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(56) Documents Cited:
US 20080159186 A1 **US 20060013120 A1**
US 20050169400 A1

(58) Field of Search:
INT CL **H04L, H04N**
Other: **EPODOC, WPI**

(54) Title of the Invention: **Transmitter and method of transmitting**
Abstract Title: **Selective local data insertion using hierarchical modulation symbols on OFDM sub-carriers in DVB-NGH system**

(57) DVB (Digital Video Broadcasting) networks, for example NGH (Next Generation for Handheld), using OFDM (orthogonal frequency division multiplexing) can be deployed as single frequency networks.
The invention allows common data (eg networked programs) sent to all/multiple base stations y_{0-3} to be combined with local data h_{0-1} (eg local news) sent to one or a small group of base stations. When only common data is transmitted OFDM sub-carriers use a first modulation 94 (eg 16QAM). When both common and local data is transmitted sub-carriers are hierarchically modulated into a larger constellation 96 (eg 64QAM).
The QAM constellations may be rotated (Figs. 8-11).
Clusters of proximate/adjacent base stations may be arranged to transmit on a TDM (time division multiplexed) basis (Fig. 12).
At the receiver (Fig. 21) data streams are separated.
The claims relate to transmitters in the above system.

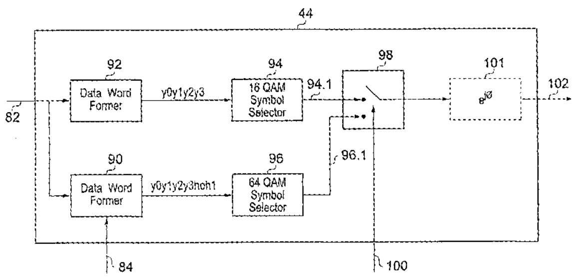


FIG. 5

GB 2478140 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

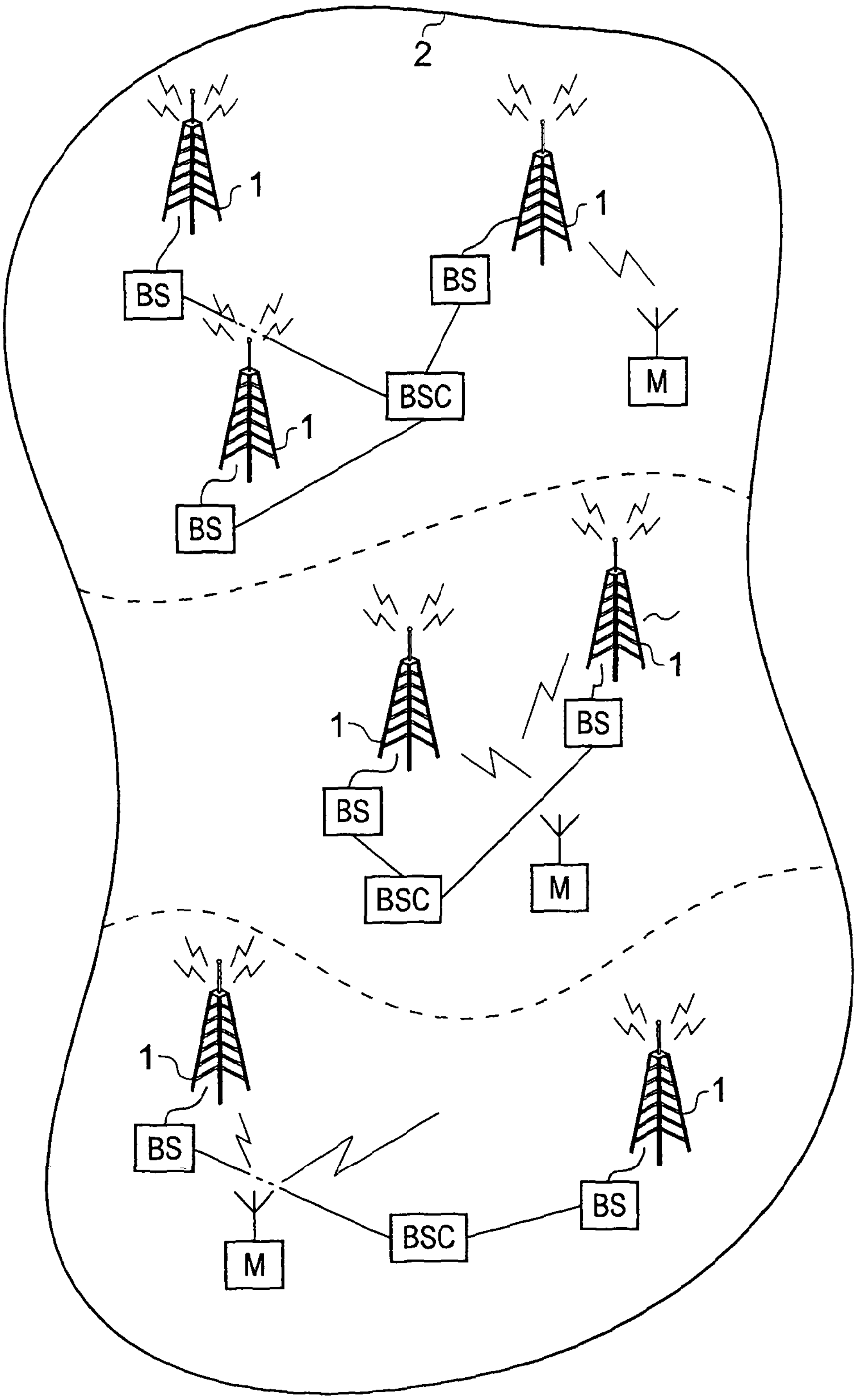


FIG. 1

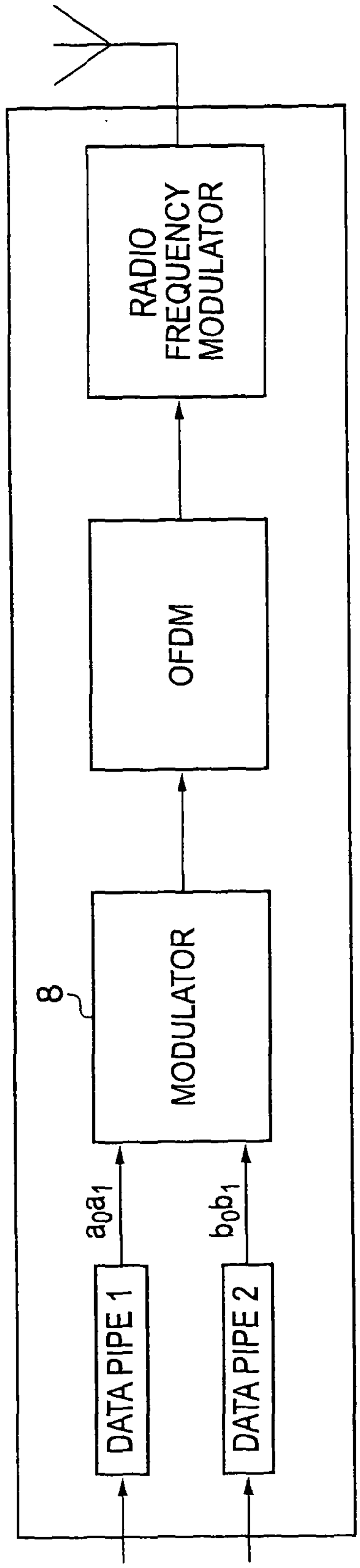

RADIO FREQUENCY MODULATOR
OFDM
MODULATOR
8
a_0a_1
b_0b_1
DATA PIPE 1
DATA PIPE 2

FIG. 2

23 47 10

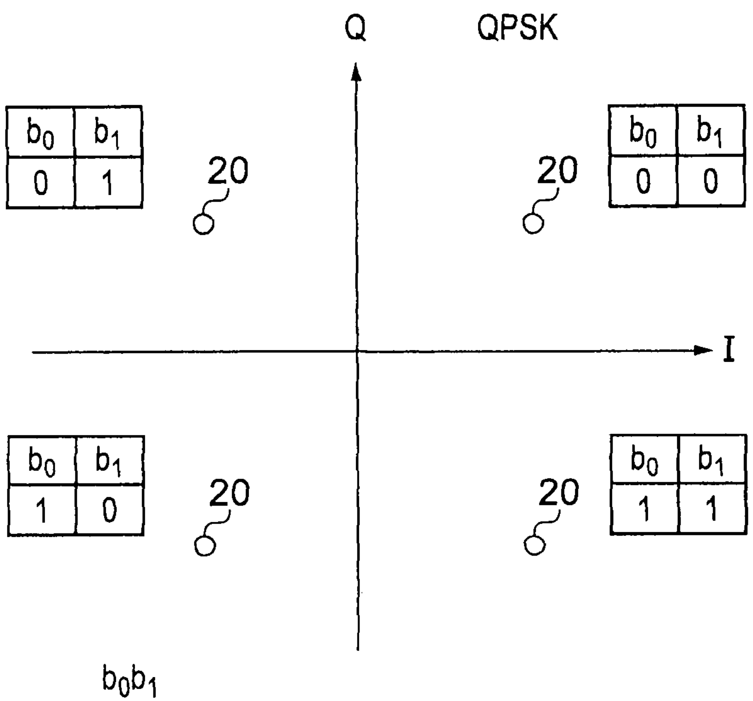


FIG. 3a

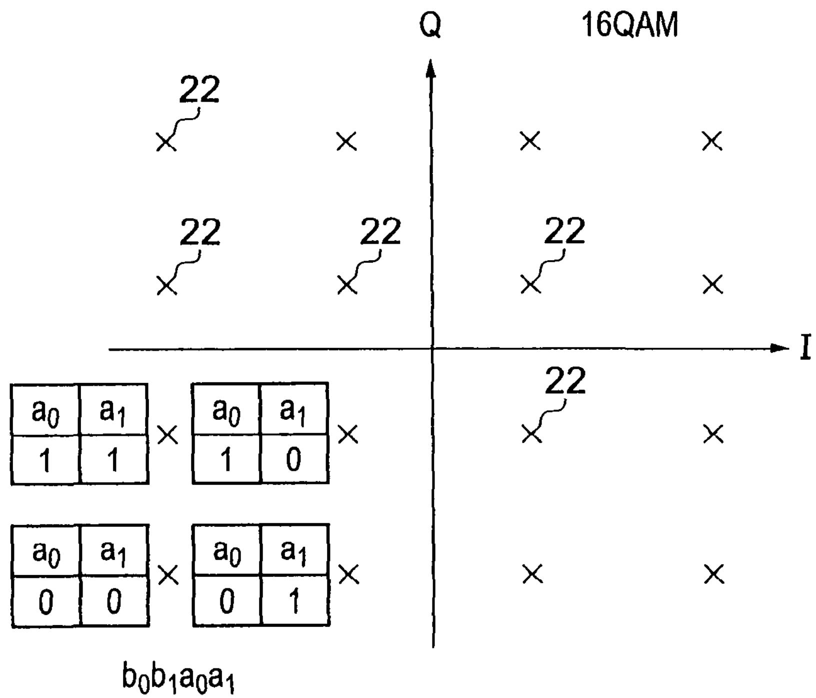
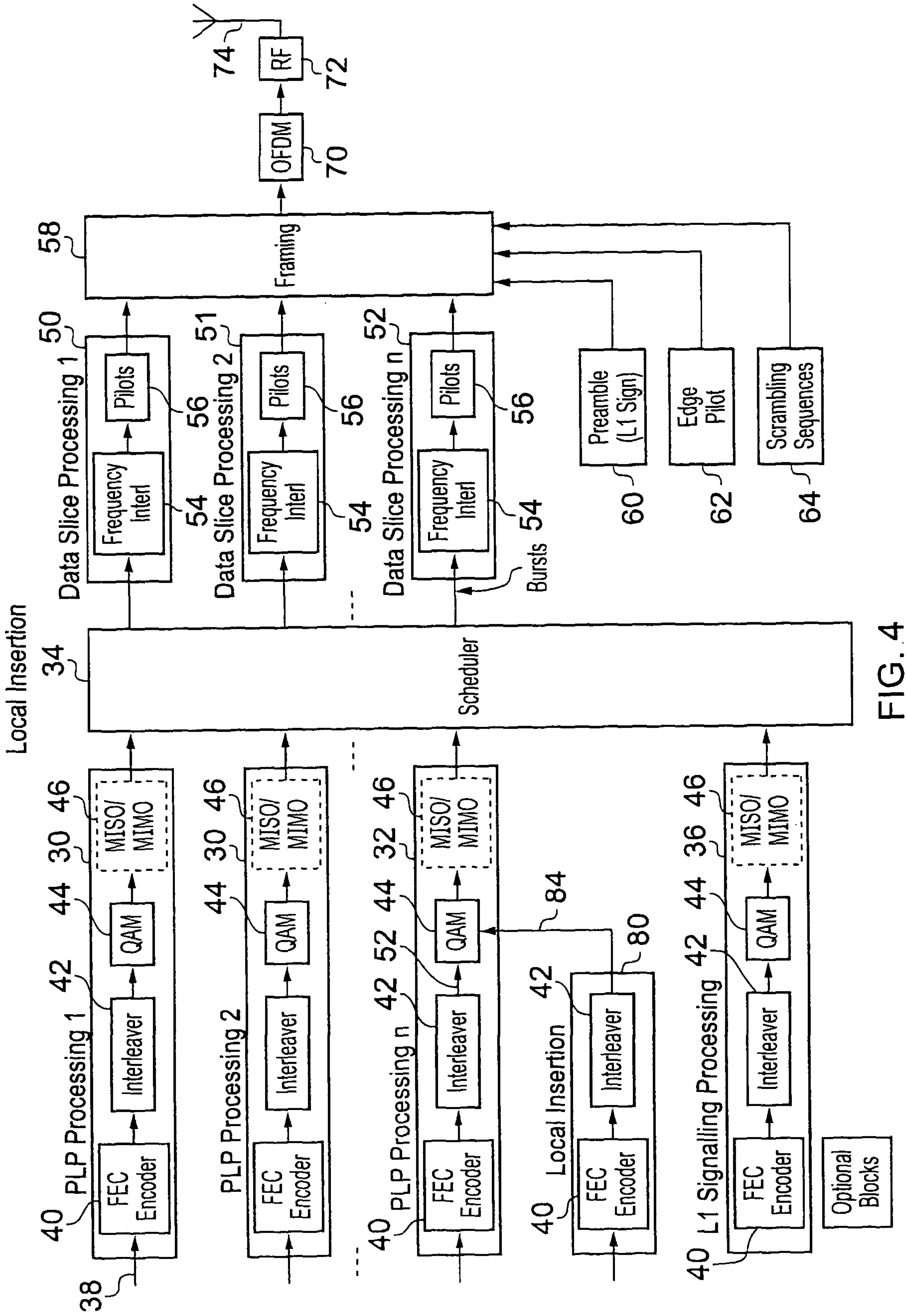


FIG. 3b



PLP Processing 1
FEC Encoder
Interleaver
QAM
MISO/ MIMO
PLP Processing 2
PLP Processing n
Local Insertion
L1 Signalling Processing
Optional Blocks
Scheduler
Local Insertion
Data Slice Processing 1
Data Slice Processing 2
Data Slice Processing n
Frequency Interl
Pilots
Bursts
Framing
Preamble (L1 Sign)
Edge Pilot
Scrambling Sequences
OFDM
RF
38
40
42
44
46
30
32
36
52
80
84
34
50
51
52
54
56
58
60
62
64
70
72
74

