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0904862.0 20 March 2009 (20.03.2009) GB(71) Applicant (for all designated States except US): **IMPERIAL INNOVATIONS LIMITED** [GB/GB]; Electrical and Electronic Engineering Bldg., Level 12, Imperial College, Exhibition Road, London SW7 2AZ (GB).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **GURCAN, Mustafa, Kubilay** [TR/GB]; 83 Blakes Farm Road, Southwater, Horsham, West Sussex RH13 9GH (GB).(74) Agents: **PITCHFORD, James, Edward** et al.; Kilburn & Strode LLP, 20 Red Lion Street, London WC1R 4PJ (GB).

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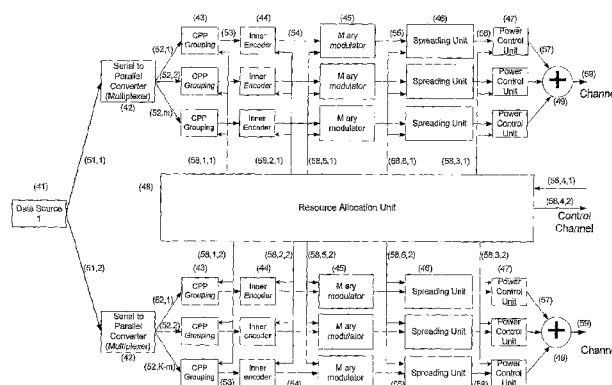


Figure 3

(57) Abstract: A method of transmitting data in a data transmission system having a plurality of channels, the method comprising: transmitting a first group of data at a first bit rate over a first group of one or more channels; and transmitting a second group of data at a second bit rate over a second group of one or more channels.

## **BIT LOADING METHOD AND APPARATUS FOR MULTICODE PARALLEL CHANNEL COMMUNICATION**

### **5 FIELD OF THE INVENTION**

The present invention relates to base-station apparatus and a method of providing communication in multicode and multichannel systems. It is applicable, but by no means limited, to Code Division Multiple Access (*CDMA*) and High Speed Downlink  
10 Packet Access (*HSDPA*) communication systems.

### **BACKGROUND OF THE INVENTION**

There have been many proposed or operational mobile systems or communication  
15 apparatus using *CDMA* transmission schemes which aim to increase the capacity of channels (links) comprising the system. Recent attempts to increase capacity includes one of the most successful systems, the High-Speed Downlink Packet Access (*HSDPA*) [1, 2, 3, 4, 5] system. Wikipedia [5] provides a clear description of the High-Speed Packet Access (*HSPA*) family, which allows networks based on Universal  
20 Mobile Telecommunications System (*UMTS*) to have higher data transfer speeds and capacity. The principal elements of the HSDPA transmitter and receiver are shown in Figures 1 and 2. At the transmitter (Figure 1) of the scheme described in Reference 1, the binary data from the data source 1 appears at 11. Blocks of incoming data are divided into  $K$  sub-blocks. The first sub-block is fed to the  
25 channel encoder 2 via the link 11,1. The second sub-block is fed at 11,2 to a second channel encoder which may be the same as 2. Likewise, the remaining sub-blocks are fed to corresponding channel encoders. From the point of operation, each of the

sub-channels  $1, \dots, K$  functions in the same way and hence, from hereon, consideration will be devoted to sub-channel 1. Data from the channel encoder 2 is fed to a serial-to-parallel converter 3. In the serial-to-parallel converter 3, successive blocks of  $b$  binary digits are taken at 12 and are fed at 13 to an  $M$ -ary signal generator 4. The term " $M$ -ary", as used herein, is well known in the art and refers to  $M$ -level signals used in modulation, with  $M$  being the order of modulation, as those skilled in the art will appreciate. The  $M$ -ary signal generator 4 produces at its output 14 a signal which generally can take one of  $2^b$  different values. These signals may therefore be voltage values. The signals appearing at 14 are then fed to a spreading sequence unit 5 which operates in a manner that is well known to those skilled in the art of spread spectrum and CDMA systems. The signals at 15 are then power amplified by the power transmission control units 6. Finally  $K$  signals appearing at 16 are added together in an adder unit 8 prior to transmission over the communication channel 18. It will be appreciated that pass-band modulation and demodulation may be involved and Figures 1 and 2 represent the equivalent baseband schemes for such systems. The resource allocation unit 7 at the transmitter uses links 17,1 and 17,2 as control channels to communicate with the control unit 108 at the receiver. The channel gain,  $h$ , information, the noise level  $\sigma^2$  at the receiver and also the multipath channel impulse response information are obtained by the control unit 108 at the receiver. The control unit 108 sends this information to the resource allocation unit 7. This information is used at the resource allocation unit 7 to control the channel encoder 2,  $M$ -ary signal generator 4

and the power control unit 6. The resource allocation unit 7 sends the channel encoder rate  $r_I$  to the channel encoder 2 via link 17,3. The resource allocation unit 7 sends the modulation level information  $b$  to the  $M$ -ary signal generator 4 via link 17,4. The resource allocation unit sends the transmission energy level to the power control unit 6 via link 17,5.

The basic operation of the HSDPA transmitter will now be described. The *HSDPA* uses adaptive modulation and coding (*AMC*), fast packet scheduling at the base station and fast retransmissions from the base station which are known as the hybrid automatic repeat-request (*HARQ*). The Transmission Time Interval (*TTI*) or interleaving period has been defined to be 2 ms. There are different classes delivering different data rates [1, 2, 3] when combining various modulation and coding rates. The modulation scheme and coding are changed on a per-user basis depending on the signal quality and cell usage. In the *HSDPA* system blocks of incoming binary data are fed to a Turbo encoder (the channel encoder 2) which is the only coding scheme used with the effective code rate of  $r_I \in \left\{ \frac{1}{4}, \frac{1}{2}, \frac{3}{4} \right\}$ . The

Turbo encoded data at 12 is fed to a serial-to-parallel converter 3 and the data appearing at 13 is fed to a modulator (the  $M$ -ary signal generator 4) which uses either Quadrature Phase-Shift Keying (*QPSK*) or *4QAM* (Quadrature Amplitude Modulation) and in good channel conditions *16QAM* modulation. The *4QAM* and *16QAM* systems transmit data at a rate  $b = 2,4$  bits per symbol respectively. The

coded modulation scheme carries  $b_p = r_I \cdot b$  bits/s for  $p=1, \dots, 5$  where  $p$  is the Transport Format and Resource Combinations (TFRC) number.

The modulated signal symbol at 14 is fed to a spreading unit (the spread sequence generator 5) at regular intervals of  $T$  seconds which is known as the symbol period. The spreading unit 5 multiplies the modulation symbol with the samples of spreading sequence which is otherwise known as the channelization code and produces the spread signal at 13. The spreading sequence has a length  $N$ , which is known as the processing gain or the spreading factor. For the HSDPA system the processing gain is  $N=16$  and the frequency division duplex FDD CDMA system has a chip rate of 3.84 Mbps hence the chip period is  $T_c = 0.26 \mu s$ . The CDMA system has the transmission symbol period equal to  $T = N \times T_c$ . The symbol period for the HSDPA system is  $T = 4.1667 \mu s$ .

The maximum number of codes that can be allocated is 15, but individual terminals may receive a maximum number,  $K$ , of 5, 10 or 15 codes. When the base station decides which users will receive data on the next frame, it also decides which channelization codes will be used for each user. This information is sent to the user devices over the associated dedicated channel 17,1 and 17,2. The total maximum

data rate for the HSDPA is  $R_T = \frac{K r_I b}{T} = \frac{K b_p}{T}$  bits/s.

In the current *HSDPA* standard [1, 2, 3] with the specified Turbo code rates are  $r_t$   $\in \left\{ \frac{1}{4}, \frac{1}{2}, \frac{3}{4} \right\}$  and with either the *4QAM* or *16QAM* modulation scheme the number of bits,  $b_p$ , carried per symbol by each spreading sequence is listed in Table 1.

5

| <i>TFRC number p</i> | <i>b</i> | $r_t$         | bits $b_p$    | $R_T$ (Mbps) |
|----------------------|----------|---------------|---------------|--------------|
| 1                    | 2        | $\frac{1}{4}$ | $\frac{1}{2}$ | 1.8          |
| 2                    | 2        | $\frac{1}{2}$ | 1             | 3.6          |
| 3                    | 2        | $\frac{3}{4}$ | $\frac{3}{2}$ | 5.3          |
| 4                    | 4        | $\frac{1}{2}$ | 2             | 7.2          |
| 5                    | 4        | $\frac{3}{4}$ | 3             | 10.7         |

Table 1: Symbol rates for different TRFC numbers

10 The range of the number of bits per symbol transmitted over each spreading sequence is  $b_p \in \left\{ \frac{1}{2}, 1, \frac{3}{2}, 2, 3 \right\}$  for the Transport Format and Resource Combination (*TFRC*) numbers  $p = 1, \dots, 5$ . In Table 1, the last column gives the total data rate when keeping the number of codes equal to  $K = 15$  for the spreading factor of  $N = 16$  and the chip rate of 3.84 Mbps [4]. The current *HSDPA* 15 deployments support down-link speeds of 1.8, 3.6, 7.2 and 10.7 Mbit/s. The signal appearing at the output 15 of the spreading unit (the spread sequence generator 5) is fed to a power adjustment unit (the power control unit 6) which adjusts the

transmission power  $P_k$  for  $k=1, \dots, K$ . For a given total transmission power

$P_T = \sum_{k=1}^K P_k$  the total energy  $E_T = T P_T$  becomes limited.

