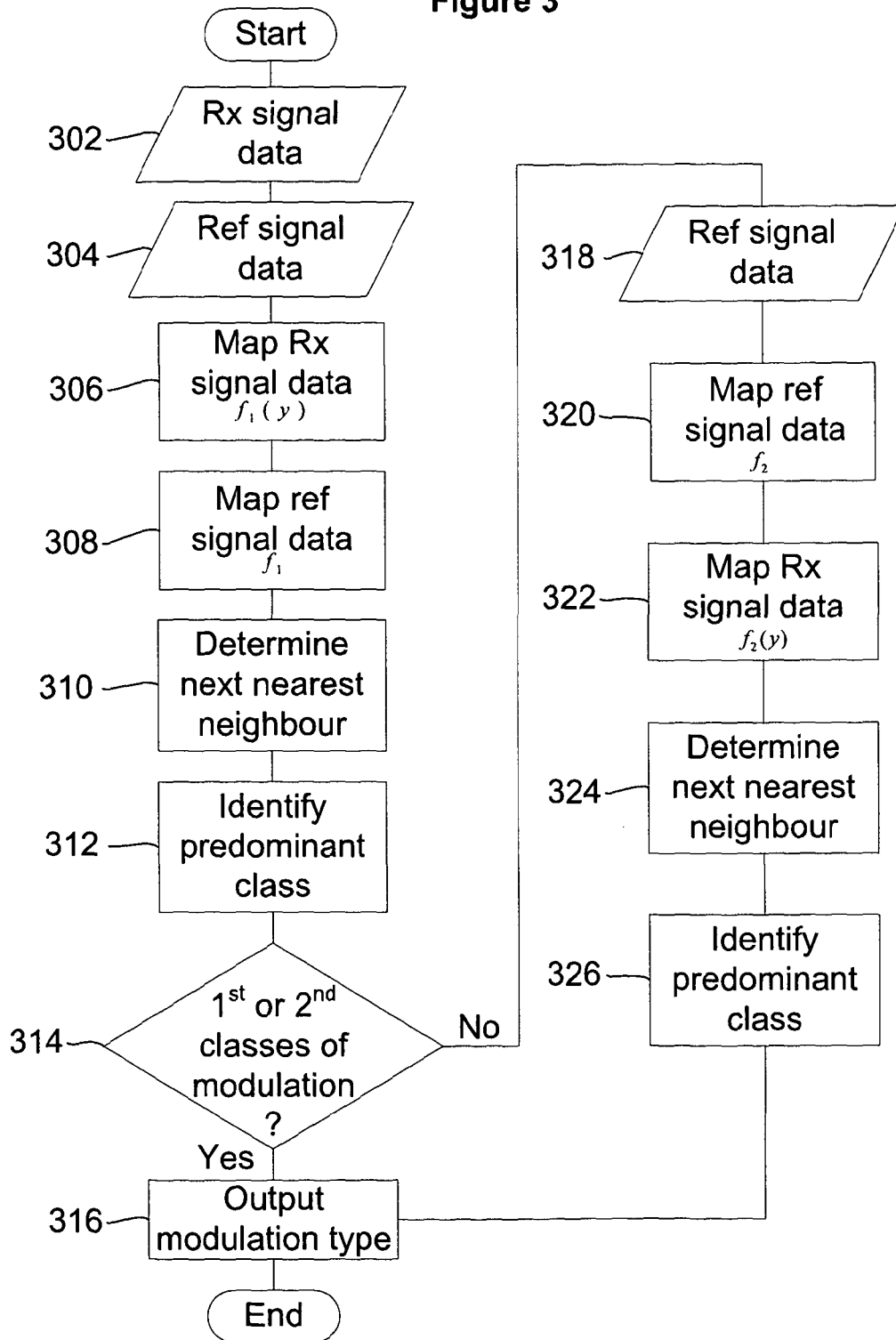
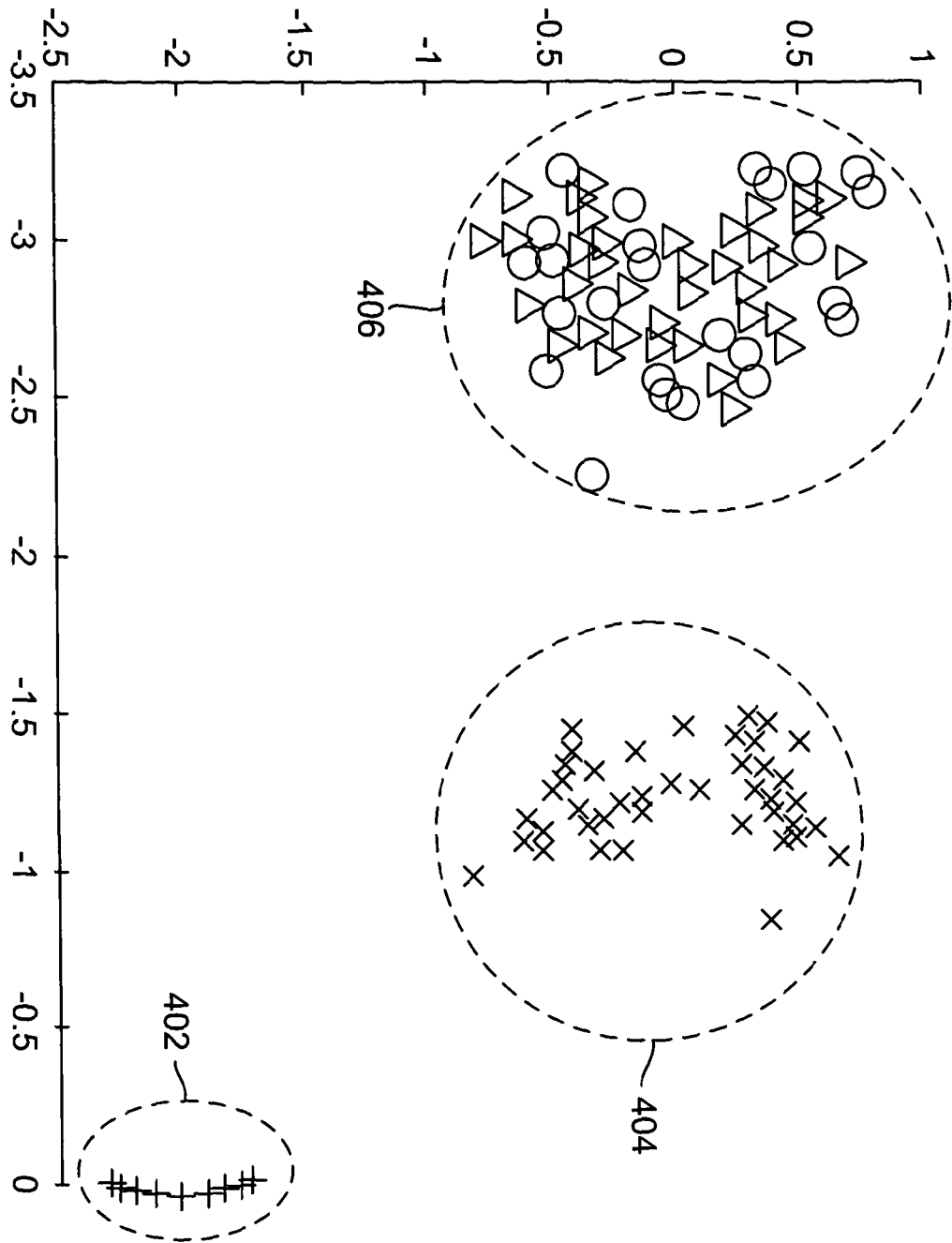