FIG. 4

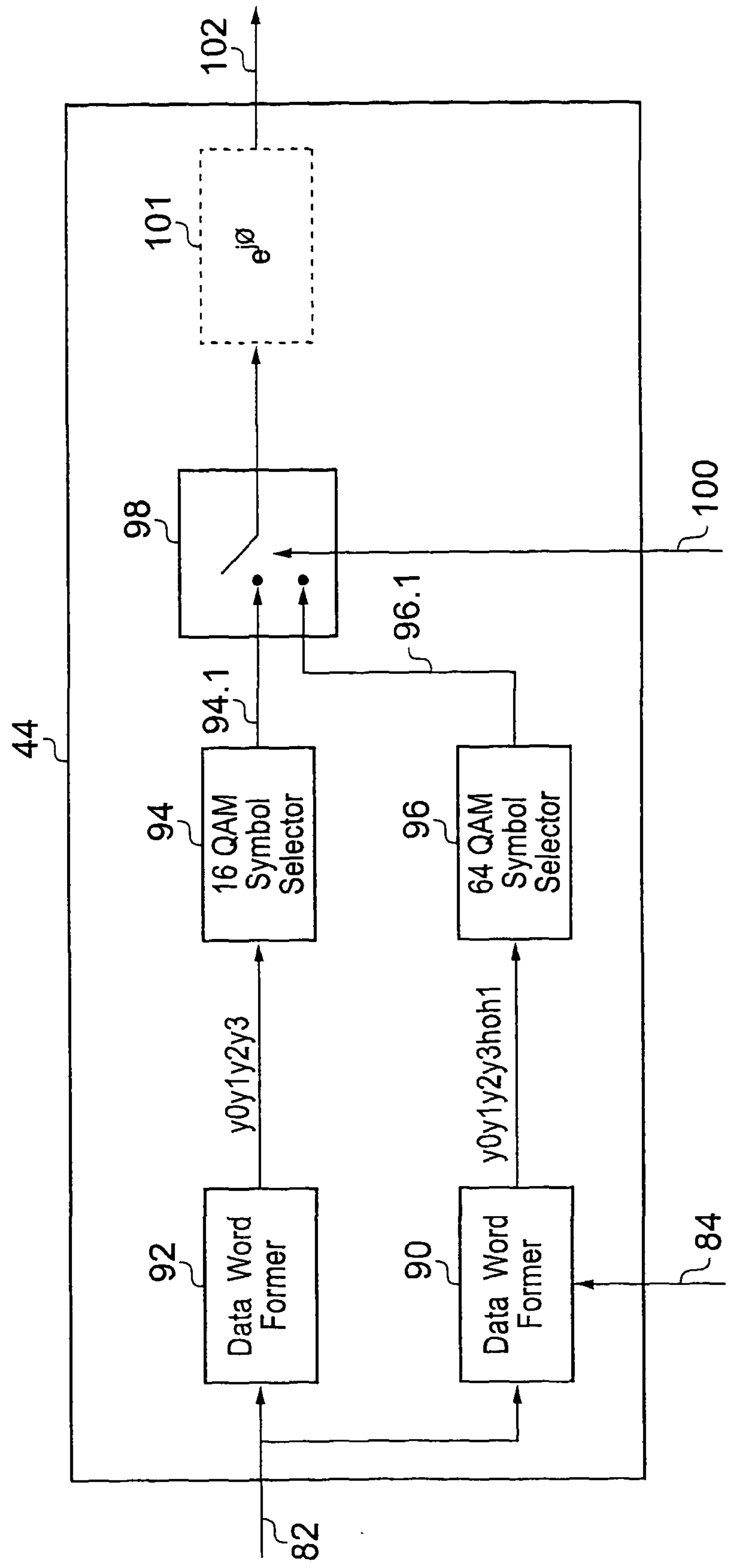

44
92
Data Word Former
90
Data Word Former
y0y1y2y3
y0y1y2y3h0h1
94
16 QAM Symbol Selector
96
64 QAM Symbol Selector
94.1
96.1
98
100
101
$e^{jø}$
102
82
84

FIG. 5

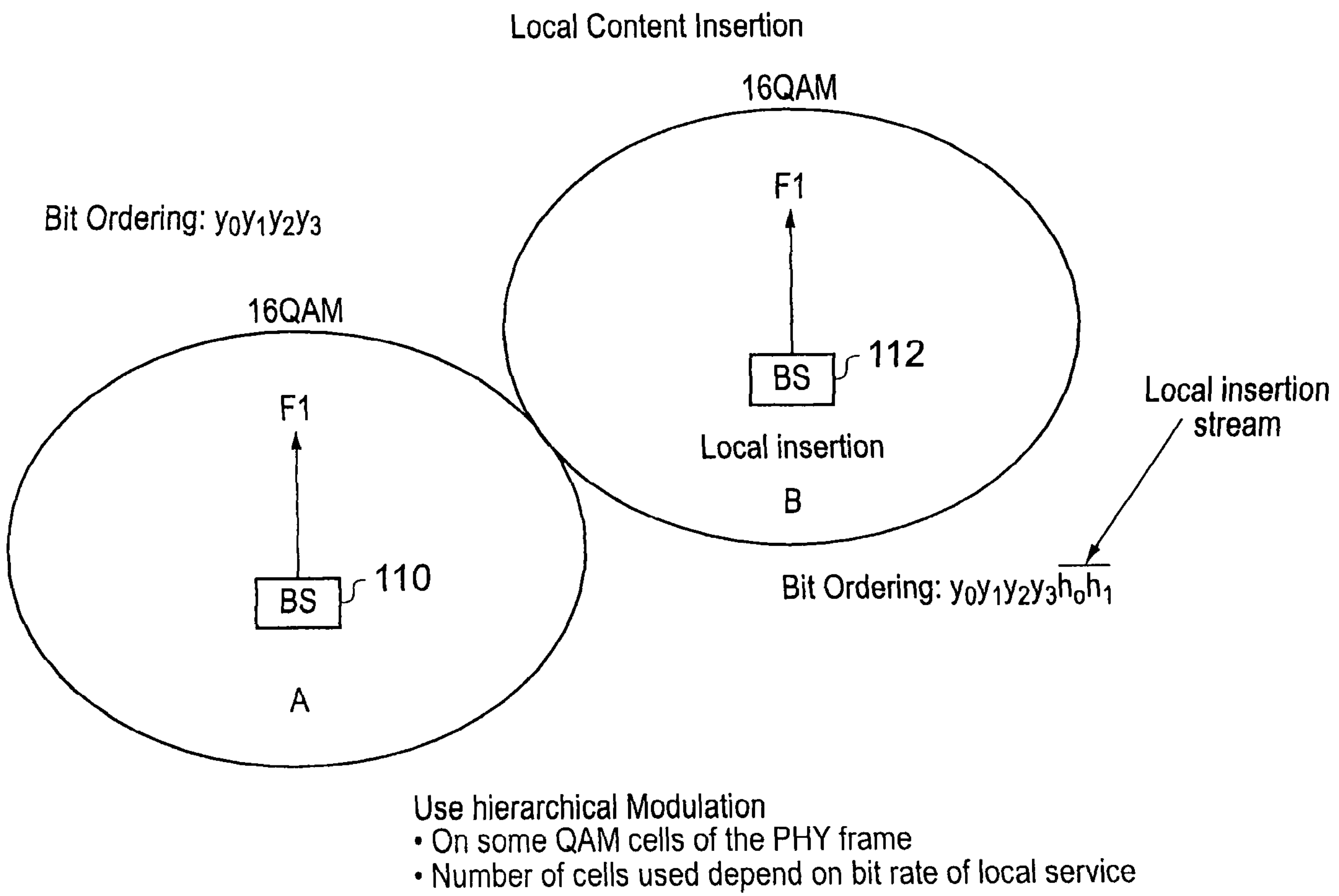

Local Content Insertion
16QAM
F1
BS
112
Local insertion
B
Local insertion stream
Bit Ordering: $y_0y_1y_2y_3\overline{h_oh_1}$
Bit Ordering: $y_0y_1y_2y_3$
16QAM
F1
BS
110
A
Use hierarchical Modulation
• On some QAM cells of the PHY frame
• Number of cells used depend on bit rate of local service

FIG. 6

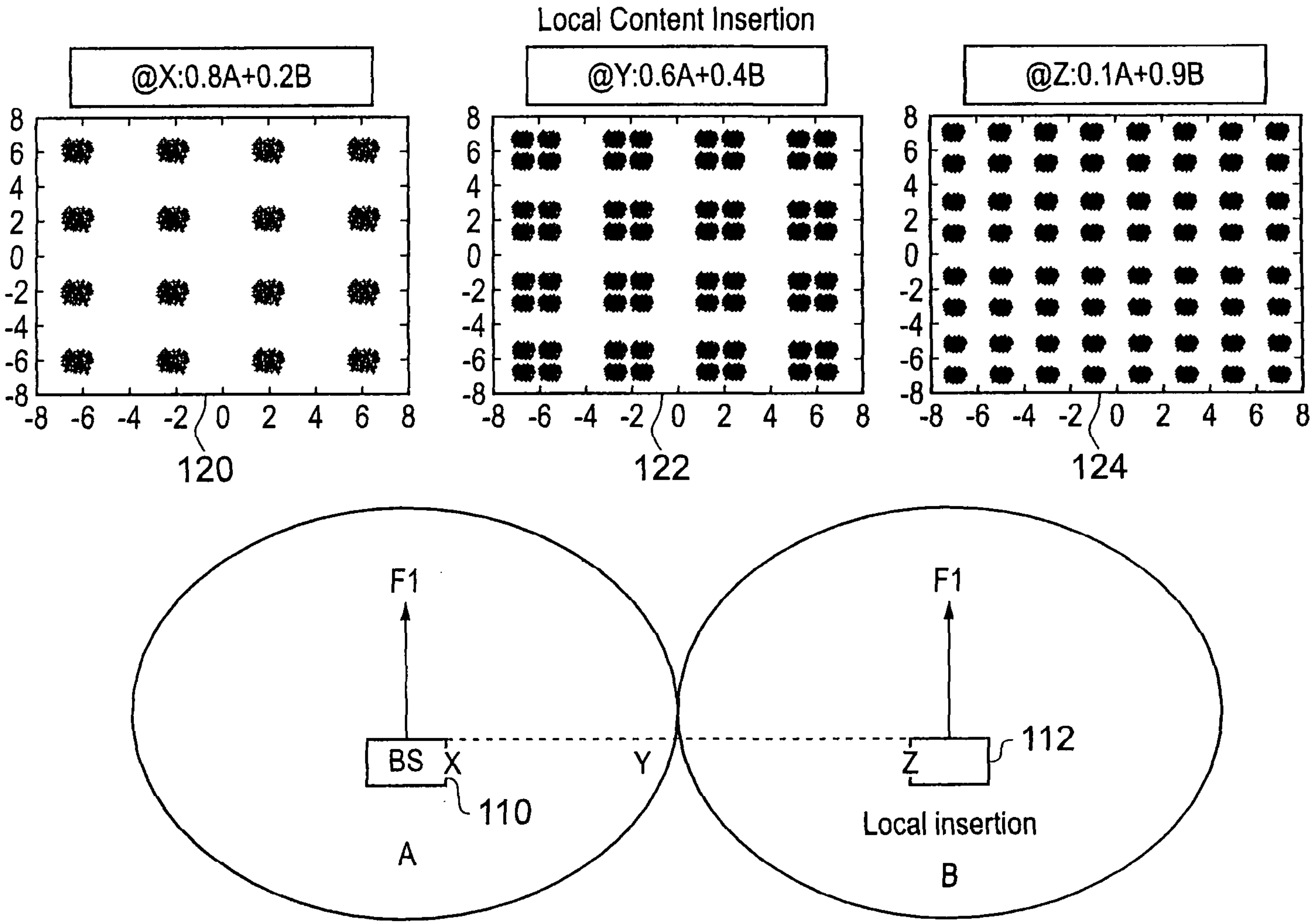

Local Content Insertion
@X:0.8A+0.2B
@Y:0.6A+0.4B
@Z:0.1A+0.9B
8
6
4
2
0
-2
-4
-6
-8
120
122
124
F1
F1
BS
X
Y
Z
110
112
Local insertion
A
B