At the receiver (Figure 2) the signals received from the channel at 18 are fed to a de-  
 5 spreading unit 109, which acts in a manner well known to those skilled in the art of  
 spread spectrum systems. These units have the effect of isolating the signals on the  
 separate channels and, at 129,  $M$ -ary signals corresponding to noise-corrupted  
 versions of those at 14 are obtained when considering a multipath interference free  
 transmission. In the scheme described in References [1, 2, 3], the capacity of the  $K$   
 10 channels comprising the system is improved by jointly using the resource allocation  
 unit 7 at the transmitter and the control unit 108 at the receiver to adjust the data  
 rate  $b_k = b_p$  and also the transmission energy  $E_k(b_p)$  for  $k=1, \dots, K$  to achieve a  
 given signal-to-noise ratio  $\gamma_k$  at the output 129 of each de-spreading unit 109 at the  
 receiver. As those skilled in the art will appreciate, the minimum energy  $E_p$  required  
 15 to transmit the data at a rate of  $b_p$  bits per symbol over a sub-channel whilst  
 achieving a sufficient signal-to-noise ratio (SNR)  $\gamma_p^*$  at the output 129 of the de-  
 spreading unit 109 is given by  $E_p = \frac{2\Gamma\sigma^2}{h} (2^{b_p} - 1)$  where  $h$  is the path gain  
 between the transmitter and receiver, and  $\sigma^2 = \frac{N_0}{2}$  is the noise variance at the  
 output of the de-spreading unit 109 at the receiver. As those skilled in the art will

appreciate, the term  $\Gamma = \frac{\gamma_p^*}{2^{b_p} - 1}$  is the gap value as defined by [13] and  $\gamma_p^*$  is the minimum signal-to-noise ratio required to transmit data at a rate of  $b_p$  bits per channel for a practical system. This SNR value  $\gamma_p^*$  is known as the desired SNR. The gap value  $\Gamma$  has a specific value determined by a particular implementation of the

5 Turbo channel encoder and decoder.

In the *HSDPA* system, each of the  $K$  parallel channels is used to transmit the data at an equal rate  $b_p$  bits. As those skilled in the art will appreciate, the control unit 108 at the receiver monitors the signal-to-noise ratio at the output 129 of the de-  
10 spreading unit 109 and communicates with the resource allocation unit 7 over the control channel 17,1 and 17,2. The control unit 108 at the receiver and the resource allocation unit 7 at the transmitter jointly determine the data rate  $b_p$  bits to be transmitted and the transmission energy  $E_p$  which is to be used over each channel.

It is considered that the values for the gap value  $\Gamma$ , the noise variance  $\sigma^2$  and the  
15 channel gain  $h$  are known at the transmitter. The minimum energy  $E_p$  value required to transmit the data at a rate of  $b_p$  bits per channel and also the total minimum energy  $KE_p$  are calculated for different numbers  $K = 5, 10, 15$  of channels and also for different *TFRC* numbers  $p = 1, \dots, 5$ . The total available energy  $E_T$  is compared with two total required energies  $KE_p$  and  $KE_{p+1}$  for two adjacent  
20 numbers  $b_p$  and  $b_{p+1}$  of bits. The aim is to identify for which values of the *TFRC*



numbers the total available energy  $E_T$  falls between  $KE_p$  and  $KE_{p+1}$  when satisfying the relationship

$$KE_p \leq E_T < KE_{p+1} \quad (1)$$

for three specific combinations of a given number of channels  $K = 5, 10, 15$  and a  
 5 corresponding *TFRC* number  $p = 1, \dots, 5$ . A specific data rate of  $b_p$  bits per channel, corresponding to the energy  $E_p$  satisfying the inequality equation (1), is identified as the possible transmission data rate of  $b_p$  bits for a given number of channels  $K = 5, 10, 15$ . Three specific combinations of  $K$  and  $b_p$  satisfying equation (1) are compared and the largest total number of bits  $Kb_p$ , for a specific combination of  $K$   
 10 and  $p$ , is then used to identify the total number  $K$  of channels and the transmission data rate of  $b_p$  bits for use in the *HSDPA* downlink in a manner that is well known to those skilled in the art of *HSDPA* systems. The total number of bits  $b_T = Kb_p$  is then calculated. When having the minimum energy  $E_p$ , the data rate  $b_p$  and also the total number of channels  $K$ , the resource allocation unit 7 uses Table 1 to  
 15 obtain the channel encoder rate  $r_I$  and the *M-ary* modulation level  $b$ . The resource allocation unit 7 informs the channel encoder unit 2 via the link 17,3 to use the channel encoding rate  $r_I$ . The resource allocation unit 7 informs the *M-ary* modulation unit 4 via the link 17,4 to use the modulation level  $b$  when generating the modulated signal samples at 14. The resource allocation unit 7 sends the energy  
 20 level  $E_p$  to the power control unit 6 via the link 17,5 in order to adjust the transmission signal power level at 16. The resource allocation unit 7 at the

transmitter communicates with the control unit 108 at the receiver via the control channels 17,1 and 17,2 to exchange the information related to the number of channels  $K$  to be used during the next transmission. The information related to the modulation level  $b$  to be used in the  $M$ -ary modulation and also the encoding rate  $r_I$  used in the channel encoding process are also transmitted in the form of data rate information  $b_p$  from the resource allocation unit 7 to the control unit 108. The resource allocation unit 7 also sends the energy level  $E_p$  to the control unit 108. The control unit 108 uses the energy level information  $E_p$  together with the spreading sequence information, which is available in lookup tables at the receiver, to calculate the coefficients for the de-spreading unit and sends the coefficients to the de-spreading unit 109 via the link 126. The control unit 108 also uses a copy of Table 1 to obtain the channel encoder rate  $r_I$  and the  $M$ -ary modulation level  $b$  from the data rate  $b_p$  information it received from the resource allocation unit 7. The control unit 108 then sends the modulation level information  $b$  to the  $M$ -ary demodulator 110 via the link 127. The control unit 108 sends the channel encoder rate  $r_I$  to the channel decoder 111 via the link 128. After the control unit 108 completes loading the spreading unit 109, the  $M$ -ary to binary decoder 110 and the channel decoder 111 with the appropriate spreading sequences, the modulation level information  $b$  and also the channel encoder rate  $r_I$ , the signals received over the channel 18 are then de-spread by the de-spreading unit 109. The signals appearing at the output 129 of the despreaders 109 are then fed to an  $M$ -ary decoder 110 which is linked to a channel decoder 111. The  $M$ -ary decoder 110 and the channel decoder 111 work

together to produce the decoded data. After decoding in the channel decoding unit (111), the data appearing at 131 corresponds to that appearing at the output 11,1 of the data source 1 are obtained.

- 5 When determining the transmission data rate  $b_p$ , usually there exists an amount of energy  $e_R(Kb_p)$  which is not used to transmit any useful information. This amount of energy is referred to as the residual energy  $e_R(Kb_p) = E_T - KE_p$ . There exists a problem with the current *HSDPA* system that this residual energy is not used to transmit data bits although the energy might be available at the transmitter.

10

As those skilled in the field of art will appreciate, from equation (1) it is observed that the residual energy  $e_R(Kb_p)$  is upper bounded by the total incremental energy  $e_I(Kb_p)$  which is given by

$$e_R(Kb_p) \leq e_I(Kb_p) = K(E_{p+1} - E_p) = K e_I(b_p) \quad (2)$$

15

$$= \frac{2 K \Gamma \sigma^2}{h} (2^{\beta_p} - 1) 2^{b_p}$$

where the incremental energy  $e_I(b_p) = E_{p+1} - E_p = \frac{2 \Gamma \sigma^2}{h} (2^{\beta_p} - 1) 2^{b_p}$  is the minimum additional energy required to transmit the data at a rate of  $b_{p+1}$  bits instead of transmitting the data at a rate of  $b_p$  bits per channel. The bit granularity  $\beta_p$  is defined as  $\beta_p = b_{p+1} - b_p$ . Although communication over parallel channels improves

20 the total data rate for the multicode *CDMA HSDPA* system, the use of the same

data rate of  $b_p$  bits for each channel severely restricts the residual energy utilization to carry useful data. The upper bound for the unused residual energy is the total incremental energy  $e_R(Kb_p) \leq K e_I(b_p)$ . The existing *HSDPA* standard [1, 2, 3], puts all the channels into one group to transmit the data at a rate of  $b_p$  per symbol per

5 channel and finds the data rate  $b_p$  and the number of channels  $K$  by solving equation (1). In the *HSDPA* standard there is not any method to use this existing energy to transmit extra information. Ideally, any residual energy higher than the incremental energy  $e_I(b_p)$  should be used to transmit useful information. There is a need to constrain the residual energy upper bound to  $e_I(b_p)$  instead of the current

10 upper bound  $K e_I(b_p)$ .

A simplified example for the *HSDPA* resource allocation problem will now be described to demonstrate how much residual energy may be available to transmit useful information. Consider an *HSDPA* system when using a total of  $K=15$

15 channels and a total transmission energy  $E_T = 3.0$ . Assume that the gap value is  $\Gamma_{dB} = 1.6dB$  or  $\Gamma = 10^{0.16}$ , the noise variance is  $\sigma^2 = 10^{-6}$  and also the channel gain is  $h = 10^{-4}$ . The energies  $E_{p+1}$  and  $E_p$  required to transmit  $b_p = 2$  and  $b_{p+1} = 3$  bits/symbol over each channel can be calculated using the energy equation for  $b_p$  using  $E_p = \frac{2\Gamma\sigma^2}{h} (2^{b_p} - 1)$ . This gives the energies  $E_{p+1}$  and  $E_p$  as  $E_{p+1} = 0.20236$

20 and  $E_p = 0.08673$ . The resulting total energies  $KE_p$  and  $KE_{p+1}$  for  $b_p = 2$  and

$b_{p+1} = 3$  and also  $K = 15$  are  $KE_p(b_p = 2) = 1.3009$  and  $KE_{p+1}(b_{p+1} = 3) = 3.0354$ . The total energy  $E_T = 3.0$  satisfies the inequality  $KE_p(b_p = 2) \leq E_T < KE_{p+1}(b_{p+1} = 3)$  as  $1.3009 \leq (E_T = 3.0) < 3.0354$ . The resulting number of bits per symbol is  $b_p = 2$ , and when using  $K = 15$  channels a total of  $Kb_p = 30$  bits are transmitted over each
   
 5 symbol period  $T$ . The unused residual energy is  $e_R(Kb_p)_{b_p=2} = E_T - KE_p(b_p = 2) = 3.0 - 1.3009 = 1.699$ . This residual energy  $e_R(Kb_p) = 1.699$  is not used to transmit any useful information and the problem of not being able to use the total residual energy will need to be solved in order to make the *HSDPA* system more efficient.