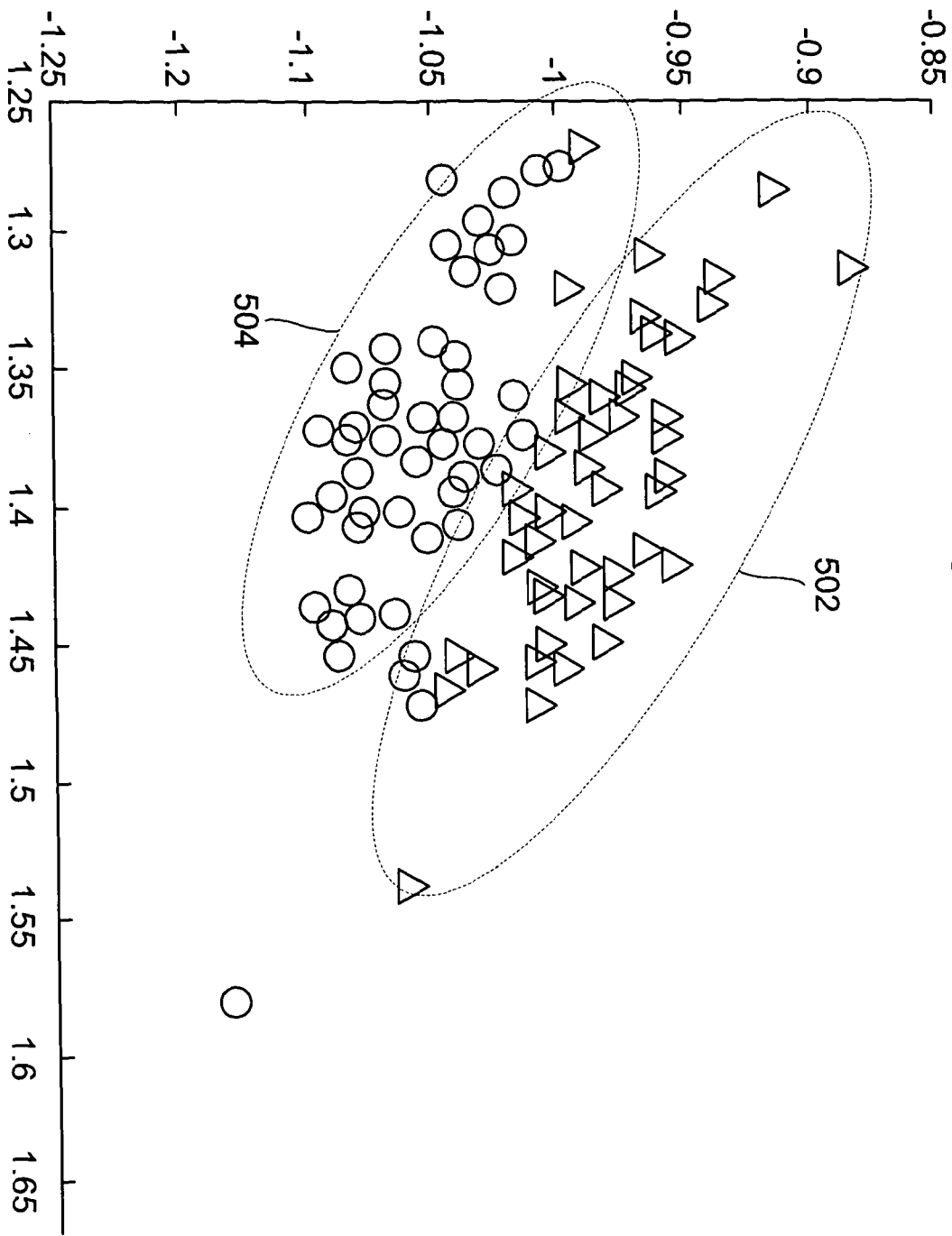
**300**