FIG. 7

Constellation rotation

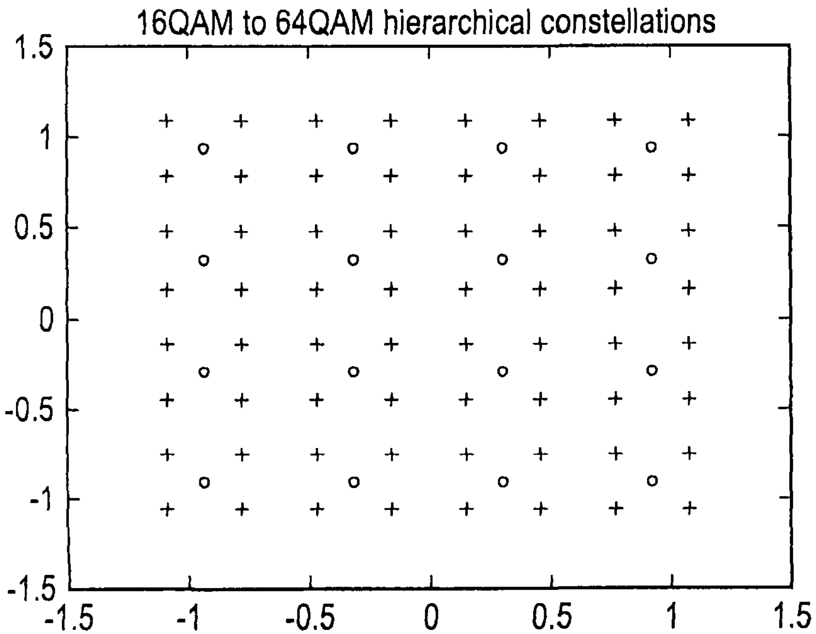


FIG. 8

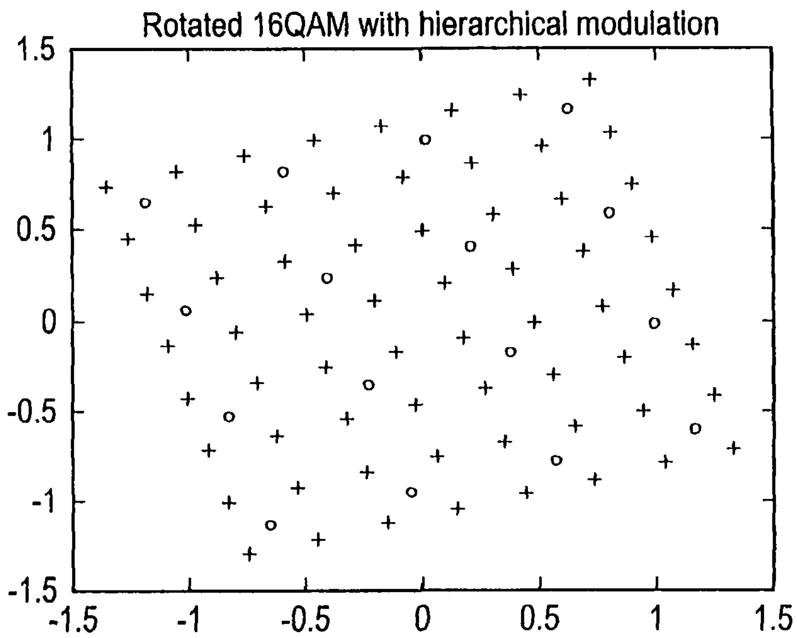


FIG. 9

Projection: Constellation rotation

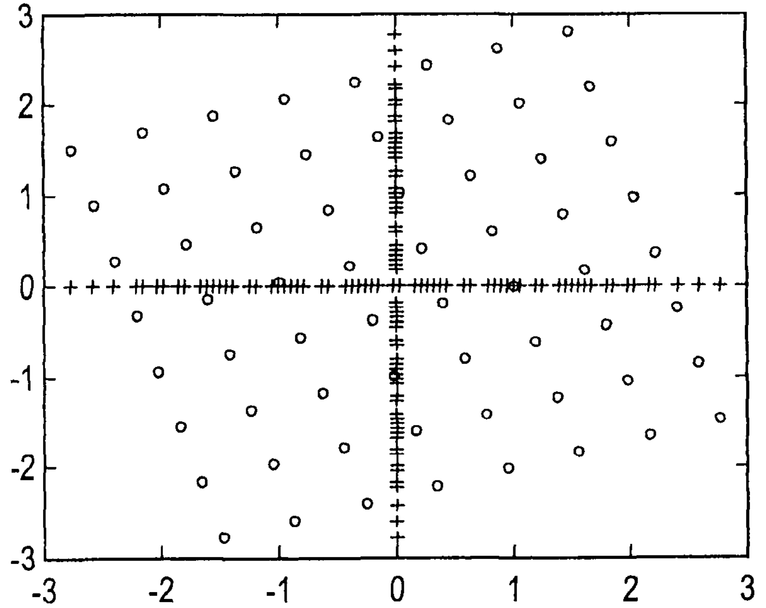


FIG. 10

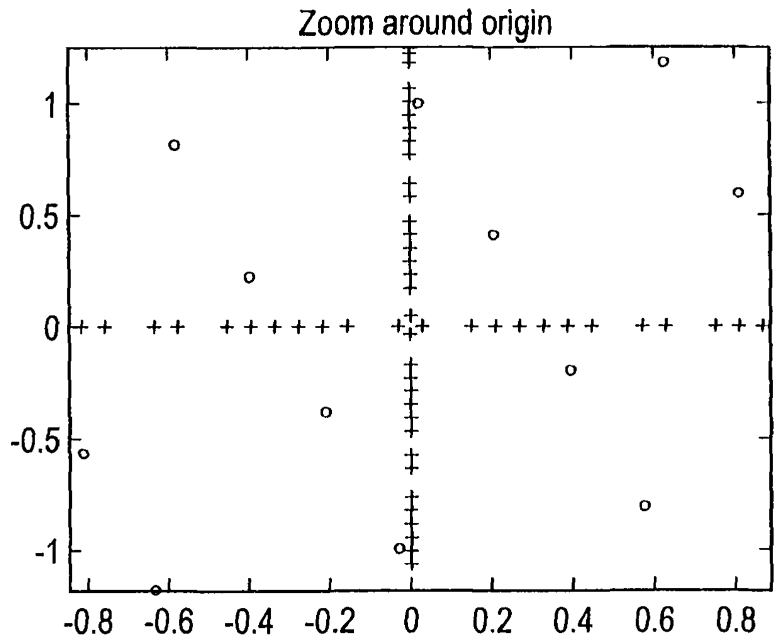


FIG. 11

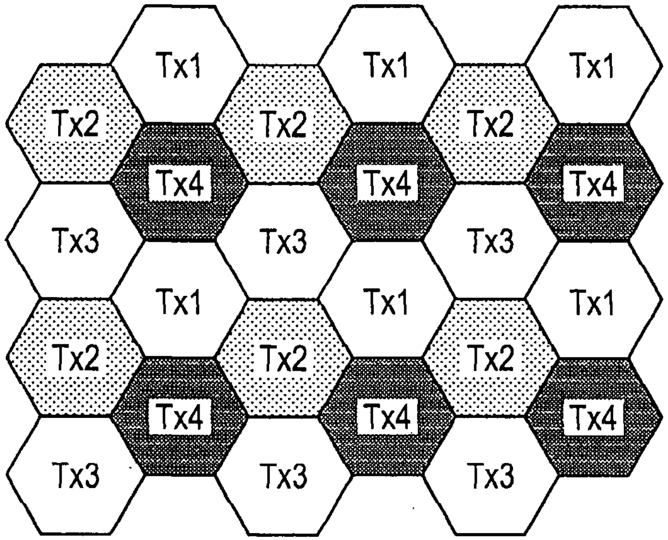


FIG. 12c

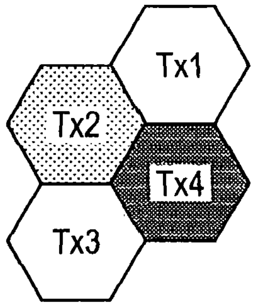


FIG. 12a

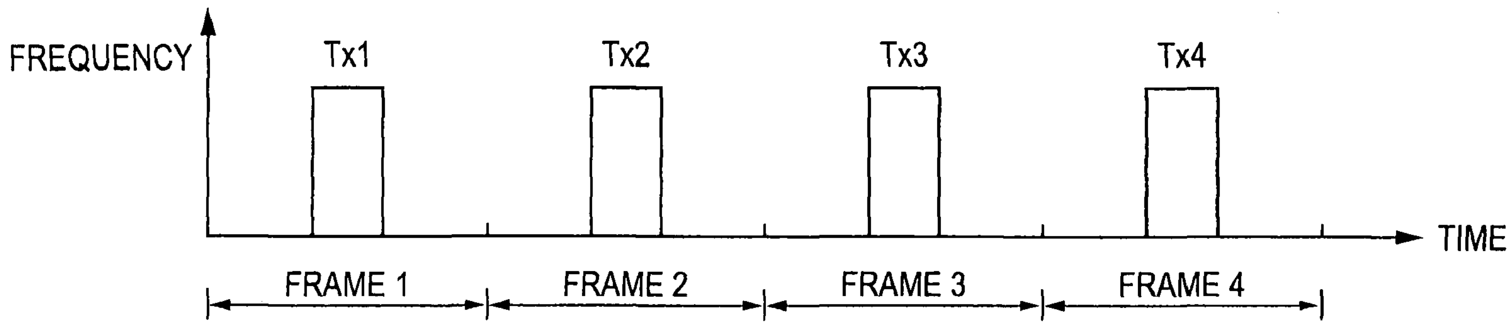


FIG. 12b

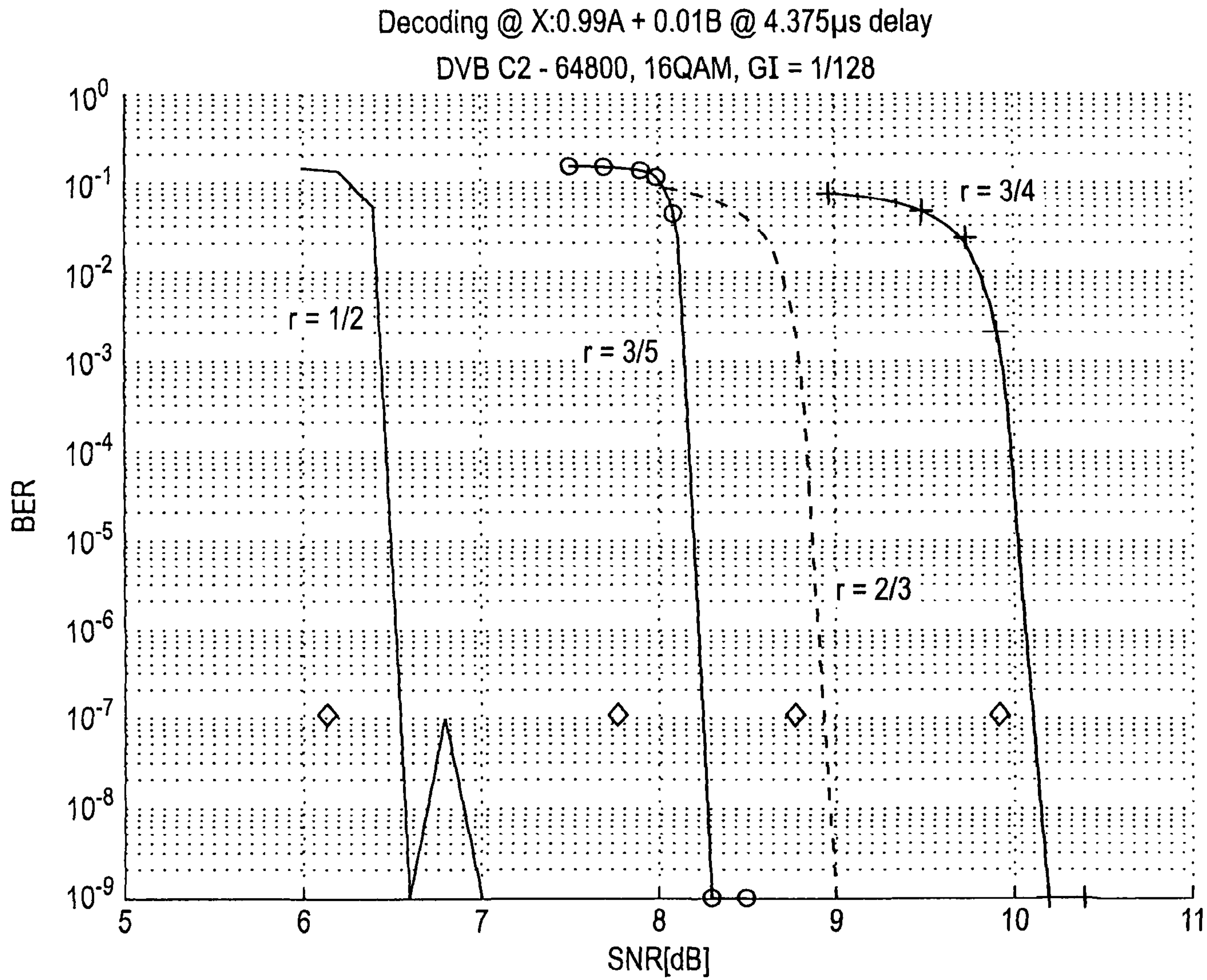
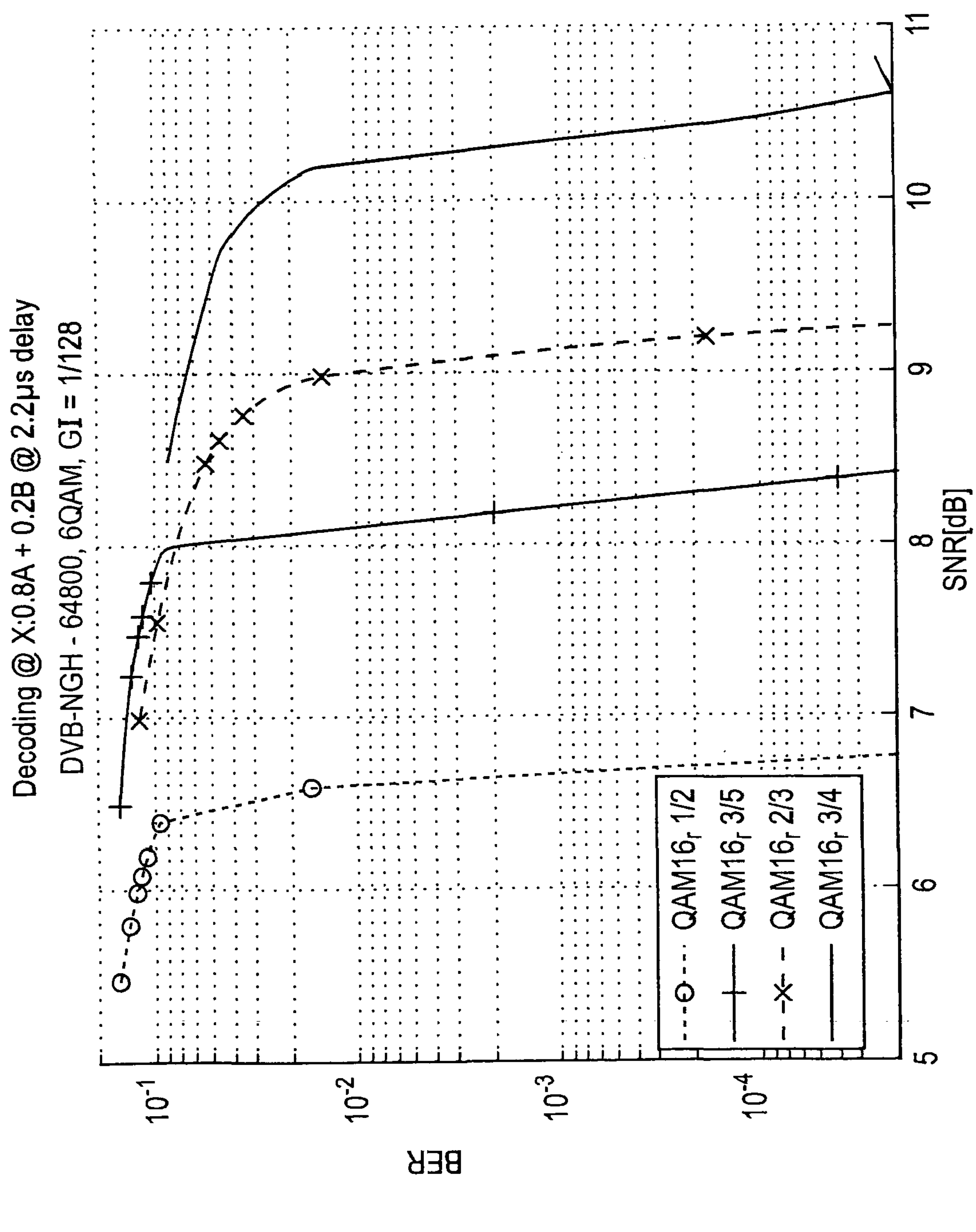

Decoding @ X:0.99A + 0.01B @ 4.375µs delay
DVB C2 - 64800, 16QAM, GI = 1/128
BER
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
r = 1/2
r = 3/5
r = 2/3
r = 3/4
5
6
7
8
9
10
11
SNR[dB]

FIG. 13



Decoding @ X:0.8A + 0.2B @ 2.2µs delay
DVB-NGH - 64800, 6QAM, GI = 1/128
BER
10^{-1}
10^{-2}
10^{-3}
10^{-4}
5
6
7
8
9
10
11
SNR[dB]
QAM16$_r$ 1/2
QAM16$_r$ 3/5
QAM16$_r$ 2/3
QAM16$_r$ 3/4