10

A patent review has been carried out to identify whether any approach has been considered as part of any existing patent to use the residual energy to transmit useful information. There are patent documents [6, 7, 8, 9, 10, 11, 12] related to the generation of a plurality of transmission rates that can be used in the multi-code
   
 15 *CDMA* systems similar to the *HSDPA* standard [1, 2, 3].

20

EP 1204284 [6] discloses an apparatus and a method for increasing the number of multicode channels by using multicode *CDMA* channels of another base station when one of the base stations the mobile unit is organized to communicate is saturated.

EP 1229678 [7] discloses an apparatus and a communication method which maintains data reception quality for high data rate adaptive modulation systems by

dealing with problems associated with sudden changes in the propagation environment by introducing a signalling channel for the *CDMA* systems.

US 7027782 [8] discloses an apparatus and a method for retransmitting coded bits by  
5 a transmitter in response to a retransmission request for an adaptive modulation coding system. This patent covers the hybrid *ARQ* aspects of the *HSDPA* system.

US 6738370 [9] discloses an apparatus and a corresponding method which is related to retransmitting a portion of the signal via a wireless communication system when  
10 the portion of the signal is received with an error. This patent deals with the hybrid *ARQ* aspect of the *HSDPA* system.

US 7206332 [10] discloses an algorithm for optimizing a number of spreading codes as well as the type of adaptive modulation and the channel coding scheme. The  
15 combination of the modulation with the highest bits and the coding with the highest rate and the highest number of codes achieves the highest bit rate  $Kb_p$ . A best bit rate is achieved for a given signal-to-noise ratio at the receiver by appropriately selecting the number of codes, the adaptive modulation and the channel code. In the method disclosed in US 7206332 a user equipment may play the role of carrying out  
20 the optimization and then signalling the result to the base station.

EP 0982870 [11] discloses a method and an apparatus for mapping and de-mapping

*CDMA* signals for use in an iterative decoding method when using multicode *CDMA* systems. The iterative decoder is a concatenated coding scheme where an inner and an outer encoder are used in series. The inner and outer binary codes can be of any type: systematic, or non-systematic, block or convolution codes. Usually  
5 for an encoder, the number of incoming bits is smaller than the number of outgoing bits. The ratio of the incoming bits to the outgoing bits is known as the code rate.

When using an adaptive modulation scheme based on an *M*-ary *QAM* transmission each constellation point carries a total of  $b$  bits. For the *4QAM* and *16QAM*  
10 systems the number of bits carried by each symbol is  $b = 2$ , and 4 respectively. If an adaptive modulation and coding scheme is implemented using a concatenated coding scheme with an inner code rate of  $r_I$  and an outer code rate  $r_o$  then the combined rate,  $b_p$ , for the transmitted signal is  $b_p = r_I \times r_o \times b$  per symbol for the scheme described in EP 0982870. However as there is only one code used in  
15 conjunction with the adaptive modulation scheme described in US 7206332, the number of bits transmitted per symbol is equal to  $b_p = r_I \times b$  if the code rate is  $r_I$ .

Amongst the patents reviewed, US 7206332 [10] is the only one which is relevant to the *HSDPA* rate allocation problem. US 7206332, however, uses two dimensional  
20 adaptive modulation and multicode scheme optimization. US 7206332 selects a number of channelization codes and a modulation and coding scheme (MCS) from a plurality of MCSs for use by a transmitter over the radio link according to said time

varying radio link quality. US 7206332 uses the lowest order MCS with increasingly larger numbers of channelization codes at correspondingly different bit rates until a maximum allowed number of channelization codes are used. US 7206332 does not specifically aim to reduce the total residual energy below the incremental energy

5  $e_I(b_p).$

WO2008/062163 [12] discloses a method to improve the capacity of communication channels. A user's incoming block of data is divided into parallel subchannels. Binary digit repetition and random phase insertions are introduced for each of the subchannels to achieve a desired rate over each channel and also to minimize the total peak power transmission power. WO2008/062163 however does not describe an algorithm to adjust the transmission data rate and also the transmission power to minimize the residual energy.

15 For the calculations of the number of channels  $K$  and the number of bits  $b_p$ , the approach, described in the HSDPA standard [1, 2, 3], uses equation (1) which is based on the assumptions that the spreading sequences are orthogonal to each other. It is further assumed that there is no frequency selective multipath over the transmission path. When encountering a multipath channel, the spreading filter at the receiver of the *HSDPA* system needs to incorporate equalizer coefficients into the de-spreading sequence to deal with the multipath reflections. The use of an equalizer as part of each de-spreading unit makes the spreading codes loose their

20



orthogonality. The  $SNR$  at the output of each despreading unit becomes dependent on the energies allocated to all the codes.

As those skilled in the field of art will appreciate, when transmitting the data at the  
 5 data rate  $b_p$  bits per symbol, using the same transmission energy for each parallel  
 channel, the  $SNR$  values  $\gamma_k$  for  $k=1, \dots, K$  at the output of the  
 equalizer/despreader units will have similar values with slight variations. The energy  
 for each multicode channel is chosen to guarantee the data rate  $b_p$  for the worst  
 channel. The  $SNR$  for the worst channel should have at least the minimum value  $\gamma_p^*$   
 10 that is sufficient to transmit  $b_p$ . The channel noise variance  $\sigma^2$ , the channel gain  $h$ ,  
 and the multipath impulse response are fed back from the control unit 108 at the  
 receiver to the resource allocation unit 7 at the transmitter via a dedicated signalling  
 channel. To minimize the total transmission energy, for a given multipath channel  
 impulse response the transmission energy for each code will need to be adjusted to  
 15 provide the same  $SNR$  value just above the desired  $SNR$  value  $\gamma_p^*$  which is  
 sufficient to transmit the data at a rate  $b_p$  bits per symbol over each channel and to  
 improve the total energy consumption. The energy allocated to each code will have  
 similar values with slight variations depending on the multipath impulse response.

20 To deal with the interactions between the energies, when using the allocated  
 energies to determine the data rate  $b_p$  for  $K$  parallel channels, the method used in

equation (1) may be modified to the following form

$$\sum_{k=1}^K E_k(b_p) \leq E_T < \sum_{k=1}^K E_k(b_{p+1}) \quad (3)$$

#### *Problem 1*

- 5 In light of the above discussion, a first problem to be considered in the present work is how to reduce the amount of residual energy that would otherwise be wasted. This applies to both interference-free channels, and to channels which introduce multipath/inter-symbol interference.

#### 10 *Problem 2*

- For multicode systems involving downlink transmission with parallel channels, when encountering a multipath transmission channel which necessitates the use of an equalizer as part of the de-spreading unit, there is a desire to allocate the minimum transmission energy  $E_k(b_p)$  values when transmitting the data rates  $b_p$  over the
- 15 total number of channels  $K$ , that achieve the same desired  $SNR$  value  $\gamma_p^*$  at the output of each equalizer/de-spreader unit, whilst achieving residual energy reduction.

#### *Problem 3*

- 20 A further, associated, problem is to determine the bit rates, the energy in each channel, and the total number of channels so as to reduce the upper bound for the

total residual energy below the incremental energy  $e_I(b_p)$  when using the optimization method given in equation (3).

*Problem 4*

- 5 A method of iteratively calculating the equalizer coefficients and transmission energies to be allocated for  $K$  parallel channels is also desired for multicode *CDMA* systems. The coefficients for each equalizer and the corresponding de-spreading sequences can be calculated in a manner well known to those skilled in the art [14]; however the problem considered in the current work is to make the calculations
- 10 operate iteratively as part of the method which reduces the upper bound for the total residual energy.

*Problem 5*

- A method is also sought to ensure that the resource allocation unit at the transmitter
- 15 and the control unit at the receiver talk to each other, to allocate the resources at the transmitter, and to feed the relevant information to the control unit at the receiver, in order to enable the control unit to calculate the equaliser coefficients and integrate them in to the de-spreading unit, and also set the parameters for the channel and modulation decoders to operate at the appropriate rates.

20

*Problem 6*

As residual energy is dependent on incremental energy, and incremental energy is

dependent on bit granularity, a method of improving or reducing the bit granularity  $\beta_p$  is also desired in order to reduce the incremental energy and hence the residual energy when transmitting multicode *CDMA* signals, concatenated codes and adaptive modulation. As can be seen from equation (2), this will reduce the residual energy and the HSDPA transmission system will operate more efficiently. The bit granularity  $\beta_p$  can be reduced using concatenated codes. Accordingly, a further problem is to find a combination of outer code and inner code rates which will result in a reduced bit granularity when combined with the number of bits  $b$  for modulation schemes. An iterative decoding method is also sought for use at the receiver, so that reduced bit granularity can be implemented for practical systems.

## SUMMARY OF THE INVENTION

None of the patent documents [6, 7, 8, 9, 10, 11, 12] examined aims to bring the upper bound for the total residual energy below the incremental energy  $e_I(b_p)$  from the current upper bound of  $Ke_I(b_p)$ . In this work the following method is proposed to increase the total number of bits when using  $K$  parallel channels and when having some residual energy available. The total residual energy  $e_R(Kb_p)$  may not be sufficient to convert the number  $b_p$  of bits to  $b_{p+1}$  bits per channel for all  $K$  parallel channels. However the incremental energy  $e_R(Kb_p)$  may be sufficient to transmit the data at a rate of  $b_{p+1}$  bits per channel for a limited number  $m$  of channels which will be bounded by  $0 \leq m \leq (K-1)$  as those skilled in the art will appreciate.