Figure 4



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Figure 5



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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/051320

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L27/00

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 practical, search terms used)

EPO-Internal , 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	MI RARAB M R ET AL: "Robust modulati on classi ficati on for PSK /QAM/ASK usi ng higher-order cumul ants" , 2007 6TH INTERNATIONAL CONFERENCE ON INFORMATION, COMMUNICATIONS & SIGNAL PROCESSING; SINGAPORE; 10 - 13 DECEMBER 2007 , I EEE, PISCATAWAY, NJ , USA, 10 December 2007 (2007-12-10) , pages 1-4, XP031229399 , ISBN : 978-1-4244-0982-2 the whol e document ----- -/- .	1-17



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

4 October 2011

Date of mailing of the international search report

11/10/2011

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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/051320

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DOBRE O A ET AL: "Robust QAM modul ati on classi ficati on algori thm usi ng cycl ic cumul ants" , WI RELESS COMMUNICATIONS AND NETWORKING CONFERENCE, 2004. WCNC. 2004 I E EE ATLANTA, GA, USA 21-25 MARCH 2004, PISCATAWAY, NJ , USA, I IEEE, vol . 2, 21 March 2004 (2004-03-21) , pages 745-748, XP010708410, ISBN : 978-0-7803-8344-9 the whol e document -----	1-17
X	HAN GANG ET AL: "Study of modul ati on recogni tion based on HOCs and SVM", VEHICULAR TECHNOLOGY CONFERENCE, 2004. VTC 2004-SPRING. 2004 I IEEE 59TH MI LAN , ITALY 17-19 MAY 2004, PISCATAWAY, NJ , USA, I IEEE, US, vol . 2, 17 May 2004 (2004-05-17) , pages 898-902 , XP010766040, DOI : 10. 1109/VETECS. 2004. 1388960 ISBN : 978-0-7803-8255-8 the whol e document -----	1-17
X	WONG M L D ET AL: "Automati c digital modul ati on recogni tion usi ng arti ficial neural network and geneti c algori thm" , SIGNAL PROCESSING, ELSEVI ER SCI ENCE PUBLISHERS B.V. AMSTERDAM, NL, vol . 84, no. 2, 1 February 2004 (2004-02-01) , pages 351-365 , XP004482274, ISSN : 0165-1684, DOI : 10. 1016/J . SIGPRO. 2003 . 10.019 the whol e document -----	1-17
A	LOUIS C ET AL: "Automati c modul ati on recogni tion with a hierarchi cal neural network" , MI LITARY COMMUNICATIONS CONFERENCE, 1994. MI LCOM '94. CONFERENCE RECOR D, 1994 I IEEE FORT MONMOUTH , NJ , USA 2-5 OCT. 1994, NEW YORK, NY, USA, I IEEE, US, 2 October 1994 (1994-10-02) , pages 713-717 , XP010149726, DOI : 10. 1109/MI LCOM. 1994.473878 ISBN : 978-0-7803-1828-1 the whol e document -----	1-17