FIG. 14

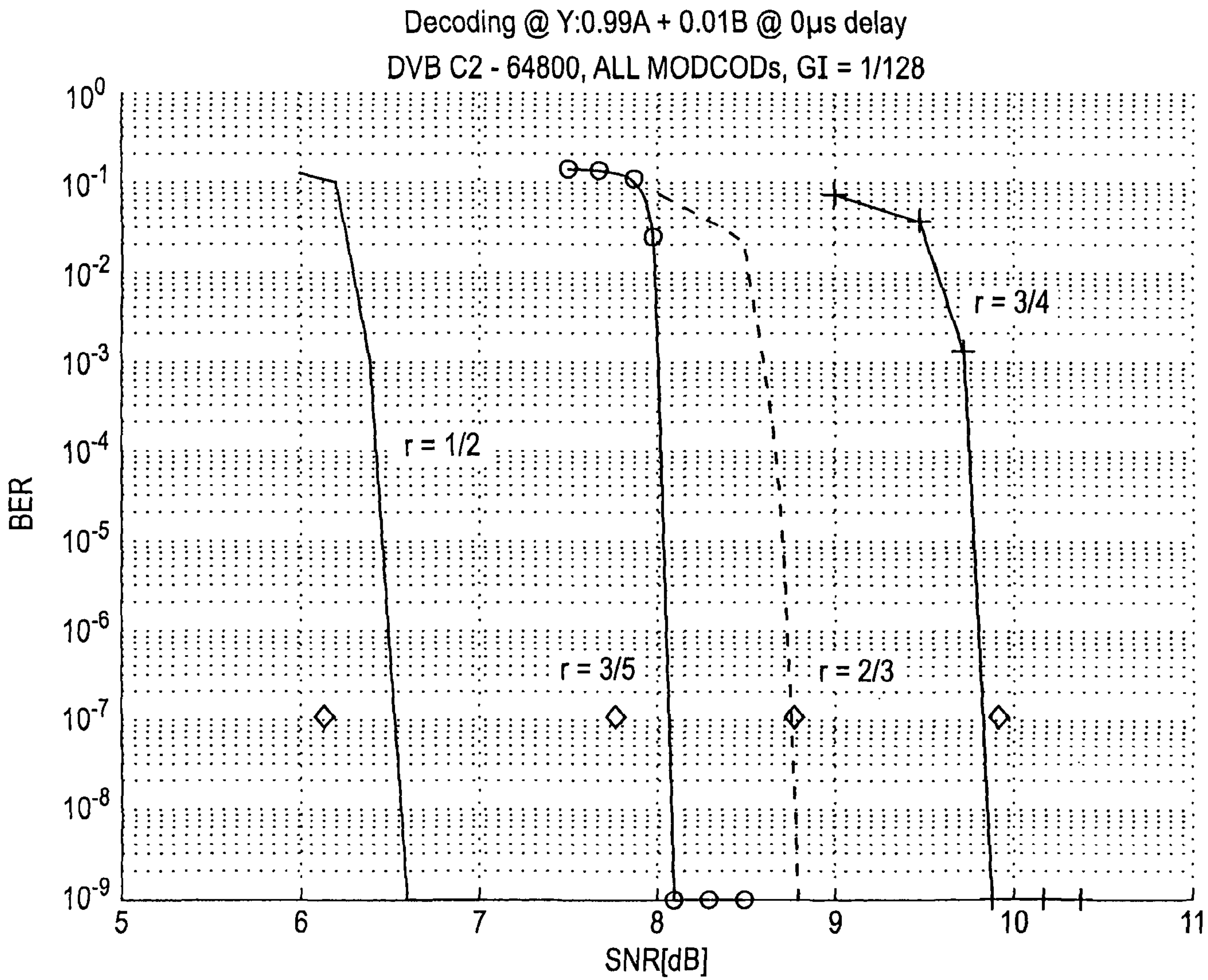

Decoding @ Y:0.99A + 0.01B @ 0μs delay
DVB C2 - 64800, ALL MODCODs, GI = 1/128
BER
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
5
6
7
8
9
10
11
SNR[dB]
r = 1/2
r = 3/5
r = 2/3
r = 3/4

FIG. 15

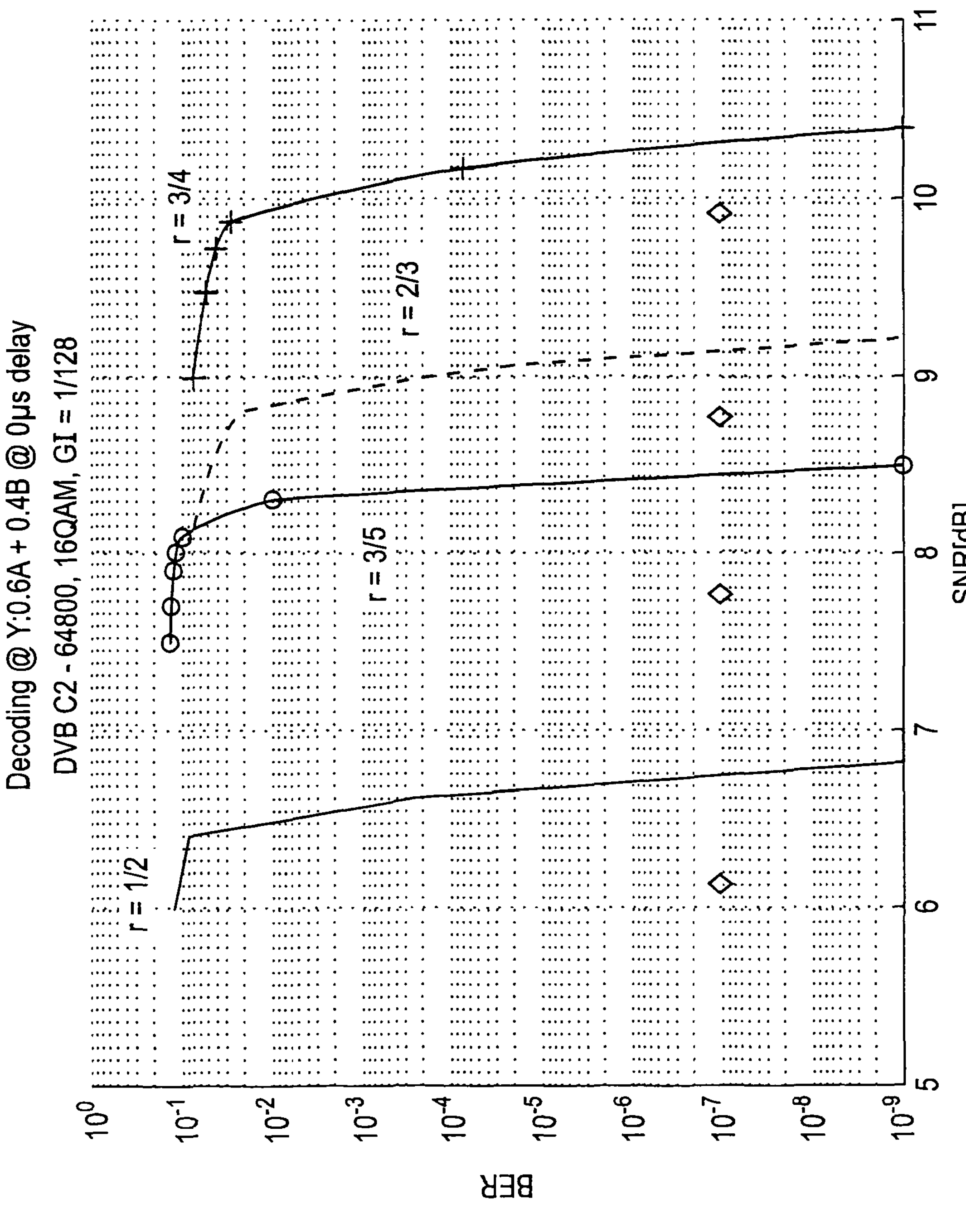

Decoding @ Y:0.6A + 0.4B @ 0µs delay
DVB C2 - 64800, 16QAM, GI = 1/128
BER
SNR[dB]
r = 1/2
r = 3/5
r = 2/3
r = 3/4
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
5
6
7
8
9
10
11

FIG. 16

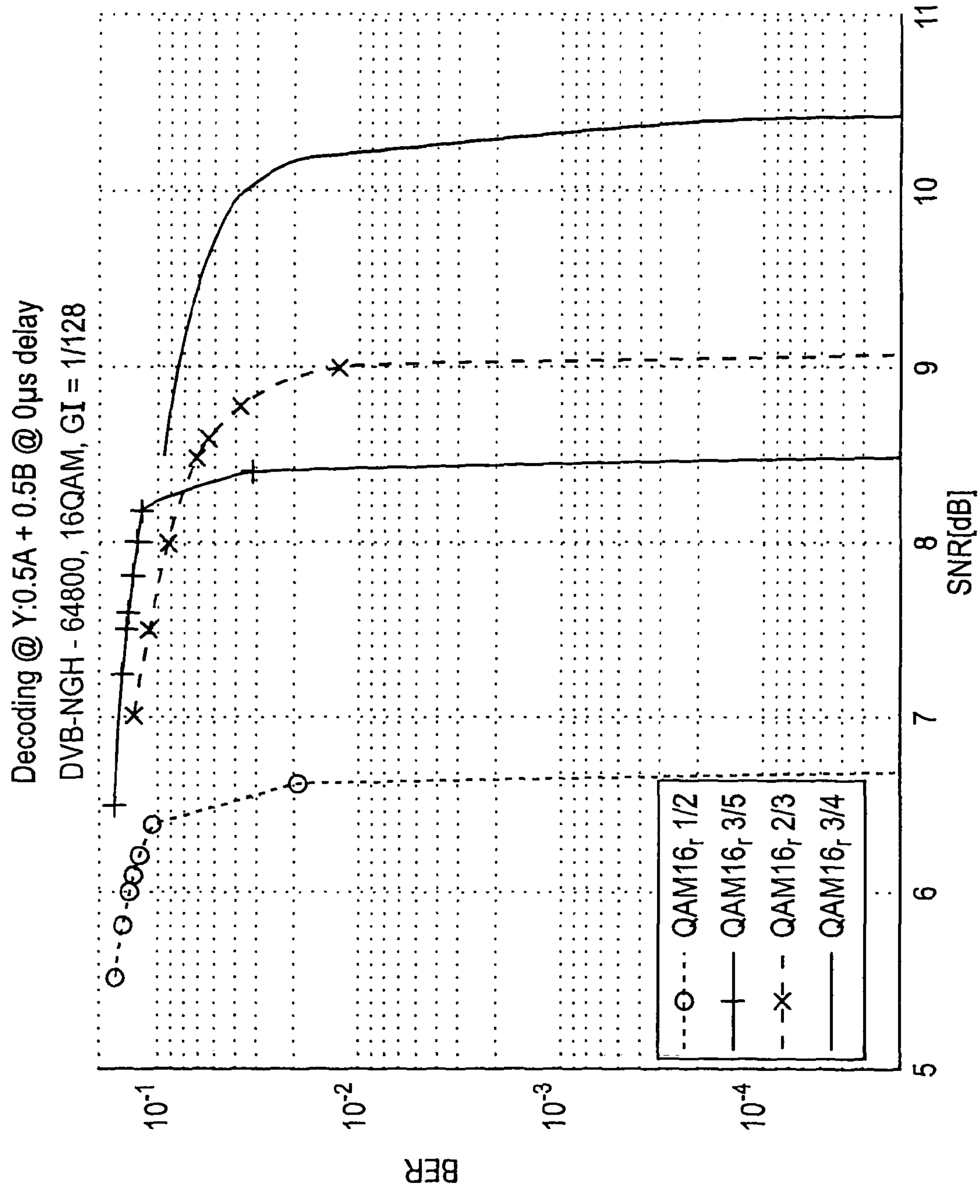

Decoding @ Y:0.5A + 0.5B @ 0µs delay
DVB-NGH - 64800, 16QAM, GI = 1/128
BER
10^{-1}
10^{-2}
10^{-3}
10^{-4}
5
6
7
8
9
10
11
SNR[dB]
QAM16$_r$ 1/2
QAM16$_r$ 3/5
QAM16$_r$ 2/3
QAM16$_r$ 3/4

FIG. 17

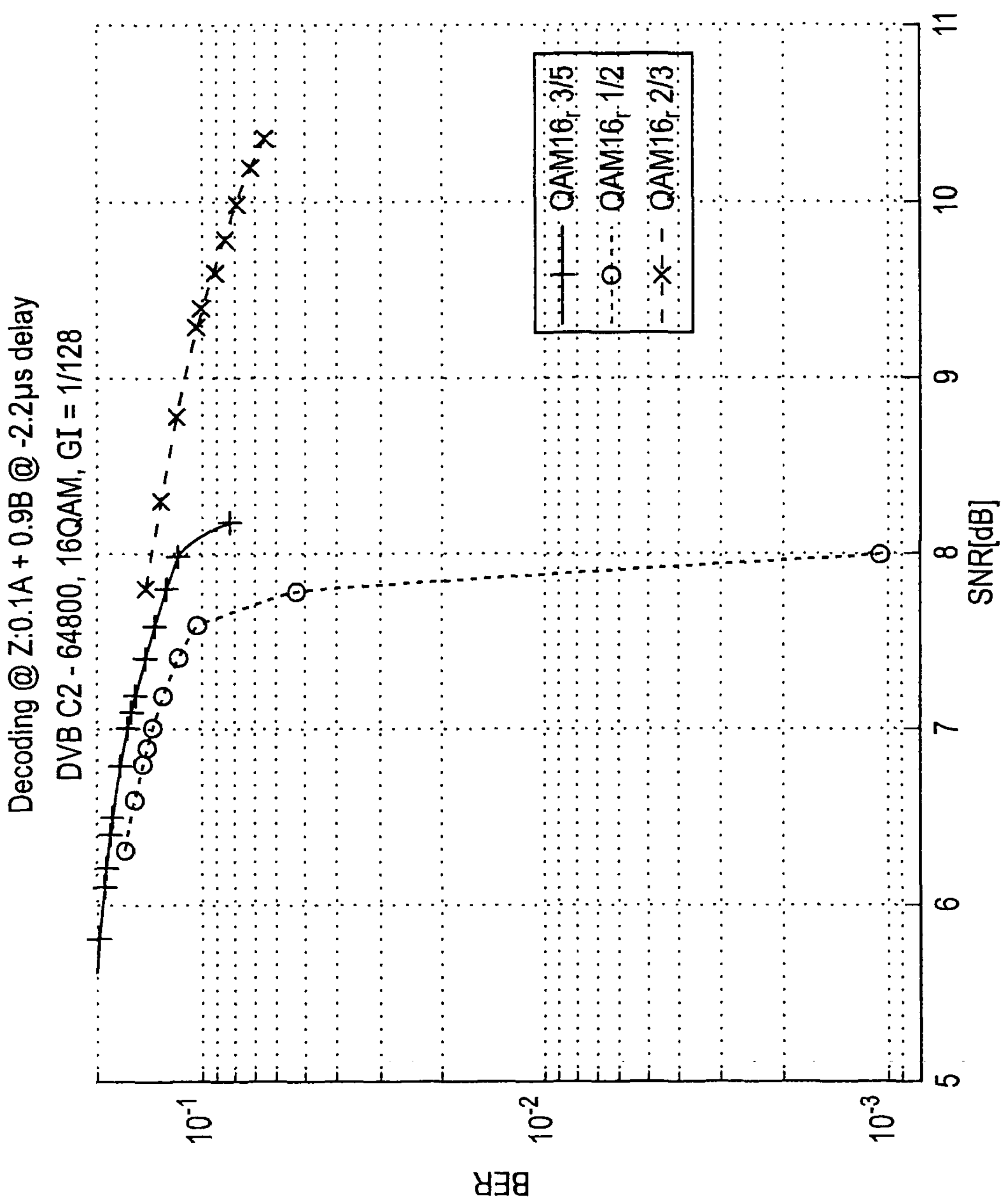

Decoding @ Z:0.1A + 0.9B @ -2.2μs delay
DVB C2 - 64800, 16QAM, GI = 1/128
BER
10^{-1}
10^{-2}
10^{-3}
5
6
7
8
9
10
11
SNR[dB]
QAM16, r 3/5
QAM16, r 1/2
QAM16, r 2/3