*Solution 1*

Accordingly, a first aspect of the present invention relates to a method of transmitting data in two groups as defined in Claim 1 of the appended claims. Thus, there is provided a method of transmitting data in a data transmission system having  
5 a plurality of channels, the method comprising: transmitting a first group of data at a first bit rate over a first group of one or more channels; and transmitting a second group of data at a second bit rate over a second group of one or more channels.

*Solution 2*

10 For multicode systems involving downlink transmission with parallel channels, when encountering a multipath transmission channel which necessitates the use of an equalizer as part of the de-spreading unit, in order to determine the data rates  $b_p$  and  $b_{p+1}$  to be transmitted and energies  $E_k$  to be used over each channel for  $k=1, \dots, K$  when using two groups of channels, in some embodiments methods as  
15 defined in Claims 2 to 5 of the appended claims may be employed. Such methods may be used in a multicode CDMA system for downlink transmission with  $K$  parallel channels.

In such embodiments, the method may involve transmitting a known sequence to  
20 enable the receiver to measure the transmission path gain  $h$ , the multipath channel impulse response and the noise variance  $\sigma^2$  at the receiver. These measurements are fed-back from the control unit at the receiver to the resource allocation unit at

the transmitter over an associated dedicated control channel. At the transmitter it is considered that a total energy  $E_T$  is available for transmission. Initially it is considered that this energy is equally distributed amongst  $K$  parallel channels. The resource allocation unit at the transmitter uses the channel gain  $h$ , the multipath

5 channel impulse response and the receiver noise variance  $\sigma^2$  and also the energy allocated to each channel to calculate the despreading filter coefficients for all the receivers for  $K$  parallel channels whilst incorporating an equalizer into the despreading unit. As those skilled in the art will appreciate, the de-spreading coefficients and the signal-to-noise ratio  $\gamma_k$  at the output of each de-spreading

10  $k=1, \dots, K$  unit can be calculated at the resource allocation unit at the transmitter in a manner that is well known to those skilled in the art, such as the method described in [14].

### *Solution 3*

15 The bit rates  $b_p$  and  $b_{p+1}$ , the energy in each channel, and the respective numbers of channels may be determined using a method as defined in Claim 6 of the appended claims. In such a method, in the first group, a total of  $m$  parallel channels are used to transmit  $b_{p+1}$  bits per symbol over each channel, and in the second group the remaining  $K-m$  parallel channels are used to transmit  $b_p$  bits per symbol over

20 each channel. For a multicode *CDMA* system a method is required to calculate the number  $m$  and the number of bits  $b_{p+1}$  and  $b_p$  in order to put the channels into two groups when having  $K$  channels and a total energy  $E_T$  at the transmitter. For each

channel the allocated energy  $E_k$  for  $k=1, \dots, K$  needs to be calculated.

If there is no multipath interference over the transmission channel, the steps involved in calculating the actual number  $m$  can be initiated by finding the total  
 5 number  $K$  of codes and also the data rate of  $b_p$  bits per channel from equation (1).  
 Once  $b_p$  and  $b_{p+1}$  are known, they can be used together with the corresponding bit granularity  $\beta_p$  to calculate the incremental energy  $e_I(b_p)$  from equation (2) and also the total incremental energies  $m e_I(b_p)$  for the integer values  $m=1, \dots, (K-1)$ . The number  $m$  of channels to be used can be determined by finding the  $m$  value for  
 10 which the total residual energy  $E_T - KE_p$  falls between the two adjacent total incremental energies  $m e_I(b_p)$  and  $(m+1)e_I(b_p)$  such that the following inequality holds

$$m e_I(b_p) \leq E_T - KE_p < (m+1)e_I(b_p) \quad (4)$$

The corresponding  $m$  value makes the residual energy sufficient to transmit the data  
 15 at a rate of  $b_{p+1}$  bits per channel over  $m$  channels. The remaining  $(K-m)$  channels can be used to transmit the data at a rate of  $b_p$  bits per symbol. This enables the *HSDPA* system to transmit a total of  $b_T = (K-m)b_p + m b_{p+1} = Kb_p + m\beta_p$  bits per  $K$  parallel channels, as opposed to transmitting just  $Kb_p$  bits, for the given total transmission energy  $E_T$ .

*Solution 4*

If there is multipath interference, then the energy allocation may be iteratively updated using a method as defined in Claim 7. Such a method using a recursive equation

$$E_{k,i}(b_p) = \frac{\Gamma(2^{b_p} - 1)}{\gamma_{k,i}} E_{k,i-1}(b_p) \quad (5)$$

where  $i=1,2,3,\dots$  is the iteration number. The initial value for  $E_{k,0}(b_p)$  for  $k=1,\dots,K$  can be any arbitrary value but it can also be set to  $E_{k,0}(b_p) = \frac{E_T}{K}$  for  $k=1,\dots,K$ . The term  $\Gamma(2^{b_p} - 1)$  is the minimum target SNR to be reached at the output of the despreading unit if the data is to be transmitted at a rate  $b_p$  bits per symbol over each channel. The resource allocation unit at the transmitter iteratively adjusts the transmission energy  $E_k(b_p)$  and also the equalizer coefficients and measures the signal-to-noise ratio,  $\gamma_{k,i}$ , at the output of each despreading unit until the energy values converge to their final values. The converged energy values are then taken as the minimum energy  $E_k(b_p)$  required to transmit data at a rate  $b_p$  bits per symbol over each channel  $k=1,\dots,K$ . These energy calculations  $E_k(b_p)$  are then repeated for all possible values of the TRFC number  $p=1,\dots,P$  and are used to check which energy values corresponding to a specific data rate  $b_p$  bits per symbol satisfy the inequality given in equation (3). The specific data rate  $b_p$  value is then taken by the resource allocation unit as the data rate to be transmitted over one group of channels and the data rate  $b_{p+1}$  is taken as the data rate to be



transmitted over the second group of channels.

In order to iteratively calculate the equalizer coefficients and transmission energies for  $K$  parallel channels, in some embodiments a method as defined in Claim 8 of the  
 5 appended claims may be employed. This method is applicable to multicode CDMA downlink transmission when encountering a multipath transmission channel which necessitates the use of an equalizer as part of the de-spreading unit. The method provides a transmission method of separating  $K$  parallel channels into the two  
 10 groups, in which a total of  $(K-m)$  channels are in one group and a total of  $m$  channels are in the other group.

In such embodiments, the method involves finding the number of channels in each group and allocating energies  $E_k(b_p)$  for  $k=1, \dots, (K-m)$  and  $E_k(b_{p+1})$  for  
 $k=(K-m+1), \dots, K$  when encountering a system which requires the use of an  
 15 equalizer as part of the de-spreading unit. The first step to calculate the number  $m$  involves the calculation of the energies  $E_k(b_p)$  and the data rate  $b_p$  to be transmitted over all the low data rate channels. The number of channels  $m$  to transmit data at the increased rate  $b_{p+1}$  is initially set to be  $m=0$  and the data rate  
 $b_p$  to be transmitted over a total of  $(K-m)$  channels is obtained using equation (3)  
 20 and a modification of the method described in Solution 3. The total residual energy is calculated using  $E_T - \sum_{k=1}^K E_k(b_p)$ . For the calculation of the number,  $m$ , of channels

that carry the data at a rate  $b_{p+1}$  bits per symbol, equation (4) will be modified to the form

$$\sum_{j=1}^m e_{I,j}(b_p) \leq E_T - \sum_{k=1}^K E_k(b_p) < \sum_{j=1}^{m+1} e_{I,j}(b_p) \quad (6)$$

where the incremental energy  $e_{I,j}(b_p) = E_j(b_{p+1}) - E_j(b_p)$  is the minimum additional

5 energy required to transmit data at a rate  $b_{p+1}$  instead of transmitting the data at a rate  $b_p$  bits per symbol over each channel  $j = 1, \dots, m$ . The  $m$  value is increased to

1. For the incremental energy calculations, for each channel in turn the energy  $E_k(b_{p+1})$  is calculated recursively when transmitting the data at the increased rate  $b_{p+1}$  bits per symbol, whilst keeping the energies for all other channels at  $E_j(b_p)$  for

10  $j = 1, \dots, K$  and  $j \neq k$  using the following relationship

$$E_{k,i}(b_{p+1}) = \frac{\Gamma(2^{b_{p+1}} - 1)}{\gamma_{k,i}} E_{k,i-1}(b_{p+1}) \quad (7)$$

for  $i = 1, 2, 3, \dots$ . When the energy  $E_k(b_{p+1})$  converges to a steady value  $E_k(b_{p+1})$  for

$k = 1, \dots, K$ , the incremental energy  $e_{I,k}(b_p) = E_k(b_{p+1}) - E_k(b_p)$  for each channel is

calculated. For the channel which requires the minimum incremental energy

15  $e_{I,j}(b_p)$ , if the incremental energy satisfies the inequality  $e_{I,k}(b_p) \leq E_T - \sum_{k=1}^K E_k(b_p)$ ,

the channel with the minimum incremental energy is organized to transmit the data

at the increased rate  $b_{p+1}$  bits per symbol and all the remaining channels are

allocated the data rate  $b_p$ . For the channel with the minimum incremental energy,

the energy  $E_{k,i}(b_{p+1})$  required to transmit the data at the rate  $b_{p+1}$  is allocated. For

each of the remaining channels the energy  $E_{k,i}(b_{p+1})$ , which is required to transmit the data at the rate  $b_{p+1}$  whilst keeping the energy at  $E_k(b_p)$  for all other channels that are earmarked to transmit the data at the rate  $b_p$ , is calculated iteratively using equation (7) together with the calculations for the de-spreading filter coefficients and the channel SNRs  $\gamma_{k,i}$ . The convergent energy values  $E_k(b_{p+1})$  are used to calculate the incremental energies  $e_{I,k}(b_p)$  for the channels which were originally allocated to transmit data at a rate  $b_p$ . The  $m$  value corresponding to the number of channels in the high data rate group is increased to  $m = m + 1$ , and the minimum incremental energy is used to test the inequality given in equation (6). If the inequality is not satisfied the data rate for the channel which requires the minimum incremental energy is increased to  $b_{p+1}$  bits per symbol. Next, the energy values  $E_k(b_{p+1})$  for the channels which are earmarked to transmit the data at the rate  $b_{p+1}$  are calculated using the iterative process corresponding to equation (7) whilst keeping the energy values for all other channels at  $E_k(b_p)$ . The incremental energies  $e_{I,k}(b_p)$ , which are required to increase the data rate to  $b_{p+1}$  bits per symbol, are calculated for all the channels earmarked to carry data at a rate  $b_p$ . The process of increasing the data rate to  $b_{p+1}$  bits per symbol for each channel with the minimum incremental energy is repeated for an increased value of  $m$  until the inequality in equation (6) is satisfied. The resultant number  $m$  which satisfies the inequality is then used as the number of channels required to transmit the data at a rate  $b_{p+1}$  bits per symbol. The remaining number  $(K - m)$  of channels are then used to transmit

the data at a rate  $b_p$  bits per symbol. By adjusting the number  $m$  and  $(K - m)$  of channels in two groups it is possible to transmit the number of bits per symbol at two different rates. This approach may enable the *HSDPA* system to transmit the data at a total rate higher than a system which uses the same data rate for each  
5 parallel channel.

#### *Solution 5*

In some embodiments, methods as defined in Claims 9 to 11 may be employed at a receiver in order to de-correlate or despread and decode the received signal. Such  
10 methods may be used when transmitting multicode CDMA signals over a channel which introduces multipath interference and necessitates the use of an equalizer as part of the de-spreading unit. In such embodiments, each channel will have outer and inner code rates and an associated modulation *4QAM*, *16QAM* or *64QAM* determined by the resource allocation unit at the transmitter unit and the control  
15 unit at the receiver. Over a dedicated channel, the identity of each channel carrying the low data rate  $b_p$  and the high data rate  $b_{p+1}$  will be transmitted from the resource allocation unit at the transmitter to the control unit at the receiver. The transmitted information will also include the energies allocated to each channel, as well as the inner and outer code rates and the type of modulation (i.e. whether they  
20 are *4QAM*, *16QAM* or *64QAM*). In a manner well known to those skilled in the art [14], the energy level for each channel may be used by the control unit at the receiver together with the multipath channel impulse response and the spreading

sequences to calculate the equalizer coefficients to incorporate the coefficients into the despreading filter coefficients for that specific channel. The code rates and the modulation type will be obtained by the control unit from the resource allocation unit at the transmitter over a dedicated control channel and will be fed to a Turbo  
5 decoder to initiate decoding of a block of data, collected from the output of each despreading unit, using a method similar to the one [15] in a manner well known to those familiar with Turbo decoding systems. For the high and low data rate group channels, two different types of decoders will be used. Each block of data decoded using the Turbo decoder may be *CRC* (cyclic redundancy checking) tested to verify  
10 the integrity of the received data. Each Turbo decoder may be used to produce a soft information, in a manner familiar to those skilled in the art, for further use in an iterative decoding process as described in the section headed "Solution 6" below. By using a despreading/equalizing unit and demodulating each one with a decoder/demodulator operating at a different rate for each channel in a multicode  
15 *CDMA* system, higher transmission rates may be achieved compared with a multicode system operating each channel at a fixed rate.

#### *Solution 6*

In order to transmit data with reduced granularity or resolution for a multicode  
20 *CDMA* system, in some embodiments a method as defined in Claims 12 or 13 of the appended claims may be employed. In such embodiments, a collection of capacity approaching coding and modulation schemes are used. The coding scheme is organized to have an outer and inner code. By adjusting the outer and inner code

rates together with the number of bits carried by  $4QAM$  or  $16QAM$ , data rates are produced with distinctive values with small and approximately equal granularity between the adjacent data rates. The outer encoder takes a total of  $x$  packets of  $L$  digits and produces an additional packet of  $L$  digits. Each packet of  $L$  digits is

5 generated using the digits of the incoming packet and also cyclic redundancy digits which are generated in a manner that is well known to those skilled in the art and appended to the incoming digits. The additional packet is known as the parity packet which is an EXCLUSIVE-OR combination of the  $x$  incoming packets. With the outer encoder, a rate  $\frac{x}{x+1}$  is achieved by taking a total of  $x$  incoming packets. The group

10 of  $x+1$  packets are referred to as the *CPP* (Coded Parity Packets) group. For a given packet in the *CPP* group, the remaining packets are said to belong to a set of associated packets. Each packet is then individually encoded using a Turbo encoder a type which is well known in the art. The resultant transmission rate is  $\frac{x}{x+1} r_t b$  where  $r_t$  is the Turbo encoder rate and  $b$  is the number of bits carried by the

15 modulation scheme. By using the data rates generated in this manner, a better bit granularity may be achieved to improve the data rate for the multicode systems.

The method may further comprise an iterative message passing and channel decoding method which operates between the packets belonging to a *CPP* group to

20 improve the detection quality of the received data packets for multicode *CDMA* systems, as defined in Claims 14 or 15 of the appended claims. In the *CPP* group

packets, when considering a given transmission packet, all other packets in the CPP group are known as the packets associated to the transmitted packet. Each packet, in the CPP group, is further decoded using a combination of the soft information of its associated packets. This process is repeated until each packet is correctly decoded or until the iteration number reaches a predetermined value. This iterative decoding process improves the detection quality of the received packets compared with the single Turbo decoding process for multicode CDMA systems.

A second aspect of the present invention provides transmitter apparatus configured to implement a method in accordance with the first aspect of the invention.

A third aspect of the present invention provides receiver apparatus configured to implement a method in accordance with the fourth aspect of the invention.

A fourth aspect of the present invention provides a telecommunications system comprising a transmitter in accordance with the second aspect of the invention, and one or more receivers in accordance with the third aspect of the invention.

Preferable, optional, features are defined in the dependent claims.

20

## **BRIEF DESCRIPTION OF THE DRAWINGS**

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

Figure 1 illustrates the transmitter of a high-speed downlink packet access scheme known from the prior art (Reference 1);

Figure 2 illustrates the receiver of a high-speed downlink packet access scheme known from the prior art (Reference 1);

5 Figure 3 illustrates the transmitter of a system according to an embodiment of the present invention; and

Figure 4 illustrates the receiver of a system according to an embodiment of the present invention, being operable with the transmitter of Figure 3.

## 10 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present embodiments represent the best ways known to the applicant of putting the invention into practice. However, they are not the only ways in which this can be achieved. Initially an example is given to show how the residual energy in the

15 *HSDPA* system can be used to increase the total number of transmitted bits.

The methods described in this work may be automatically initiated or used when the amount of data gathered at the transmitter is greater than the amount of data that can be carried in a block over the total number of available parallel channels. This  
20 may be done on an ongoing basis, or at regular or irregular intervals, whenever a user is granted access to the channels.

When considering the *HSDPA* system and the data rate  $b_p \in \left\{ \frac{1}{2}, 1, \frac{3}{2}, 2, 3 \right\}$



bits per channel, the total number of bits that can be transmitted over  $K=15$  channels is  $b_T = Kb_p = 7.5, 15, 22.5, 30$  and  $45$  bits. In the *HSDPA* example considered here it is not possible to produce the total number of bits between 30 and 45 with the bit loading method which uses  $b_T = Kb_p$ . When transmitting a total

5 of 30 bits and 45 bits the total required energies will be  $90 \frac{\Gamma \sigma^2}{h}$  and  $210 \frac{\Gamma \sigma^2}{h}$  respectively. In the example considered here, if the total available energy is  $E_T = 201 \frac{\Gamma \sigma^2}{h}$  it is then possible to transmit a total of 30 bits. However having a large gap of 15 bits between 30 and 45 results in a large residual energy of  $e_R = 111 \frac{\Gamma \sigma^2}{h}$  which may not be used to transmit any useful information. More

10 than half of the total available energy may not be used by the *HSDPA* system.

An illustrative example of one embodiment of the invention will now be described herein with reference to equation (8) to show how the residual energy can be reduced when using the two group approach described in this work and be kept very

15 small compared with the energy allocation approach adapted by the *HSDPA* standard [1, 2, 3]. The example considers the case where the total transmission energy  $E_T$  is limited and the total number of bits to be carried over all the available channels will be maximized. In the example a multipath interference-free transmission model is considered.

The  $K \times P$  dimensional matrix  $C_{K \times P}$  given in equation (8), for  $K=15$  and  $P=5$ , is generated by taking the number of bits  $b_p \in \left\{ \frac{1}{2}, 1, \frac{3}{2}, 2, 3 \right\}$  as the first row of the matrix. The remaining rows  $k=1, \dots, K$  are generated by multiplying the first row by the row number  $k$ .

$$C_{K \times P} = \begin{bmatrix} 0.5 & 1 & 1.5 & 2 & 3 \\ 1 & 2 & 3 & 4 & 6 \\ 1.5 & 3 & 4.5 & 6 & 9 \\ 2 & 4 & 6 & 8 & 12 \\ 2.5 & 5 & 7.5 & 10 & 15 \\ 3 & 6 & 9 & 12 & 18 \\ 3.5 & 7 & 10.5 & 14 & 21 \\ 4 & 8 & 12 & 16 & 24 \\ 4.5 & 9 & 13.5 & 18 & 27 \\ 5 & 10 & 15 & 20 & 30 \\ 5.5 & 11 & 16.5 & 22 & 33 \\ 6 & 12 & 18 & 24 & 36 \\ 6.5 & 13 & 19.5 & 26 & 39 \\ 7 & 14 & 21 & 28 & 42 \\ 7.5 & 15 & 22.5 & 30 & 45 \end{bmatrix} \quad (8)$$

The second column in this matrix is used for two purposes: as the row number counter and also the total number of bits to be carried over the number of channels corresponding to the row number when using a data rate  $b_2 = 1$  bit per channel. The entries in the  $p^{\text{th}}$  column identify the total number of bits to be carried over the number of channels corresponding to the row number when using a data rate equal to the first element of the  $p^{\text{th}}$  column. For instance the entries in the fifth column identify the total number of bits to be carried over the number of channels

corresponding to the row number when using a data rate  $b_5 = 3$  bit per symbol. As an example consider the entry of row 8 at column 4 which identifies the total number of bits to be 16 over 8 channels when each channel carries  $b_4 = 2$  bits.