FIG. 18

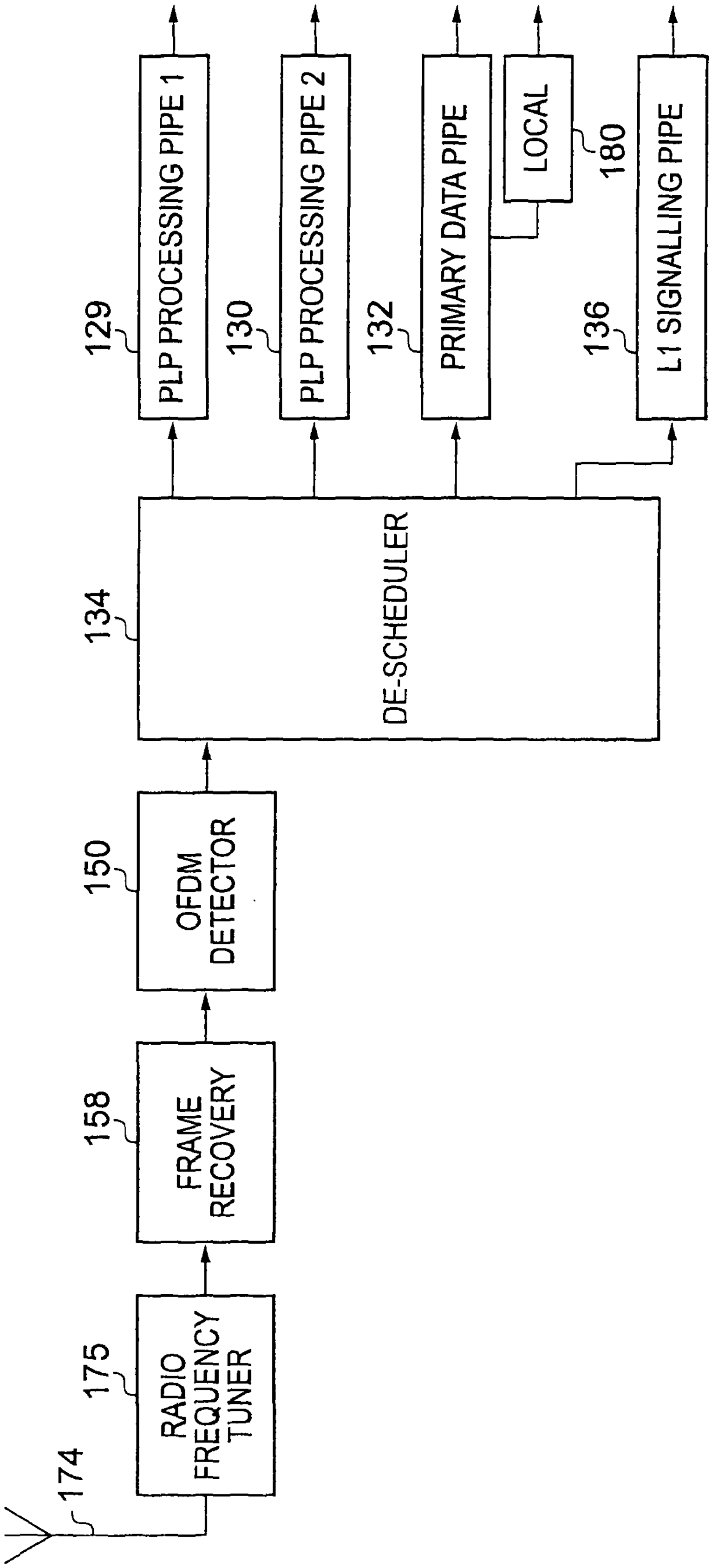

174
175
RADIO FREQUENCY TUNER
158
FRAME RECOVERY
150
OFDM DETECTOR
134
DE-SCHEDULER
129
PLP PROCESSING PIPE 1
130
PLP PROCESSING PIPE 2
132
PRIMARY DATA PIPE
LOCAL
180
136
L1 SIGNALLING PIPE

FIG. 19

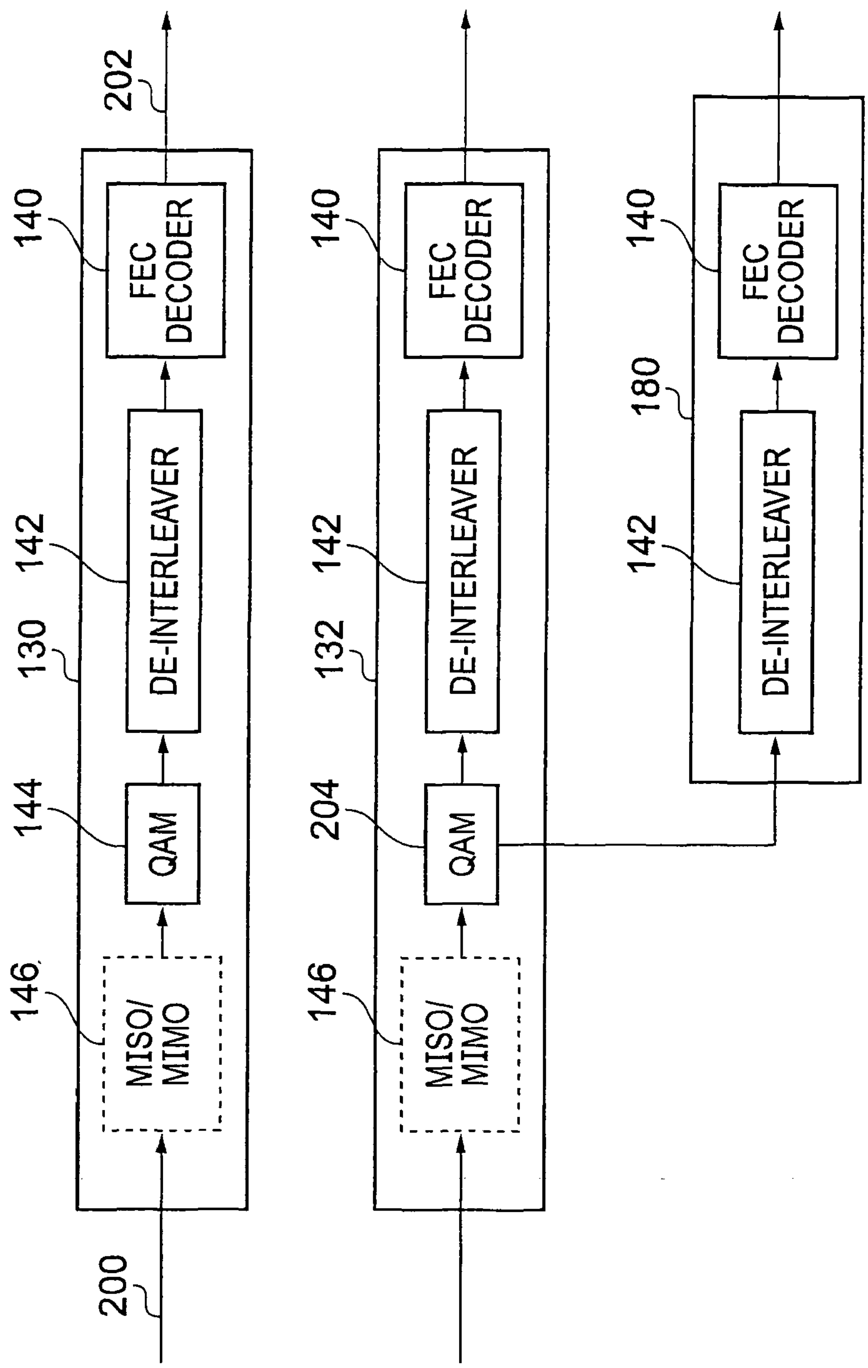
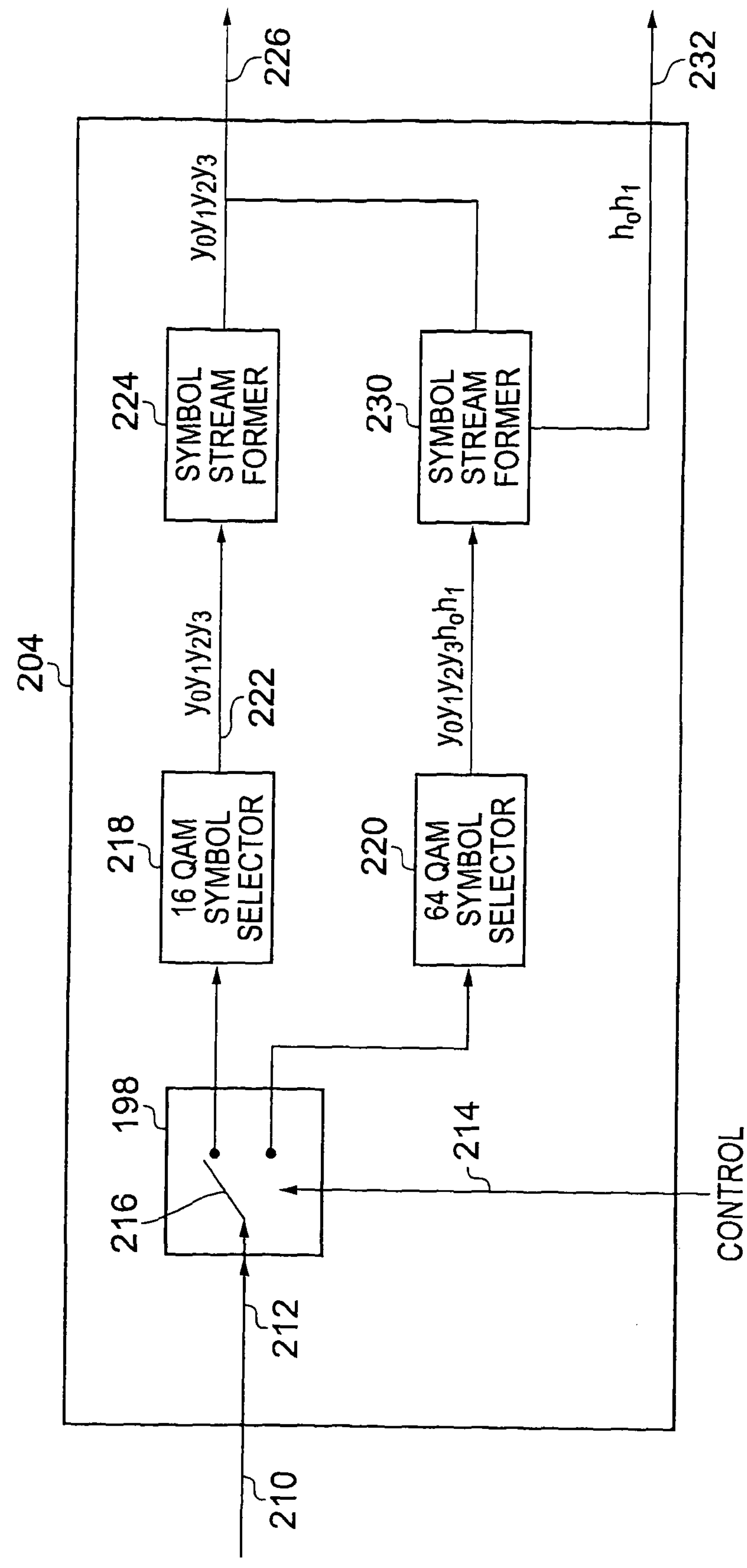

202
140
FEC DECODER
142
DE-INTERLEAVER
130
144
QAM
146
MISO/ MIMO
200
140
FEC DECODER
142
DE-INTERLEAVER
132
204
QAM
146
MISO/ MIMO
140
FEC DECODER
180
142
DE-INTERLEAVER

FIG. 20



226
232
204
y0y1y2y3
h0h1
224
SYMBOL STREAM FORMER
230
SYMBOL STREAM FORMER
y0y1y2y3
222
y0y1y2y3h0h1
218
16 QAM SYMBOL SELECTOR
220
64 QAM SYMBOL SELECTOR
198
216
214
CONTROL
212
210

FIG. 21

TRANSMITTER AND METHOD OF TRANSMITTING

Field of Invention

The present invention relates to transmitters for transmitting data via Orthogonal Frequency Division Multiplexed (OFDM) symbols in which the data is provided from a plurality of different data pipes.

Embodiments of the present invention find application in receiving data communicated using OFDM symbols which are transmitted using communication systems which comprise a plurality of base stations disposed throughout a geographical area. In some embodiments the communication system is arranged to broadcast video, audio or data.

Background of the Invention

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation technique which has found much favour in communication systems, such as for example those designed to operate in accordance with the Digital Video Broadcasting standards and is also being proposed for fourth generation mobile communication systems which are also known as Long Term Evolution (LTE). OFDM can be generally described as providing K narrow band sub-carriers (where K is an integer) which are modulated in parallel, each sub-carrier communicating a modulated data symbol such as Quadrature Amplitude Modulated (QAM) modulation symbol or Quaternary Phase-shift Keying (QPSK) modulation symbol. The modulation of the sub-carriers is formed in the frequency domain and transformed into the time domain for transmission. Since the data symbols are communicated in parallel on the sub-carriers, the same modulated symbols may be communicated on each sub-carrier for an extended period, which can be longer than the coherence time of the radio channel. The sub-carriers are modulated in parallel contemporaneously, so that in combination the modulated carriers form an OFDM symbol. The OFDM symbol therefore comprises a plurality of sub-carriers each of which has been modulated contemporaneously with different modulation symbols.

In the Next Generation for Hand held (NGH) television system it has been proposed to use OFDM to transmit television signals from base stations disposed throughout a geographical area. In some examples the NGH system will form a network in which a plurality of base stations communicate OFDM symbols contemporaneously on the same carrier frequency thereby forming a so-called single frequency network. As a result of some of the properties of OFDM, a receiver may receive the OFDM signals from two or more different base stations which can then be combined in the receiver to improve the integrity of the communicated data.

Whilst a single frequency network has advantages in terms of operation and improved integrity of the communicated data, it also suffers a disadvantage if data local to a part of the geographical area is required to be communicated. For example, it is well known in the United Kingdom that the national carrier, the BBC, broadcasts television news throughout the entire national network but then switches, at certain times, to "local news" in which a local news programme is transmitted which is specifically related to a local area within the national network. However, the United Kingdom operates a multi-frequency DVB-T system so that the insertion of local news or local content of any sort is a trivial matter because the different regions transmit DVB-T television signals on different frequencies and so television receivers simply tune to an appropriate carrier frequency for the region without interference from other regions. However, providing an arrangement to insert data locally in a single frequency network presents a technical problem.

A known technique for providing a hierarchical or multi-layer modulation scheme in a single frequency OFDM network is disclosed in US 2008/0159186. The hierarchical modulation scheme provides a plurality of modulation layers which can be used to communicate data from different data sources or pipes contemporaneously.

Summary of Invention

According to the present invention there is provided a transmitter for communicating data using Orthogonal Frequency Division Multiplexed (OFDM) symbols, the OFDM symbols including a plurality sub-carrier symbols formed in the frequency domain for modulating with the data to be carried, the transmitter including

a modulator arranged in operation

to receive on a first input, data symbols from a first data pipe according to a first communications channel for transmission,

to receive on a second input, data symbols from a local insertion data pipe according to a local communications channel for transmission, and

to modulate the sub-carrier signals of the OFDM symbols with either

the data symbols from the first data pipe or

the data symbols from both the first data pipe and the local insertion pipe, the modulation of the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe being performed by mapping the data symbols according to a first modulation scheme, and

the modulation of the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe and the local insertion pipe being performed by mapping the data symbols from the local insertion pipe and the first communications channel according to a second modulation scheme, and

a radio frequency modulator which is arranged to modulate a radio frequency carrier signal with the OFDM symbols for transmission, wherein

the first modulation scheme is a lower order modulation scheme providing first modulation symbols with values from a smaller number of constellation points in the complex plane than the second modulation scheme which is a higher order modulation scheme, the second modulation scheme providing second modulation symbols with values which are disposed in the complex plane about corresponding values of the first modulation scheme, with the effect that detection of one of the second modulation symbols of the second modulation scheme will provide data symbols from both the local insertion pipe and the first data pipe and allow the detection of first modulation symbols from the first modulation scheme providing data symbols from the first data pipe, in the presence of modulation symbols from the second modulation scheme, thereby providing the modulator with a plurality of modulation layers.