5 In the example considered here, it is assumed that the total available energy is

$$E_T = 201 \frac{\Gamma \sigma^2}{h} \text{ and a total of } K = 15 \text{ channels are available together with the bit}$$

allocation matrix  $C$  given in equation (8) for use in the calculation of the total

number of bits. As the total available energy  $E_T$  is between  $E(Kb_4) = 90 \frac{\Gamma \sigma^2}{h}$  and

$$E(Kb_5) = 210 \frac{\Gamma \sigma^2}{h}, \text{ the numbers of bits to be transmitted in two groups become}$$

10  $b_4 = 2$  and  $b_5 = 3$  bits per channel respectively. The actual number of total bits that

can be carried over  $K = 15$  channels will be between the minimum and maximum

total number of bits which are given to be  $Kb_4 = 30$  bits and  $Kb_5 = 45$  bits as the

entries of the the last row of columns 4 and 5 of matrix  $C$  given in equation (8). To

find the actual number of bits carried by  $K = 15$  channels the residual energy is

15 calculated to be  $e_R(Kb_4) = E_T - E(Kb_4) = 111 \frac{\Gamma \sigma^2}{h}$  energy units for the case when a

$$\text{total of 30 bits is transmitted, together with the incremental energy } e_I(b_4) = 8 \frac{\Gamma \sigma^2}{h}$$

which is the additional energy required to transmit  $b_5 = 3$  bits instead of  $b_4 = 2$  bits

over a channel. Next the residual energy  $e_R(Kb_4)$  is compared with the integer

multiples of the incremental energy  $e_I(b_4)$  to determine which integer multiple of

the incremental energy has the largest value which is smaller than the residual energy. The multiplications of the incremental energy  $e_I(b_4)$  with two consecutive integers 13 and 14 produce the values  $13e_I(2)=104\frac{\Gamma\sigma^2}{h}$  and  $14e_I(2)=112\frac{\Gamma\sigma^2}{h}$

such that the residual energy  $e_R(Kb_4)=111\frac{\Gamma\sigma^2}{h}$  lies between the two. It is then

5 identified that the multiplication of integer 13 with the incremental energy

$e_I(b_4=2)$  produces the largest value  $13e_I(2)=104\frac{\Gamma\sigma^2}{h}$  which is smaller than the

total residual energy  $e_R(Kb_4)=111\frac{\Gamma\sigma^2}{h}$ . This integer number 13 is then taken as the

number  $m=13$  of channels which will be used to transmit the data at a rate of

$b_5=3$  bits. The number  $m=13$  is then used to read the entry, at column 5 and row

10  $m=13$  of the matrix in equation (8), to obtain the total number of bits as

$m \times b_5 = 39$  over  $m=13$  channels. The number of channels  $(K-m)=2$  is then used

to read the entry of row  $(K-m)=2$  at column 4 when identifying the total number

of bits transmitted over  $(K-m)=2$  channels. The total number of bits carried over

$K=15$  channels is  $b_T=(15-13) \times 2 + 13 \times 3 = 43$  bits. The total required energy is

15  $E(43)=E(Kb_2)+13e_I(b_4)=194\frac{\Gamma\sigma^2}{h}$  energy units. When using the two group bit

loading algorithm, the total number of bits transmitted is increased to 43 bits per

symbol period instead of 30 bits that can be carried by the current *HSDPA* system.

The unused residual energy is reduced from  $e_R(Kb_4)=111\frac{\Gamma\sigma^2}{h}$  units of energy to a

total of  $7 \frac{\Gamma \sigma^2}{h}$  energy units.

### The transmitter

The principal elements of the transmitter and the receiver considered in this work are shown in Figures 3 and 4 respectively when using a system with a total of  $K$  parallel channels. At the transmitter of the system one data source is considered, where each data source may correspond to a single user and the data is fed to two different multiplexer units 42 via the links 51,1 and 51,2. The operations performed at the multiplexers on data from the data source are similar and for purposes of illustration, consideration will be restricted to the method of operation as applied to one multiplexer. The output from the multiplexer 42 at the top of Figure 3 is fed to  $m$  different parallel channels via the links 52,1 to 52,m. The output from the multiplexer 42 at the bottom of Figure 3 is fed to  $(K - m)$  different parallel channels via the links 52,( $m+1$ ) to 52, $K$ . The operations performed on data over each channel are similar and for purposes of illustration, consideration will be restricted to the method of operation as applied to first channel. At 42, binary data is taken from the source 1 in blocks. The blocks may contain  $mxL$  binary digits. These digits are fed to a serial-to-parallel converter 42 which divides the sequence of  $mxL$  digits into  $m$  separate sub-blocks each consisting of  $xL$  digits.  $L$  is chosen to be the packet length used to transmit data.  $x$  is determined by the resource allocation unit 48.  $x$  has different values for the multiplexers 42 at the top and bottom of Figure 3.

The first sub-block of  $xL$  digits is fed at 52,1 to an outer channel encoder 43. The second sub-block of  $xL$  digits is fed at 52,2 to second channel encoder which may be the same as 43. Likewise, the remaining sub-blocks, each of  $xL$  digits are fed to corresponding outer channel encoders. From the point of operation, each sub-  
 5 channels  $1, \dots, m$  functions in the same way hence, from hereon, consideration will be devoted to sub-channel 1.

At sub-channel 1, the first sub-block of  $xL$  digits is divided into  $x$  packets each consisting  $L$  digits. The outer encoder unit 43, known as the CPP Grouping unit,  
 10 takes the  $x$  packets each of  $L$  digits and combines them using an EXCLUSIVE-OR operation to produce an additional packet of  $L$  digits. With the additional packet, the outer encoder operates at a rate  $\frac{x}{x+1}$ . When using values  $x = 2, 3, 4, 5, 6, \dots$  it is possible to operate the outer encoder at rates  $\frac{2}{3}, \frac{3}{4}, \frac{4}{5}, \frac{5}{6}, \dots$ . The CPP grouping unit  
 43 feeds at 53 each of  $(x+1)$  packets of  $L$  digits in turn to an inner Turbo encoder  
 15 44 of a type well known in the art.

The inner encoder 44 produces check sum digits for each packet of length  $L$  digits and encodes the resultant data packet using a Turbo encoder which increases the packet length to  $L_c$  digits. The inner Turbo encoder 44 operates at a rate  $r_I$  which is  
 20 determined by the resource allocation unit 48. The inner encoder 44 produces a packet of  $y = \frac{L_c}{r_I}$  digits for each of  $x+1$  packets in turn.

After channel encoding, the binary digits appearing at 54 are fed into an  $M$ -ary modulation unit 45 of a type well known in the art. The modulation unit 45 operates using a total of  $M$  constellation points which is determined by the resource allocation unit 48. The  $M$ -ary modulation unit 45 takes in sequence a total of  $b = \log_2 M$  binary digits of data every symbol period from the incoming  $x+1$  packets of length  $L_c$  digits. The modulation unit produces one of  $M$  symbols at 55 for each of  $b$  binary digits.

10 The signals which appear at 55 are then each fed to a spreading code sequence generator 46 where, in a manner well known to those familiar with spread spectrum systems, each  $M$ -ary modulation symbol is multiplied by the same spreading sequence. It will be appreciated that the spreading code sequence differs for each of the sub-channels employed by each user, and also differs from user to user. The  
15 outputs from the spreading code sequence generator which appear at 56, the chips as they are well known in the art, are then fed to a power control unit 47 which adjusts the energy for each symbol before transmission. The energy level used by each sub-channel is determined by the resource allocation unit 48.

20 The resource allocation unit 48 communicates with the control unit 64 at the receiver via a control channel over the uplink 58,4,1 and over the downlink 58,4,2. The resource allocation unit 48 uses the link 58,1,1 to send the value  $x$  which

identifies the number of packets to be used by the outer encoder, or the CPP Grouping, unit 43 when generating the additional packet which is the EXCLUSIVE-OR combination of  $x$  packets of  $L$  digits. The resource allocation unit 48 uses the link 58,2,1 to send the rate  $r_I$  information to the inner encoder unit 44. The resource allocation unit 48 uses the link 58,3,1 to send the energy level information to the power control unit 47. The resource allocation unit 48 uses the link 58,5,1 to send the modulation level information  $b$  to the  $M$ -ary modulation unit 45. The resource allocation unit 48 uses the link 58,6,1 to send the spreading sequence code information to the spreading unit 46.

10

At the resource allocation unit 48, different combinations of the outer code rates

$\frac{x}{x+1} \in \left\{1, \frac{3}{4}, \frac{4}{5}, \frac{5}{6}, \frac{6}{7}, \frac{7}{8}, \frac{11}{12}\right\}$ , the inner code rates  $r_I \in \left\{\frac{1}{2}, \frac{2}{3}, \frac{3}{4}\right\}$  and also the

number of bits  $b \in \{2, 4, 6\}$  for the  $M$ -ary QAM transmission signals are available to define different number of bits  $b_p$  per symbol, as listed in Table 2, for varying  $TRFC$

15 values when transmitting symbols over each sub-channel. Note that the outer code rate 1 corresponds to  $x=1$  without any parity packet.

| $p$ | $b_p$ | $b$ | $r_I$         | $\frac{x}{x+1}$ |
|-----|-------|-----|---------------|-----------------|
| 1   | 0.5   | 2   | $\frac{1}{4}$ | 1               |
| 2   | 0.75  | 2   | $\frac{1}{2}$ | $\frac{3}{4}$   |
| 3   | 1     | 2   | $\frac{1}{2}$ | 1               |



|    |       |   |               |                 |
|----|-------|---|---------------|-----------------|
| 4  | 1.25  | 2 | $\frac{3}{4}$ | $\frac{5}{6}$   |
| 5  | 1.375 | 2 | $\frac{3}{4}$ | $\frac{11}{12}$ |
| 6  | 1.5   | 2 | $\frac{3}{4}$ | 1               |
| 7  | 1.75  | 4 | $\frac{1}{2}$ | $\frac{7}{8}$   |
| 8  | 2     | 4 | $\frac{1}{2}$ | 1               |
| 9  | 2.25  | 6 | $\frac{1}{2}$ | $\frac{3}{4}$   |
| 10 | 2.5   | 4 | $\frac{3}{4}$ | $\frac{5}{6}$   |
| 11 | 2.75  | 4 | $\frac{3}{4}$ | $\frac{11}{12}$ |
| 12 | 3     | 6 | $\frac{1}{2}$ | 1               |
| 13 | 3.2   | 6 | $\frac{2}{3}$ | $\frac{4}{5}$   |
| 14 | 3.5   | 6 | $\frac{2}{3}$ | $\frac{7}{8}$   |
| 15 | 3.75  | 6 | $\frac{3}{4}$ | $\frac{5}{6}$   |
| 16 | 4.0   | 6 | $\frac{2}{3}$ | 1               |
| 17 | 4.125 | 6 | $\frac{3}{4}$ | $\frac{11}{12}$ |
| 18 | 4.5   | 6 | $\frac{3}{4}$ | 1               |

Table 2: Modified symbol rates for different increased number of TRFC values

In a manner well known to those familiar with the spread spectrum systems, the

5 minimum required SNR  $\gamma_p^* = \Gamma(2^{b_p} - 1)$  at the output of the de-spreading unit for a

given number of bits  $b_p$  is also available at the resource allocation unit 48 for

$p=1, \dots, 18$ . Before the initiation of the transmission of  $x$  packets of  $xL$  digits of

data, unit 48 uses the control channels 58,4,1 and 58,4,2 to obtain the information related to the multipath channel impulse response, the channel gain  $h$  and also the noise variance  $\sigma^2$  from the receiver in a manner well known to those experienced in the field of data transmission. The resource allocation unit 48 then calculates the

5 minimum energy  $E_p$  required to transmit the data at a rate of  $b_p$  bits per symbol using the equation  $E_p = \frac{2\sigma^2}{h} \gamma_p^*$  which is well known in the art. For a given available total energy value  $E_T$ , the resource allocation unit 48 then runs the method described in the sections headed "Solution 3" and "Solution 4" above, in order to determine the two consecutive bit rates  $b_p$  and  $b_{p+1}$  to be used as part of the two

10 group bit rate allocation algorithm described in this work. After having identified the rates  $b_p$  and  $b_{p+1}$ , the resource allocation unit 48 uses these values and also Table 2 to determine the number of packets  $x$ , the inner code rate  $r_I$  and the number of bits  $b$  to be carried by the  $M$ -ary QAM modulation channels over the sub-channels carrying the low data rate  $b_p$  and high data rate  $b_{p+1}$  symbols. When completing the

15 identification of the parameters  $x$ ,  $r_I$  and  $b$  for the two sub-groups of channels, the resource allocation unit 48 does not have a clear idea how many codes will be used or which codes will be placed in either group.

The resource allocation unit 48 then runs the method described in the sections

20 headed "Solution 3" and "Solution 4" above, to determine the number of channels  $m$  and  $(K-m)$  in two sub-groups for the multicode system with  $K$  parallel

channels. When completing the recursive calculations, unit 48 separates  $K$  different spreading code sequences into groups of  $m$  and  $K-m$  codes and places the spreading sequences corresponding to the  $m$  high bit rate,  $b_{p+1}$ , channels into the spreading units given at the top of Figure 3 via the link 58,6,1. The remaining codes  
 5 are placed into the spreading units at the bottom of Figure 3 via the links 58,6,2. The resource allocation unit 48 then sends the  $x$  value to the outer encoder or the CPP unit 43 via the link 58,1,1. The resource allocation unit 48 sends the inner code rate  $r_i$  to the inner encoder 44 via the link 58,2,1. The resource allocation unit 48 sends the number of bits  $b$  to be carried by the  $M$ -ary modulator 45 via the link 58,5,1.  
 10 The resource allocation unit 48 sets the energy values to be used by the power adjustment unit 47 via the link 58,3,1.

After having completed the loading of the CPP or the outer encoder unit 43, the inner encoder 44, the  $M$ -ary modulator 45, the spreading unit 46, and the power  
 15 control unit 47 with the appropriate control parameters  $x$ ,  $r_i$  and  $b$  and also the energy levels,  $xL$  binary digits are then processed by units 43, 44, 45, 46 and 47. The signals of the  $m$  high data rate and the  $(K-m)$  low data rate channels appearing at 57 are then added together in adders 49 prior to feeding them to the transmission channel at 59. It will be appreciated that pass-band modulation and demodulation  
 20 may be involved and Figures 3 and 4 represent the equivalent baseband schemes in the current work.

## The receiver

Figure 4 shows an illustration of the receiver of the system, operable with the transmitter described above. At 59, signals are received from the channel and are fed to a bank of  $K$  de-spreading units 60 with each of the de-spreading units operating as inverse of the spreading code sequence generator 46 employed at the transmitter in a manner that is well known to those skilled in the art of spread spectrum communication. The de-spreading unit coefficients are also organized to incorporate the coefficients of an equalizer to remove the effects of the intersymbol interference introduced by the multipath channel impulse response. At the output 10 72,1 of the de-spreader unit 61 the de-spread signal samples are fed to a buffer 62,1. The signals appearing at 72,1 correspond to the noise corrupted version of the modulated signal samples appearing at the output 56 of the  $M$ -ary modulation unit 45.

15 The blocks of  $(x+1)L_c$  the noise corrupted version of the  $M$ -ary modulated symbols appearing 72,1 are fed to a total of  $(x+1)$  buffers each storing  $L$  the noise corrupted  $M$ -ary symbol samples. The actual value of  $x$  changes from transmission to transmission depending on the outer encoder code rate and is obtained by the control unit 66 at the receiver from the resource allocation unit 48 at the transmitter 20 via the control channels 58,4,1 and 58,4,2. The different values  $x$  takes are listed in Table 2, the receiver block diagram given in Figure 4 is for the value of  $x = 2$  and a total of 3 buffers are used to collect noise corrupted  $M$ -ary signal symbols of block

length of  $L_c$ . After having collected a total of  $(x+1)L_c$   $M$ -ary signal symbols in the buffers, each block of  $L_c$  symbols appearing at the output of each buffer 73,1 and 73,2 and also 73,3 are fed to the Turbo decoders 63,1 and 63,2 and also 63,3.

- 5 Each Turbo decoder 63,1 acts as an  $M$ -ary demodulator and also as a channel decoder in a manner that is well known to those skilled in the art of channel encoding and decoding [15]. The rate  $r_I$  Turbo decoder uses is provided by the resource allocation unit 48 at the transmitter to the control unit 65 at the receiver via the link 58,4,2. The control unit sends the rate  $r_I$  to the Turbo decoder 73,1 via
- 10 the link 76. The Turbo decoder decodes the packet of length  $L_c$  and produces the log likelihood ratios (LLR) for each packet binary digit of length  $L$ . The log likelihood ratios include both the a posteriori LLRs and the extrinsic LLRs both of which appear at the output of the Turbo decoder at 78,1. The a posteriori and extrinsic LLR are fed to the outer decoder unit 64 at 78,1. The outer encoder unit 64 combines the
- 15 extrinsic LLRs corresponding to the associated packets of a packet decoded by one of the Turbo decoders to produce the a priori LLRs for that specific Turbo decoder in a manner well known to those skilled in the art of Turbo decoding [16]. The a priori probabilities produced from the associated set of packets for a given Turbo encoder are then fed back at 77,1 to the Turbo decoder to re-run the Turbo decoder for a
- 20 given number of iterations. After a number of iterations of the extrinsic and the a priori LLRs for each of the Turbo decoders, the outer decoder uses the a posteriori probabilities from each Turbo decoder to produce the decoded  $x$  packets and

outputs the decoded binary digits of length  $xL$  at 74.

## Applications

- 5 The techniques and embodiments described above are suitable for the transmission of data in a mobile network, e.g. in a 3G CDMA network. It should be noted, however, that their application is not limited to CDMA, and could, for example, be used in encryption devices or modulators for non-CDMA applications.

## 10 Technical construction

- The "units" in the transmitter, such as the channel encoder 43, the *M*-ary modulation unit 45, the spreading unit 46, the power control unit 47, the resource allocation unit and the adder 49, may be provided as separate pieces of equipment  
15 or discrete components or circuits that are communicatively connected in order to enable the signal processing methods described herein to be performed. Alternatively, two or more of the "units" may be integrated into a single piece of equipment, or provided as a single component or circuit. In further alternatives, one or more of the "units" may be provided by a computer processor programmed to  
20 provide equivalent functionality.

- Similarly, the "units" in the receiver, such as the de-spreading unit 61, the buffer unit 62, the Turbo decoder unit 63, the outer decoder unit 64, and the control unit 65 may be provided as separate pieces of equipment or discrete components or circuits  
25 that are communicatively connected in order to enable the signal processing

methods to be performed. Alternatively, two or more of the "units" may be integrated in a single piece of equipment, or provided as a single component or circuit. In further alternatives, one or more of the "units" may be provided by a computer processor programmed to provide equivalent functionality.