According to the arrangement disclosed in US 2008/0159186 published 3 July 2008, a single carrier frequency OFDM network is provided with a facility for communicating data from different pipes contemporaneously by using two related modulations schemes to form a plurality of different modulation "layers". As will be explained shortly, a first modulation scheme is selected for communicating data from a first data pipe and a second modulation scheme related to the first modulation scheme is selected for communicating data according to the first and a second communications pipes. The second modulation scheme comprises an increased number of constellation points in the complex plane than the first modulation scheme.

According to example embodiments of the present invention, a communication system is arranged such that one or more base stations from a plurality of base stations which form a communications network are selected to transmit OFDM symbols which have sub-carriers modulated in accordance with the second modulation scheme. Thus, the second modulation scheme is used to convey data symbols from both the first data pipe and the local insertion pipe. Because of the arrangement of the second modulation scheme with respect to the first modulation scheme, the data symbols from the first data pipe may be received even when transmitted on the same radio frequency carrier, because detection of a constellation point from the first modulation scheme will require a lower signal to noise ratio than the second modulation scheme. This is because the first modulation scheme forms a sub-set of constellation points in the complex plane of the second modulation scheme, which can be thought of as a more course version of the second modulation scheme, so that differentiation between constellation points of the first modulation symbols in the complex plane allows the data from the first data pipe to be more easily recovered. Furthermore, because other base stations may not be communicating the local insertion pipe data, receivers, within the geographical area in which these other base stations are disposed, will still be able to detect the data from the first data pipe. This is because OFDM signals transmitted from a neighbouring base station on the common radio frequency carrier signal using the second modulation scheme will simply appear as noise with respect to a detector detecting OFDM symbols according to the first modulation scheme. Thus an effective and efficient way of inserting local content in a single frequency network is provided.

In some embodiments the modulator may be arranged to introduce a phase rotation into the modulation symbols of the first and the second modulation scheme, with the effect that detection of either one of the In-phase or the Quadrature components of one of the modulation symbols in the complex plane will identify that modulation symbol. Furthermore in some examples the phase rotation is the same for both the first and the second modulation schemes and is set as an optimum value for the first modulation scheme.

It has been discovered that by rotating the constellation points of the first and the second modulation schemes by the same amount, the receiver is able to recover the data symbols from either the first or second modulation symbols from either the In-phase I or Quadrature phase Q components, whilst providing an effective and efficient way of inserting local content in a single frequency network. Furthermore, it has been discovered that the phase rotation used for both the first and the second modulation scheme should be that which is optimum for the first modulation scheme.

In some examples, the transmitter may include a scheduler for forming the modulated sub-carrier signals into the OFDM symbols and a framing unit which arranges the OFDM symbols for transmission according to a time division multiplexed frame. Furthermore, the scheduler and the framing unit are arranged to transmit OFDM symbols which are carrying data symbols from both the first data pipe and the local insertion pipe using the second modulation scheme in some time division multiplexed frames and not others. More particularly, in other examples, the base stations of the communications network maybe formed into clusters, each cluster including a predetermined number of the base stations, each base station in the cluster being assigned to one of a corresponding number of time division multiplexed frames, and the transmitter of the base station is arranged to transmit the OFDM symbols which are carrying data symbols from both the first data pipe and the local insertion pipe using the second modulation scheme in the time division multiplexed frame which has been assigned to that base station and not others. As a result an amount of "interference" caused by transmitting OFDM symbols using the second modulation scheme on the common radio frequency carrier to a receiver which is detecting and recovering the data symbols from OFDM symbols modulated using the first modulation scheme will be reduced in proportion to the number of base stations in each cluster. The word "interference" is used here in the sense that the OFDM symbols with sub-carriers modulated in accordance with the second modulation scheme will reduce the signal to noise ratio of a receiver detecting data symbols carried by OFDM symbols with sub-carriers modulated in accordance with the first modulation scheme, because as explained above a property of a layered modulation arrangement will be to increase noise to a receiver.

Various further aspects and features of the present invention are defined in the appended claims and include a method of transmitting.

Brief Description of Drawings

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings in which like parts are referred to using the same numerical designations and in which:

Figure 1 is a schematic representation of a plurality of base stations which form a single carrier frequency network for broadcasting for example video signals which may form part of a Next Generation Hand-held (NGH) TV broadcasting system;

Figure 2 is a schematic block diagram of an example transmitter according to the prior art;

Figure 3a is a schematic representation of a complex plane providing an illustration of signal constellation points for a first modulation scheme of QPSK; and Figure 3b is a schematic representation of a complex plane providing an illustration of signal constellation points for a second modulation scheme of 16QAM according to the prior art;

Figure 4 is a schematic block diagram of part of a transmitter used in one or more of the base stations shown in Figure 1 according to the present technique;

Figure 5 is a schematic block diagram of an example modulator which forms part of the transmitter shown in Figure 4;

Figure 6 is an illustrative representation of two neighbouring base stations forming two cells A and B which are using a first modulation scheme of 16QAM and a second modulation scheme of 64QAM respectively;

Figure 7 is a schematic representation showing the effects on the constellation points as received by a mobile device at three different positions X, Y, Z between the two base stations A and B of Figure 6;

Figure 8 is an illustrative representation of constellation points in a complex plane for a first modulation scheme of 16QAM superimposed on a second modulation scheme of 64QAM;

Figure 9 is an illustrative representation of the constellation points for Figure 6 with a phase rotation corresponding to an optimum phase rotation for the first modulation scheme of 16QAM;

Figure 10 is an illustrative representation of a rotated signal constellation for 64QAM;

Figure 11 is an illustrative representation of the signal constellation diagram of Figure 10 with a zoomed in or magnified view of part of that constellation diagram;

Figure 12a is an illustrative representation of a cluster of four cells served by four base stations according to the present technique; Figure 12b is a graphical representation of a plot of frequency with respect to time providing an illustration of a time division multiplexed frame structure; and Figure 12c is an illustrative representation of a pattern of cell clusters according to the present technique;

Figure 13 is a graphical plot of bit error rate with respect to signal to noise ratio for example of a low density parity check (LDPC) coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5, 2/3 and ¾, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell A and to receive OFDM symbols with 99% of the signal power from base station A and 1% from base station B with the signal from B arriving at the receiver 4.375us after the signal from base station A as illustrated by the example diagram shown in Figure 6;

Figure 14 is a graphical plot of bit error rate with respect to signal to noise ratio for the example of a LDPC coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5, 2/3 and ¾, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell A and to receive OFDM symbols with 80% of the signal power from base station A and 20% from base station B with the signal from B arriving at the receiver 2.2μs after the signal from base station A as illustrated by the example diagram shown in Figure 6;

Figure 15 is a graphical plot of bit error rate with respect to signal to noise ratio for example of a LDPC coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5, 2/3 and ¾, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell A and to receive OFDM symbols with 99% of signal power from base station A and 1% from base station B with zero delay between the signal times of arrival from the two cells illustrated by the example diagram shown in Figure 6;

Figure 16 is a graphical plot of bit error rate with respect to signal to noise ratio for example of a LDPC coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5, 2/3 and ¾, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell A and to receive OFDM symbols with 60% of signal power from base station A and 40%

from base station B with zero delay between the signal times of arrival from the two cells illustrated by the example diagram shown in Figure 6;

Figure 17 is a graphical plot of bit error rate with respect to signal to noise ratio for example of a LDPC coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5, 2/3 and ¾, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell A and to receive OFDM symbols with 50% signal power from base station A and 50% from base station B with zero delay between the signal times of arrival from the two cells illustrated by the example diagram shown in Figure 6;

Figure 18 is a graphical plot of bit error rate with respect to signal to noise ratio for example of a LDPC coded OFDM transmitter-receiver chain, with error correction encoding of rate ½, 3/5 and 2/3, a first modulation scheme of 16QAM, a second modulation scheme of 64QAM and in which the receiver is considered to be located within coverage area of cell B and to receive OFDM symbols with 10% of signal power from base station A and 90% from base station B with the signal from A arriving at the receiver 2.2μs after the signal from base station B as illustrated by the example diagram shown in Figure 6;

Figure 19 is a schematic block diagram of a receiver according to an embodiment of the present technique;

Figure 20 is a schematic block diagram of two Physical Layer Pipe (PLP) processors which appear in Figure 19; and

Figure 21 is a schematic block diagram of a demodulator according to the present technique which is shown in one of the PLP processors shown in Figure 20.

Description of Example Embodiments

As set out above embodiments of the present invention seek to provide, in one application, an arrangement in which local content can be transmitted within a single frequency network whilst allowing other parts of the network still to receive a primary broadcast signal. One example illustration is where local content is required to be broadcast contemporaneously with a national broadcast television programme.

Figure 1 provides an example illustration of a network of base stations BS which are transmitting, via transmit antennas 1, a signal in accordance with a commonly modulated OFDM signal. The base stations BS are disposed throughout a geographical area within a boundary 2, which may be, in one example, a national boundary. As explained above because the base stations BS are all broadcasting the same OFDM signal at the same time on the same frequency, mobile devices M may receive the OFDM signal from anyone of the base stations. More particularly, the mobile devices M may also receive the same signal from other base stations because the signal is simultaneously broadcast from all of the base stations within the area identified by boundary 2. This so-called transmit diversity arrangement is typical of a single frequency OFDM network. As part of the detection of the OFDM signals in a receiver which is recovering data from OFDM symbols, energy from the transmitted OFDM symbols which is received for each symbol from different sources is combined in the detection process. Thus transmitting the same signal from different base stations can improve the likelihood of correctly recovering the data communicated by the OFDM symbols, provided that any component of the received OFDM symbol or echo of that OFDM symbol falls within a total guard interval period allowed for the network deployment.

As shown in Figure 1, in some examples the base stations BS may be controlled by one or more base station controllers BSC, which may control the operation of the base stations. In some examples the base station controllers BSC may control one or more of the base stations within a part of the network associated with a geographical area. In other examples the base station controllers BSC may control one or more clusters of base stations so that the transmission of local content is arranged with respect to a time division multiplexed frames.

As mentioned above, the area identified by the boundary 2 could correspond to a national boundary so that the network of base stations is a national network. As such, in one example the television signals broadcast nationally are each transmitted from the base stations BS shown in Figure 1. However embodiments of the present technique are aimed at addressing a technical problem associated with providing an arrangement for transmitting locally broadcast signals from some of the base stations shown in Figure 1 but not others. An example of such an arrangement might be if local broadcast news or traffic news which is associated with a particular area is broadcast from some of the base stations but not others. In a multi-frequency network this is trivial, because the signals for the local broadcast maybe transmitted from different transmitters on different frequencies and therefore detected independently of what is broadcast from other base stations. However in a single frequency network a technique must be provided in order to allow for local insertion of content for some of the base stations but not others.

As mentioned above prior art document US 2008/0159186 discloses a technique for combining two modulation schemes to form a modulation layer for each of a plurality of data sources. A transmitter which is implementing such an arrangement is shown in Figure 2. In Figure 2 data is fed from a first data pipe 4 and second data pipe 6 to a modulator 8, which modulates the data onto the sub-carriers to form an OFDM symbol. The modulation is performed in such a way that the data from the first data pipe 4 can be detected separately from the detection of the data from both the first and the second data pipes 4, 6. An OFDM symbol former 10 then forms the OFDM symbol in the frequency domain as provided at the output of the modulator 8 and converts the frequency domain OFDM symbol into the time domain by performing an inverse Fourier transform in accordance with a conventional operation of an OFDM modulator/transmitter. The time domain OFDM symbols are then fed to a radio frequency modulator 12 which up converts the OFDM symbols onto a radio frequency carrier signal so that the OFDM signal may be transmitted from an antenna 14.

The technique disclosed in US 2008/0159186 is illustrated in Figures 3a and 3b. Figures 3a and 3b provide an illustration of signal constellation points in the complex plane comprising in-phase I and Quadrature-phase Q components. The example signal constellation points shown in Figure 3a is for QPSK, whereas the example shown in Figure 3b is for 16QAM. In accordance with the known technique for obtaining multi-layer modulation, data from two sources is modulated onto the signal constellation points of a second modulation scheme. The signal constellation points of the second modulation scheme represent the possible modulation symbol values available for the modulation scheme. For the first modulation scheme shown in Figure 3a, the signal constellation points for QPSK are provided as small circles "o" 20. As such the bits from a source B that is provided from the source data pipe 6 are mapped onto the signal constellation points as shown in Figure 3a, so that each possible modulation symbol value represents two bits from the source b0b1 in conventional manner using Grey coding for example.

The second modulation scheme shown in Figure 3b is 16QAM, which provides 16 possible signal constellation points 22 represented as "x". In addition to the modulation of the signal by data from the first data pipe 6, which is shown as b0b1 a selection of one of the constellation points from each of the four quadrants shown in Figure 3b also identifies one of the four possible values for two bits from the second source data pipe 4 for the values a0a1. Thus detection of one of the signal points shown in Figure 3b will not only identify a value for a0a1, but also a value for b0b1 depending upon which of the four quadrants from which the signal point is detected. Accordingly, a mutli-layer modulation scheme can be made.

Transmitter

Embodiments of the present technique provide an arrangement which utilises the multi-layer modulation technique according to US 2008/0159186 to provide a local broadcast service for local content whilst still allowing base stations in neighbouring areas to detect a national broadcast signal.

A transmitter embodying the present technique, which might be used to insert local content from one of the base stations shown in Figure 1 is shown in Figure 4. In Figure 4 a plurality n of Physical Layer data Pipes (PLP) 30, 31, 32 are arranged to feed data for transmission to a scheduler 34. A signalling data processing pipe 36 is also provided. Within each of the pipes the data is received for a particular channel from an input 38 at a forward error correction encoder 40 which is arranged to encode the data, for example, in accordance with a Low Density Parity Check (LDPC) code. The encoded data symbols are then feed into an interleaver 42 which interleaves the encoded data symbols in order to improve the performance of the LDPC code used by the encoder 40. The interleaved encoded data symbols are then mapped by modulator 44 onto modulation symbol values of the modulation scheme which is used by the modulator 44. In accordance with the above explanation the modulator 44 maps words of data bits onto M-QAM symbols. Optionally each data processing pipe may also include a MISO/MIMO element 46, which can implement a Multiple Input Single Output or Multiple Input Multiple Output system by broadcasting the same signal simultaneously from two or more displaced antennae of the same transmitter.

The scheduler 34 then combines each of the modulation symbols from each of the data pipes 30, 31, 32 as well as the signalling processing pipe 36 into data frames for mapping onto OFDM symbols. The scheduled data is presented to a data slice processing unit 50, 51, 52 which includes a frequency interleaver 54 and a pilot generator 56. The data slice processor arranges the QAM symbols carrying data for a given PLP in such a manner so that they occupy only certain sub-carriers of the OFDM symbol. The data output from the data slice processors 50, 51, 52 is then fed to a Time Division Multiple Access (TDMA) framing unit 58. The TDMA framing unit 58 also receives a pre-amble signal from a pre-amble generator 60 an edge pilot signal generator 62 and a scrambling sequence 64 for the scrambling of the data signal. The output of the TDMA framing unit 58 feeds an OFDM modulator 70 which generates the OFDM symbols in the time domain which are then modulated onto a radio frequency carrier signal by an RF modulator 72 and then fed to an antenna for transmission 74.

As explained above, embodiments of the present invention provide a technique for allowing for local content to be broadcast from one or more base stations within a local area relating to a national area covered by the network shown in Figure 1. To this end, the transmitter shown in Figure 4 also includes a local insertion data pipe 80 which includes a forward error correction encoder 40 and an interleaver 42, which corresponds in function to those present in the PLP data communications pipes 30, 31 and 32. However, in addition, according to the present technique, the modulator 44 shown in the communications pipe 32 has a second input for receiving the data from the local insertion pipe 80. According to the present technique the modulator 44 modulates the local insertion data onto a related set of signal constellation points according to a second modulation scheme. The signal constellation points of the second modulation scheme, which is used for the local content as well as the primary data from the PLP pipe n 32, are related to constellation points of the first modulation scheme which is used for just communicating the primary data from the PLP pipe n as will be explained with reference to Figures 5 and 6.

As shown in Figure 4 the modulator 44 has a first input 82 which receives data from the PLP data communications pipe n and a second input 84 which receives data from the local insertion pipe 80. In the following description the data from the PLP data communications pipe n 32, will be referred to as the first or primary data pipe. In one example the data from the first data pipe 32 carries a national broadcast channel, which would be communicated throughout the entire network of Figure 1.

The modulator 44 is shown in more detail in Figure 5. As shown in Figure 5 the data from the local insertion pipe 80 is fed from the second input 84 into a first data word former 90. The data from the first data pipe is fed from the first input 82 into a second data word former 92. The data from the first data pipe when received in the data word former 92 is arranged to form four groups of bits y0y1y2y3 for mapping onto one of 16 possible values of a 16QAM modulation symbol within a symbol selector 94. Similarly, the data word former 90 forms the data from the first data pipe 82 into data words comprising four bits y0y1y2y3. However, the data word former 90 also receives the data symbols from the local insertion pipe 80 and so appends two of the bits from the local insertion data pipe 84 to the data bits from the first data pipe 82 to form a six bit data word y0y1y2y3h0h1, which is four bits y0y1y2y3 from the symbol stream from the first data pipe 32 and two bits h0h1 from the local insertion pipe 80, thus forming a six bit word for selecting one of 64 possible modulation symbol values of 64QAM ($2^6 = 64$).

A symbol selector 96 is arranged to receive the six bit word y0y1y2y3h0h1 and in accordance with the value of that word select one of the 64 possible values of the 64QAM modulation scheme to form at an output 96.1 a stream of 64QAM symbols. The respective outputs from the symbol selectors 94, 96 are then fed to a switch unit 98 which also receives on a control input 100 an indication as to when the local content received from the local insertion pipe 90 is present and is to be broadcast from the base station. If the local insertion data is to be broadcast from the base station then the switch 98 is arranged to select the output 96.1 from the 64QAM symbol selector 96. If not then the switch is arranged to select the output 94.1 from the 16QAM symbol selector 94. Modulation symbols are therefore output from the modulator 44 for transmission on the OFDM symbols on an output channel 102.

The control input 100 may provide, in some examples, a control signal which indicates when local content is being transmitted from the local insertion data pipe 80. The control signal provided in the control input 100, may be generated from a base station controller to which the transmitter within the base station is connected.

In other examples the signalling data processing pipe 36 may be arranged to communicate via L1 signalling data an indication to when the local insertion pipe 80 is or will be transmitting the local data. Thus a receiver may recover may detect and recover the L1 signalling data and determine when or whether the local content is being or will be transmitted. Alternatively, the receiver may be provided with a data providing a schedule of when the local content data is to be transmitted, by some other means, such as by pre-programming the receiver.

Deployment of Base Stations

Figure 6 provides an example illustration of an arrangement which may be produced within Figure 1 in which a first base station BS 110 may transmit data from the first data pipe 32 within a cell A, whereas a neighbouring base station BS 112 transmits data within a second cell B, the transmitted data including data from the first data pipe 32 but also the local insertion data from the local insertion pipe 80. Thus the base station 110 from the cell A is transmitting an OFDM symbol with sub-carriers modulated using 16QAM whereas the base station 112 from the cell B is transmitting the OFDM symbols by modulating sub-carriers with 64QAM. Thus as shown in Figure 6 as the bit ordering shows, the final two bits h0h1 are used to select a finer detail of a signal constellation point according to 64QAM whereas the bits y0y1y2y3 are used to select one of the 16QAM symbols in a coarser grid within the complex plane.

As already explained, both of the base stations 110, 112, within the cells A and B will be transmitting the OFDM symbols contemporaneously on the same frequency. As such a receiver in a mobile terminal will receive a combined OFDM signal as if, in part, the signal was being received via different paths in a multi-path environment. However, the OFDM signal transmitted from base station 110 within cell A comprises OFDM symbols modulated using the first modulation scheme 16QAM whereas the OFDM symbols transmitted from the base station 112 within cell B will be modulated using the second modulation scheme 64QAM. At the receiver within the mobile terminal, a proportion of the total power with which the OFDM symbols are received with the first modulation scheme and the second modulation scheme will depend on the proximity of a mobile device M to each of the transmitters within the cells A and B. Furthermore, the likelihood of correctly recovering the data symbols from the first data pipe and the local insertion pipe will depend on the extent to which the receiver can detect OFDM symbols according to the first modulation scheme 16QAM transmitted from cell A or OFDM symbols according to 64QAM transmitted from cell B in the presence of OFDM signals modulated with the second and the first modulation schemes respectively.

As shown in Figure 7 three plots 120, 122, 124 of possible simulated signal constellation values are shown. The first left hand plot 120 provides a plot in the complex plane of received modulation symbol values when the transmitters in the base stations 110, 112 of cells A and B are transmitting OFDM symbols with sub-carriers modulated with 16QAM and 64QAM modulation schemes respectively, because cell B is transmitting local insertion data. The first plot 120 corresponds to a mobile device being at position X for which it is assumed that 80% of the received signal power is from cell A and 20% of the received signal power is from cell B. As can be seen in Figure 7 the plot 120 provides discrete signal points in accordance with a 16QAM received signal, but with an apparent increase in noise as a result of a spread of possible points caused by the 20% power coming from the cell B which is transmitting 64QAM modulation symbols.

Correspondingly, a middle plot 122 provides a plot of signal values in the complex plane when the receiver is at position Y and for which it is assumed that 60% of the received power is from cell A and 40% of the received power is from cell B. As can be seen, although the signal constellation plots are grouped into clusters corresponding to an association with each of the possible values of a 16QAM symbol, discrete constellation points have been formed in accordance with a 64QAM modulation scheme. Thus it will be appreciated that if the signal to noise ratio is high enough then a receiver at position Y can detect one of the 64QAM signal points and therefore recover the local inserted data. Correspondingly, a right hand plot 124 illustrates the case at position Z, for which it is assumed, for example, that only 10% of the signal power comes from the cell A and 90% of the signal power comes from cell B. Therefore, as shown in the plot 124, clearly each of the 64QAM signal constellation points are available for detecting and recovering data, which is produced for both the first data pipe and the local insertion data pipe. Accordingly, it will be appreciated that depending on the position of the receiver, a mobile terminal can recover the locally transmitted data and the data transmitted from the first data pipe (for example the national broadcast) when in or around cell B, whereas in cell A a receiver will still be able to recover the data from the first data pipe. Therefore an effect of using the layered modulation provided by the second modulation scheme of a 64QAM signal and the first modulation scheme 16QAM will not disrupt the reception of the nationally broadcast data when locally broadcast data is transmitted from a neighbouring cell.

Constellation Rotation

Referring to Figure 5 there is also shown a phase rotation element 101 which is disposed between the switching unit 98 and the output of the modulator 102. Optionally the transmitter shown in Figure 5 may include a phase rotation element 101 for rotating the phase of the modulation symbols fed from the output of the switching unit 98. Introducing a phase rotation in this way is a known technique which allows a receiver to detect and recover the data associated with a received modulation symbol value using just one or the other of the in-phase I or Quadrature phase components Q alone thereby enabling a more robust reception in severe multipath propagation conditions. This is illustrated in Figures 8 and 9.

In Figure 8 the constellation points for 64QAM are shown as "+", whereas the constellation points for 16QAM are shown as "o". In Figure 8 no phase rotation is present. As can be seen from Figure 8, detection of the In-phase I component does not unambiguously identify the received modulation symbol constellation point uniquely. This is because when the signal constellation values are not rotated, then an In-phase value I or Quadrature phase value Q component of a received symbol value can represent eight possible modulation symbol values for the 64QAM modulation scheme and four possible modulation symbol values for 16QAM. To identify uniquely the individual signal constellation points when there is no phase rotation present requires that both of the I and Q components must be recovered. However as shown in Figure 9 by introducing a phase off-set into the modulation symbol values at the output of the switching unit 98, to rotate the phase of each of the generated modulation symbols by the same amount, recovering any one of the in-phase I or Quadrature phase Q components will uniquely identify the modulation symbol value and therefore allow the data to be recovered.

A further illustration of this technique is provided in Figures 10 and 11. In Figure 10 a 64QAM signal constellation is shown with the component values for the I and Q components for each of the modulation symbol values marked on the corresponding orthogonal axis of the I and Q components. As can be seen these values are unique for each of the components of each of the modulated symbols. Figure 11 provides a clearer indication of the component values for each of the modulation symbols and it will be observed that some of these symbol value components are closer together than others. As such the space between projected points is non-uniform.

According to this present technique, the phase rotation introduced by the phase rotation unit 101 for a hierarchal modulation symbols using 64QAM shown in Figure 5 is the same as that used for 16QAM, and moreover the phase rotation is the value which is optimum for 16QAM. Thus according to the present technique, the phase rotation used for the modulation symbols of the second modulation scheme carrying the local insertion data is the same for both 16QAM and 64QAM. Although this is sub-optimal for 64QAM, it has been identified that the signal constellation points for 64QAM can nevertheless be recovered from their individual I and Q components when a phase rotation for a 16QAM modulation scheme is used for a 64QAM modulation scheme. Thus, as shown in Figure 9, the same phase rotation is used for both 16QAM and 64QAM symbols and as shown in Figure 10, although the spacing of the component values for the 64QAM symbols is non-uniform, each of these nevertheless can still be recovered.

Thus in general the phase rotation for an M-QAM constellation should be the same as that for a 4M-QAM constellation and the phase rotation should be that which is optimal for the M-QAM modulation. Therefore for example a phase rotation for a second modulation scheme which is 16QAM should be the same as that for the first modulation scheme of QPSK, with the value of the phase rotation being that which is optimal for the QPSK modulation scheme.

TDMA Local Insertion

A further enhancement which some embodiments of the present technique may use is to distribute the transmission of the local data between a cluster of neighbouring cells to the effect that the local content transmitted using the higher order (second) modulation scheme is transmitted at different times in different cells. This technique is illustrated with reference to Figures 12a, 12b and 12c.

In Figure 12a a cluster of four cells is shown. These are shown with different grades of shading and are labelled respectively Tx1, Tx2, Tx3, Tx4. Thus Figure 12a illustrates a cluster of four cells. As will be appreciated in addition to receiving the data from the first data pipe, which may be for example the national broadcast channel, a regional broadcast may also be provided using the local data insertion pipe in combination with the higher order hierarchal modulation technique as explained above. However as explained above when the second or higher order modulation technique is being used, the effect is to introduce noise or interference which reduces the signal to noise ratio for receivers receiving the data from the first communications channel that is the national broadcast using the first or lower order modulation scheme. More specifically, for example, if the national broadcast signal from the first data pipe is modulated using QPSK and the combined first communications channel and the local insertion channel are modulated onto the second or higher order modulation scheme of 16QAM then the 16QAM broadcast will appear as an increase in noise for a receiver trying to receive the OFDM symbols modulated with the QPSK modulation scheme.

In order to reduce the amount of interference caused by the second/higher order modulation scheme (16QAM) with respect to the first/lower order modulation scheme (QPSK) the cells which broadcast the OFDM signals are clustered as shown in Figure 12a. Furthermore the transmitters within the four cell cluster illustrated in Figure 12a take turns on a frame by frame basis to broadcast the higher order 16QAM modulation signal providing data symbols from the first data communications pipe and the local insertion pipe. Such an arrangement is illustrated in Figure 12b.

In Figure 12b a TDMA frame composed of four physical layer frames is shown. The physical layer frames are labelled frame 1, frame 2, frame 3 and frame 4. Within each physical layer frame the OFDM signals are communicating data from various PLPs. As explained above contemporaneously with the transmission of the data for the first data pipe using QPSK, OFDM symbols carrying data from both the first data pipe and the local insertion pipe are also transmitted using for example 16QAM. However in order to reduce the interference caused by the 16QAM modulation only one of transmitters Tx1, Tx2, Tx3, Tx4 within the cluster of four cells is allowed to transmit OFDM symbols with the higher order 16QAM modulated sub-carriers during each physical layer frame of the TDMA frames.

Thus in physical layer frame 1, only Tx1 transmits the OFDM symbols with sub-carriers modulated with 16QAM to provide data from the combined first data pipe and local insertion pipe, whilst in frame 2 only transmitter Tx2 transmits the OFDM symbols with 16QAM, and thereafter TX3 in frame 3 and TX4 in frame 4. Then the pattern repeats for the next TDMA frame. In each case, all other transmitters are transmitting OFDM symbols modulated with QPSK or the constellation used for carrying only the first data pipe.

As a result of time dividing the transmission of the local insertion data between each of the four transmitters Tx1, Tx2, Tx3, Tx4, effectively the local data rate is a quarter of that of the first data pipe. Thus in each cell transmits local insertion content every fourth physical layer frame. However correspondingly because the higher order modulation scheme is only transmitted from a cell once in every four frames, the effective interference experienced by receivers located in the coverage area of the four cells that wish to receive the first/lower order modulations scheme (QPSK) is correspondingly reduced. Thus in a pattern of cells illustrated in Figure 12c, the interference which is caused by the local insertion data and would appear as increased noise to the receiver is distributed throughout the cluster of four cells. Therefore the relative interference or increasing noise caused by the local insertion data is reduced. This can be considered to be the equivalent of frequency re-use in a multi frequency network. For the example illustrated in Figure 12a, 12b, 12c, the following table represents the transmission of OFDM symbols with each of the first (16QAM) and second (64QAM) modulation schemes:

	Frame 1	Frame 2	Frame 3	Frame 4
Tx1	64QAM	16QAM	16QAM	16QAM
Tx2	16QAM	64QAM	16QAM	16QAM
Tx3	16QAM	16QAM	64QAM	16QAM
Tx4	16QAM	16QAM	16QAM	64QAM

Table illustrating the modulation of OFDM symbols, when the local insertion data is modulated using a second/higher modulation scheme of 64QAM and the first/lower order modulation scheme is 16QAM for carrying data symbols from the first/national data pipe.

As will be appreciated, a result of allocating the transmission of the local content over a cluster of four TDMA frames between a cluster of four base stations, may be to reduce the bandwidth for the local content service by one quarter, if a receiver is only able to receive the OFDM carrying signal from one base station only, which will typically be the case. The allocation of the local content to the transmitter of the base station in each cluster may be provided for example via the L1 signalling data provided by the signalling data pipe.

Although in the example provided above the cells are clustered into groups of four, it will be appreciated that any number can be used. Advantageously the cells are grouped into clusters of four to provide a balanced trade-off between an amount of baseband bandwidth (bit rate) afforded to the local insertion service and an amount of reduction in the signal to noise ratio caused to the reception of data from the first data pipe using the lower order modulation scheme by the transmission of the higher order modulation scheme carrying data from both the first data pipe and the local insertion channel. As such a cell structure shown in Figure 12c can be used to transmit local content every fourth physical layer frame for a different group of four cells and the arrangement of the cell clustering repeated throughout to represent an equivalent arrangement of frequency re-use.

According to the present technique the transmitter within the base stations shown in Figure 5 may be adapted to implement the TDMA frame structure illustrated above. In one example, the scheduler 34 for forming the modulated sub-carrier signals into the OFDM symbols and a framing unit 58 may be arranged to schedule the transmission of the OFDM symbols according to the time divided frame illustrated in Figure 12b. The scheduler 34 and the framing unit 58 are arranged to transmit OFDM symbols which are carrying data symbols from both the first data pipe and the local insertion pipe using the second modulation scheme as illustrated in the table above.

Results

Various results are provided in Figures 13 to 18 for example transmitter-receiver chains operating with different forward error correction encoding rates of rate ½, 3/5, 2/3 and ¾, and for a first modulation scheme of 16QAM, a second modulation scheme of 64QAM. Figures 13, 14, 15, 16, 17 and 18 provide examples for different ratios of the power from cell A and cell B. For Figure 13 the fraction of the power of the received signal from cell A is 99% and 1% from cell B. The relative delay between time of arrival from cells A and B is 4.375us. For Figure 14 80% of the power is from cell A and 20% is from cell B with a 2.2 μs delay in time of arrival from cell B. Figure 15 provides a 99% power from cell A and 1% of power from cell B at a 0 μs delay in relative time of arrival. Figure 16 shows 60% of power from cell A and 40% of power from cell B at a 0 μs relative delay and Figure 17 shows a 50% power from base station A and 50% power from cell B at a 0 μs relative delay. Finally, Figure 18 shows results in a situation where 10% of the power is from cell A and 90% is from cell B with the signal from cell A arriving the receiver 2.2 μs after the arrival of the signal from cell B.. As can be seen from the example in Figure 18 there is insufficient signal to noise ratio to decode the 3/5, 2/3 rate codes. The required SNR should be that enough for the decoding of 64QAM.With respect to each of the plots is shown a signal to noise ratio value which would correspond to a situation in which the transmitter for the same neighbouring cell was not transmitting the local insertion data on the higher order modulation scheme 64QAM for this example. Where appropriate some of the plots include points for each of the respective coding rates of ½, 3/5, 2/3 and ¾ at a bit error rate of 10^{-7} as represented as a "◊". As shown in each case there is an increase in the signal to noise ratio required in order to reach the same bit error rate value. However the performance of the scheme would still seem to be acceptable.

Receiver

A receiver which may form part of a mobile device for receiving the signals broadcast by any of the base stations of the network shown in Figure 1 will now be described. An example architecture for a receiver for receiving any of the transmitted PLP pipes shown in Figure 4 is provided in Figure 19. In Figure 19 a receiver antenna 174 detects the broadcast radio frequency signal carrying the OFDM signals which are fed to a radio frequency tuner 175 for demodulation and analogue to digital conversion of a time domain base band signal. A frame recovery processor 158 recovers time division multiplex physical layer frame boundaries and OFDM symbol boundaries and feeds each of the symbols for each of each physical layer frame to an OFDM detector 150. The OFDM detector 150 then recovers the data from the OFDM symbols in the frequency domain. The recovered symbols are then fed to a de-scheduler 134 which divides each of these symbols into the respectively multiplexed PLP processing pipes. Thus the de-scheduler reverses the multiplexing of applied by the scheduler 134 shown in Figure 4 to form a plurality of data streams, which are fed respectively to PLP processing pipes 130, 132, 136. A typical receiver would have only a single PLP processing pipe as each PLP may carry a full broadcast service.

The PLP processing pipes 129, 130 correspond to the processing pipes 29 and 30 shown in Figure 4. Similarly the L1 signalling pipe 136 corresponds to the signalling pipe 36 shown in Figure 4. The PLP processing pipe labelled primary data pipe 132 corresponds to the PLP processing pipe 32 which has been referred to in the above description as the primary or first data pipe. As for the example shown in Figure 4 the first data pipe 132 also includes a local insertion pipe 180 which is recovering data inserted by the local insertion pipe 80 shown in Figure 4. The processing elements forming part of the PLP processing pipes shown in Figure 19 is shown in Figure 20.

In Figure 20 the first example PLP processing pipe 130 is shown to include a QAM demodulator 144, a de-interleaver 142 and a forward error correction decoder 140 which are arranged to substantially reverse the operations of the QAM modulator 44, the interleaver 42 and the FEC encoder 40 of Figure 4. Optionally, the PLP processing pipe 130 may also include a MISO/MIMO detector 46 for performing multiple input multiple output or multiple input signal output processing. In operation therefore modulation symbols are received at an input 200 and fed to the MISO/MIMO processor 146 whose role is to decode the space-time code that was used at the transmitter thereby producing one stream of modulation symbols into a signal symbol stream which are then fed to the QAM demodulator 144. The QAM demodulator detects one of the constellation points in the QAM modulation scheme used and for each detected point recovers a data word corresponding to that point. Thus the output of the QAM demodulator 144 is a data symbol stream which is fed to the de-interleaver 142 for de-interleaving the data stream from a plurality of OFDM symbols or from within an OFDM symbol.

Since the data symbols have been encoded in the transmitter shown in Figure 4, for example, using a low density parity check code, the symbols are decoded by the FEC decoder 140 to form at an output 220 base band data stream for the PLP.

The first data pipe 132 and the local insertion pipe 180 are also shown in Figure 20 to include a MISO/MIMO unit 146, a demodulator 204, a de-interleaver 142 and a forward error correction decoder 140. Similarly the local insertion pipe 180 includes a de-interleaver 142 and a forward error correction decoder 140.

In accordance with the present technique the demodulator 240 is arranged to reverse the operation of the modulator 45 shown in Figure 4. The demodulator 204 is shown in more detail in Figure 21.

In Figure 21 the modulation symbol stream is fed from the MISO/MIMO unit 146 to an input 210 of the demodulator 204. The modulation symbol stream is fed to first input 212 of a switching unit 198. On a second input 214 a control signal is provided which controls the position of a switch 216 between feeding the symbol stream to a first symbol selector for the first modulation scheme 218 or a second symbol selector for the second modulation scheme 220. In the present example the first modulation scheme is 16 QAM and the second modulation scheme is 64 QAM. The first modulation symbol selector 218 then recovers data corresponding to each of the detected constellation points to feed at an output 222 a symbol stream according to the first data pipe y0y1y2y3 which is fed to a symbol stream former 224 to form an output 226 of data symbols y0y1y2y3for the first data pipe.

On the other hand if the control signal is set to indicate that data has been transmitted by the local insertion data pipe then the switch 198 is arranged to switch the modulation symbol stream from the input 212 to the 64QAM symbol selector 220. The symbol selector 220 recovers data words from each of the detected signal constellation points to recover a data word comprising four bits for the first data pipe y0y1y2y3 and two bits h0h1 for the local insertion pipe. Thus the symbol stream former 230 feeds symbols for the primary data pipe y0y1y2y3 to the output 226 and the local insertion pipe on an output 232.

In accordance with the present technique the symbol selectors 218, 220 both identify signal constellation points for the received modulation symbols by mapping the in-phase I and quadrature phase Q values to those expected for the modulation scheme with or without a phase rotation corresponding to whether the phase rotation was introduced by the phase rotation unit 101 in the transmitter. Again the phase rotation corresponds to that for the first modulation scheme which is optimal for 16 QAM.

In accordance with the present technique in some embodiments, the de-scheduler 150 is arranged to apply the TDMA frame in accordance with a cluster of base stations described above to recover OFDM symbols which have been modulated with the second modulation scheme and transmitted on one of the physical layer frames. Thus in accordance with the signal transmission arranged for the cell cluster the receiver times the recovery of the OFDM symbols with sub-carriers modulated in accordance with the second modulation scheme in accordance with the frame timing applied by the transmitter in the base station. The information as to which physical layer frames carry hierarchical modulation for the given PLP is carried in the signalling PLP which the receiver first receives and decodes before any payload carrying PLP.

Various modifications maybe made to the present invention described above without departing from the scope of the present invention as defined in the appended claims. For example, other modulation schemes could be used other than those described above, with appropriate adjustments being made to the receiver. Furthermore, the receiver could be used in various systems, which utilise OFDM modulation other than those defined according to the DVB-NGH standards.

CLAIMS

1. A transmitter for communicating data using Orthogonal Frequency Division Multiplexed (OFDM) symbols, the OFDM symbols including a plurality of sub-carrier symbols formed in the frequency domain for modulating with the data to be carried, the transmitter including

a modulator arranged in operation

to receive on a first input, data symbols from a first data pipe according to a first communications channel for transmission,

to receive on a second input, data symbols from a local insertion data pipe according to a local communications channel for transmission, and

to modulate the sub-carrier signals of the OFDM symbols with either

the data symbols from the first data pipe or

the data symbols from both the first data pipe and the local insertion pipe, the modulation of the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe being performed by mapping the data symbols according to a first modulation scheme, and

the modulation of the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe and the local insertion pipe being performed by mapping the data symbols from the local insertion pipe and the first communications channel according to a second modulation scheme, and

a radio frequency modulator which is arranged to modulate a radio frequency carrier signal with the OFDM symbols for transmission, wherein

the first modulation scheme is a lower order modulation scheme providing first modulation symbols with values from a smaller number of constellation points in the complex plane than the second modulation scheme which is a higher order modulation scheme, the second modulation scheme providing second modulation symbols with values which are disposed in the complex plane about corresponding values of the first modulation scheme, with the effect that detection of one of the second modulation symbols of the second modulation scheme will provide data symbols from both the local insertion pipe and the first data pipe and allow the detection of first modulation symbols from the first modulation scheme providing data symbols from the first data pipe, in the presence of modulation symbols from the second modulation scheme, thereby providing the modulator with a plurality of modulation layers.

2. A transmitter as claimed in Claim 1, wherein the modulator is arranged to introduce a phase rotation into the modulation symbols of the first and the second modulation scheme, with the effect that detection of either one of the In-phase or the Quadrature components of one of the modulation symbols in the complex plane will identify that modulation symbol, wherein the phase rotation is the same for both the first and the second modulation schemes and is set as an optimum value for the first modulation scheme.

3. A transmitter as claimed in Claim 1 or 2, wherein the first modulation scheme is M-QAM and the second modulation scheme is 4M-QAM and the phase rotation which is used for both the first and the second modulations schemes is optimum for M-QAM.

4. A transmitter as claimed in Claim 1, 2 or 3, comprising

a signalling data pipe providing signalling data including data indicative of when data from the local insertion pipe is to be communicated using the second modulation scheme, wherein the modulator and the radio frequency modulator are arranged to transmit the data from the signalling pipe.

5. A transmitter as claimed in any preceding Claim, wherein the second modulation scheme provides two or more constellation points in the complex plane for each constellation point in the complex plane of the first modulation scheme.

6. A transmitter as claimed in any preceding Claim, wherein the first modulation scheme is N-QAM and the second modulation second is M-QAM, where $N < M$ and M/N is two or more.

7. A transmitter as claimed in any of Claims 2 to 6, wherein the first modulation scheme is M-QAM and the second modulation scheme is 4M-QAM and the phase rotation which is used for both the first and the second modulation schemes is optimum for M-QAM.

8. A transmitter as claimed in any preceding Claim, wherein the transmitter is arranged in operation to transmit the OFDM symbols with the sub-carriers modulated with the second modulation scheme carrying the data symbols from the first data pipe and the local data pipe in accordance with a time division multiplexed frame.

9. A transmitter as claimed in Claim 8, wherein the transmitter is arranged to transmit the OFDM symbols which are carrying data symbols from both the first data pipe and the local insertion pipe using the second modulation scheme in the time division multiplexed frame which has been assigned to each base station of a cluster of base stations.

10. A transmitter as claimed in any preceding Claim, wherein the transmitter is arranged to transmit data symbols from the OFDM symbols in accordance with a Next Generation Hand-held standard.

11. A method of transmitting data using Orthogonal Frequency Division Multiplexed (OFDM) symbols, the OFDM symbols including a plurality of sub-carrier symbols formed in the frequency domain for modulating with the data to be carried, the method including

receiving data symbols from a first data pipe according to a first communications channel for transmission,

receiving data symbols from a local insertion data pipe according to a local communications channel for transmission, and

modulating the sub-carrier signals of the OFDM symbols with either

the data symbols from the first data pipe or

the data symbols from both the first data pipe and the local insertion pipe, the modulating of the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe being performed by mapping the data symbols according to a first modulation scheme, and

the modulating the sub-carrier signals of the OFDM symbols with the data symbols from the first data pipe and the local insertion pipe being performed by mapping the data symbols from the local insertion pipe and the first communications channel according to a second modulation scheme, and modulating a radio frequency carrier signal with the OFDM symbols for transmission, wherein

the first modulation scheme is a lower order modulation scheme providing first modulation symbols with values from a smaller number of constellation points in the complex plane than the second modulation scheme which is a higher order modulation scheme, the second modulation scheme providing second modulation symbols with values which are disposed in the complex plane about corresponding values of the first modulation scheme, with the effect that detection of one of the second modulation symbols of the second modulation scheme will provide data symbols from both the local insertion pipe and the first data pipe and allow the detection of first modulation symbols from the first modulation scheme providing data symbols from the first data pipe, in the presence of modulation symbols from the second modulation scheme, thereby providing the modulator with a plurality of modulation layers.

12. A method as claimed in Claim 11, wherein the modulating includes introducing a phase rotation into the modulation symbols of the first and the second modulation scheme, with the effect that detection of either one of the In-phase or the Quadrature components of one of the modulation symbols in the complex plane will identify that modulation symbol, wherein the phase rotation is the same for both the first and the second modulation schemes and is set as an optimum value for the first modulation scheme.

13. A method as claimed in Claim 11 or 12, wherein the first modulation scheme is M-QAM and the second modulation scheme is 4M-QAM and the phase rotation which is used for both the first and the second modulations schemes is optimum for M-QAM.

14. A method as claimed in Claim 11, 12 or 13, the method including

receiving signalling data from a signalling data pipe indicating when data from the local insertion pipe is to be communicated using the second modulation scheme, and

transmitting the signalling data from the signalling pipe.

15. A method as claimed in any of Claims 11 to 14, wherein the second modulation scheme provides two or more constellation points in the complex plane for each constellation point in the complex plane of the first modulation scheme.

16. A method as claimed in any of Claims 11 to 15, wherein the first modulation scheme is N-QAM and the second modulation second is M-QAM, where N < M and M/N is two or more.

17. A method as claimed in any of Claims 12 to 16, wherein the first modulation scheme is M-QAM and the second modulation scheme is 4M-QAM and the phase rotation which is used for both the first and the second modulation schemes is optimum for M-QAM.

18. A method as claimed in any of Claims 11 to 17, the method including

transmitting the OFDM symbols with the sub-carriers modulated with the second modulation scheme carrying the data symbols from the first data pipe and the local data pipe in accordance with a time division multiplexed frame.

19. A method as claimed in Claim 18, wherein the transmitting includes

transmitting the OFDM symbols which are carrying data symbols from both the first data pipe and the local insertion pipe using the second modulation scheme in the time division multiplexed frame which has been assigned to each base station of a cluster of base stations.

20. A method as claimed in any of Claims 11 to 19, wherein the transmitter is arranged to transmit data symbols from the OFDM symbols in accordance with a Next Generation Hand-held standard.

21. A transmitter substantially as hereinbefore described with reference to Figures 1 and 4 to 21 of the accompanying drawings.

22. A method of transmitting substantially as hereinbefore described with reference to Figures 1 and 4 to 21 of the accompanying drawings.

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Claims searched:	1-22	**Date of search:**	10 June 2010

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-20	US 2008/159186 A1 [STEER] See para. 44,45,51,53,57-59
X	1-20	US 2006/013120 A1 [JIANG] See Figs. 3,4,8 and para. 6-9
X	1-20	US 2005/169400 A1 [CHOULY] See Fig. 2 and para. 10

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X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

H04L; H04N

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
H04L	0027/26	01/01/2006
H04L	0027/34	01/01/2006
H04N	0005/00	01/01/2006