5

In some instances, the sequence of the units in the transmitter or the receiver may be changed, as those skilled in the art will appreciate.

## SUMMARY

10

A method has been described for improving the capacity of communication channels. We have presented a technique for capacity optimization, using a two group discrete bit loading algorithm for communicating over multiple parallel channels. The algorithm divides a group of channels into two groups and determines the number of channels in each of the two groups. The algorithm may also be used to select the spreading codes and the type of modulation and channel coding used to spread and modulate transmitted data over a radio transmission connection, as well as improving the use of adaptive modulation and channel coding in the High Speed Data Packet Access (*HSDPA*) and multi-code *CDMA* communication system.

20

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## **CLAIMS**

1. A method of transmitting data in a data transmission system having a plurality of channels, the method comprising:
  - transmitting a first group of data at a first bit rate over a first group of
  - 5 one or more channels; and
  - transmitting a second group of data at a second bit rate over a second group of one or more channels.
2. A method as claimed in Claim 1, further comprising:
  - 10 transmitting a known bit sequence to a receiver;
  - measuring, at the receiver, values representative of the quality of transmission of the said bit sequence; and
  - feeding back the measured values from a control unit at the receiver to a resource allocation unit at the transmitter, the resource allocation unit
  - 15 using the said values to iteratively update one or more variable parameters governing the distribution of the data into the first and second groups.
3. A method as claimed in Claim 2, wherein the measured values are fed back to the resource allocation unit via a dedicated control channel.
- 20 4. A method as claimed in Claim 2 or Claim 3, wherein the measured values are one or more of the transmission path gain, the multipath channel impulse response, and the noise variance at the receiver.
- 25 5. A method as claimed in Claim 4, wherein the resource allocation unit at the transmitter uses the channel gain, the multipath channel impulse response and the receiver noise variance, and also the energy allocated to each channel, to calculate the despreading filter coefficients for all the receivers for  $K$  parallel channels whilst incorporating an equalizer into the

despreading unit.

6. A method as claimed in any preceding claim, using one or more transmitters having total available energy  $E_T$ , the method further comprising:

5 determining a number of parallel channels,  $K$ , on which to transmit data, the number of channels being greater than one; and

determining the minimum energy  $E_p$  required to transmit data at a rate of  $b_p$  bits per symbol, and the minimum energy  $E_{p+1}$  required to transmit data at an increased rate of  $b_{p+1}$  bits per symbol,  $b_{p+1}$  requiring a minimal incremental energy increase with respect to  $b_p$  ;

10

wherein  $K$ ,  $E_p$  and  $E_{p+1}$  are controlled by a resource allocation unit at the transmitter(s) such as to satisfy the inequality  $KE_p \leq E_T < KE_{p+1}$  ;

the method further comprising:

transmitting the first group of data at the rate of  $b_{p+1}$  bits per symbol over  $m$  channels; and

15

transmitting the second group of data at the rate of  $b_p$  bits per symbol over  $K-m$  channels;

wherein the number of channels  $m$  and the rates  $b_{p+1}$  and  $b_p$  are controlled by the resource allocation unit such as to satisfy the inequality

20

$$m e_I(b_p) \leq E_T - KE_p < (m+1) e_I(b_p) ;$$

where  $e_I(b_p)$  is the minimum additional energy required to transmit the data at the rate of  $b_{p+1}$  bits per symbol rather than at the rate of  $b_p$  bits per symbol;

$K$ ,  $m$ ,  $E_p$ ,  $E_{p+1}$ ,  $b_{p+1}$  and  $b_p$  being variable parameters.

25

7. A method as claimed in Claim 6, wherein an optimum energy allocation is iteratively updated at the transmitter using a recursive equation of the form

$$E_{k,i}(b_p) = \frac{\Gamma(2^{b_p} - 1)}{\gamma_{k,i}} E_{k,i-1}(b_p), \text{ where } i = 1, 2, 3, \dots \text{ is the iteration number, and}$$

- the term  $\Gamma(2^{b_p} - 1)$  is the minimum target signal-to-noise ratio to be reached at the output of the despreading unit if the data is to be transmitted at a rate  $b_p$  bits per symbol over each channel;

wherein, at the transmitter:

- the resource allocation unit iteratively adjusts the transmission energy  $E_k(b_p)$  and the equalizer coefficients and measures the signal-to-noise ratio,  $\gamma_{k,i}$ , at the output of each despreading unit until the energy values converge to their final values;

- the converged energy values are then taken as the minimum energy  $E_k(b_p)$  required to transmit data at a rate  $b_p$  bits per symbol over each channel  $k = 1, \dots, K$ , in which  $K$  is an optimum value upper-bounded by the maximum number of available parallel channels;

- the energy calculations  $E_k(b_p)$  are then repeated for all possible values of the TRFC number  $p = 1, \dots, P$  and are used to check which energy values corresponding to a specific data rate  $b_p$  bits per symbol for the optimum  $K$  value satisfy the inequality  $\sum_{k=1}^K E_k(b_p) \leq E_T < \sum_{k=1}^K E_k(b_{p+1})$ ; and

- the specific data rate  $b_p$  value is then taken by the resource allocation unit as the data rate to be transmitted over one group of channels, and the data rate  $b_{p+1}$  is taken as the data rate to be transmitted over the other group of channels.

8. A method as claimed in Claim 6 or Claim 7, further comprising the following steps at the transmitter for determining the number of channels  $m$ :

- (a) initially setting the number of channels  $m$  to be zero, so as to earmark all  $K$  channels for transmission of data at the rate  $b_p$  ;
- (b) determining the total residual energy using  $E_T - \sum_{k=1}^K E_k(b_p)$ ;
- (c) determining the number of channels  $m$  according to the inequality

$$\sum_{j=1}^m e_{I,j}(b_p) \leq E_T - \sum_{k=1}^K E_k(b_p) < \sum_{j=1}^{m+1} e_{I,j}(b_p) ;$$

where the incremental energy  $e_{I,j}(b_p) = E_j(b_{p+1}) - E_j(b_p)$  is the minimum additional energy required to transmit data at a rate  $b_{p+1}$  rather than at a rate  $b_p$  bits per symbol over each channel  $j=1, \dots, m$  , this step (c) comprising:

- (i) increasing the number of channels  $m$  to 1;
- (ii) for each channel in turn, recursively calculating the energy  $E_k(b_{p+1})$  for transmitting the data at the increased rate  $b_{p+1}$  bits per symbol whilst keeping the energies for all other channels at  $E_j(b_p)$  for  $j=1, \dots, K$  and  $j \neq k$ ;
- (iii) when  $E_k(b_{p+1})$  converges to a steady value  $E_k(b_{p+1})$  for  $k=1, \dots, K$ , calculating the incremental energy  $e_{k,I}(b_p) = E_k(b_{p+1}) - E_k(b_p)$  for each channel;
- (iv) for the channel which requires the minimum incremental energy  $e_{j,I}(b_p)$ , if the incremental energy satisfies the inequality  $e_{k,I}(b_p) \leq E_T - \sum_{k=1}^K E_k(b_p)$ , allocating the channel having the minimum incremental energy with the energy  $E_{k,I}(b_{p+1})$  to transmit data at the increased rate  $b_{p+1}$  bits per symbol, and allocating all the remaining channels to transmit data at the rate  $b_p$  bits per symbol;
- (v) for each of the remaining channels, iteratively calculating the energy  $E_{k,i}(b_{p+1})$  required to transmit the data at the rate  $b_{p+1}$

whilst keeping the energy at  $E_k(b_p)$  for all other channels that are earmarked to transmit the data at the rate  $b_p$ ;

(vi) using the convergent energy values  $E_k(b_{p+1})$  to calculate the incremental energies  $e_{k,l}(b_p)$  for the channels which were originally allocated to transmit data at a rate  $b_p$ ;

(vii) increasing the value of  $m$  to  $m = m + 1$ ;

(viii) testing the inequality  $\sum_{j=1}^m e_{I,j}(b_p) \leq E_T - \sum_{k=1}^K E_k(b_p) < \sum_{j=1}^{m+1} e_{I,j}(b_p)$

using the minimum incremental energy, and if the inequality is satisfied, proceed to step (d), but if the inequality is not satisfied, proceed to step (ix):

(ix) increasing the data rate for the channel which requires the minimum incremental energy to  $b_{p+1}$  bits per symbol;

(x) for the channels earmarked to transmit data at the rate  $b_{p+1}$ , iteratively calculating the energy  $E_k(b_{p+1})$  required to transmit the data at the rate  $b_{p+1}$  whilst keeping the energy at  $E_k(b_p)$  for all other channels;

(xi) repeating steps (vii) to (x) until the inequality in step (viii) is satisfied; and then

(d) transmitting the first group of data at the rate of  $b_{p+1}$  bits per symbol over  $m$  channels, and transmitting the second group of data at the rate of  $b_p$  bits per symbol over  $K-m$  channels.

9. A method as claimed in any preceding claim, wherein each channel has outer and inner code rates and an associated modulation, the method further comprising the following steps to cause the receiver to de-correlate or despread and decode a received signal:

(a) transmitting from the resource allocation unit at the transmitter to a

control unit at the receiver:

- (i) the identities of the first and second groups of channels,
- (ii) the energies allocated to each channel,
- (iii) the inner and outer code rates, and
- (iv) the modulation type; and

(b) feeding the code rates and the modulation type to a Turbo decoder to initiate decoding of a block of data collected from the output of each despreading unit;

wherein the first group of channels are decoded using decoders at a first rate, and the second group of channels are decoded using decoders at a second rate.

10. A method as claimed in Claim 9, further comprising using the energy level for each channel together with the multipath channel impulse response and the spreading sequences to calculate the equalizer coefficients to be incorporated into the despreading filter coefficients for that specific channel.

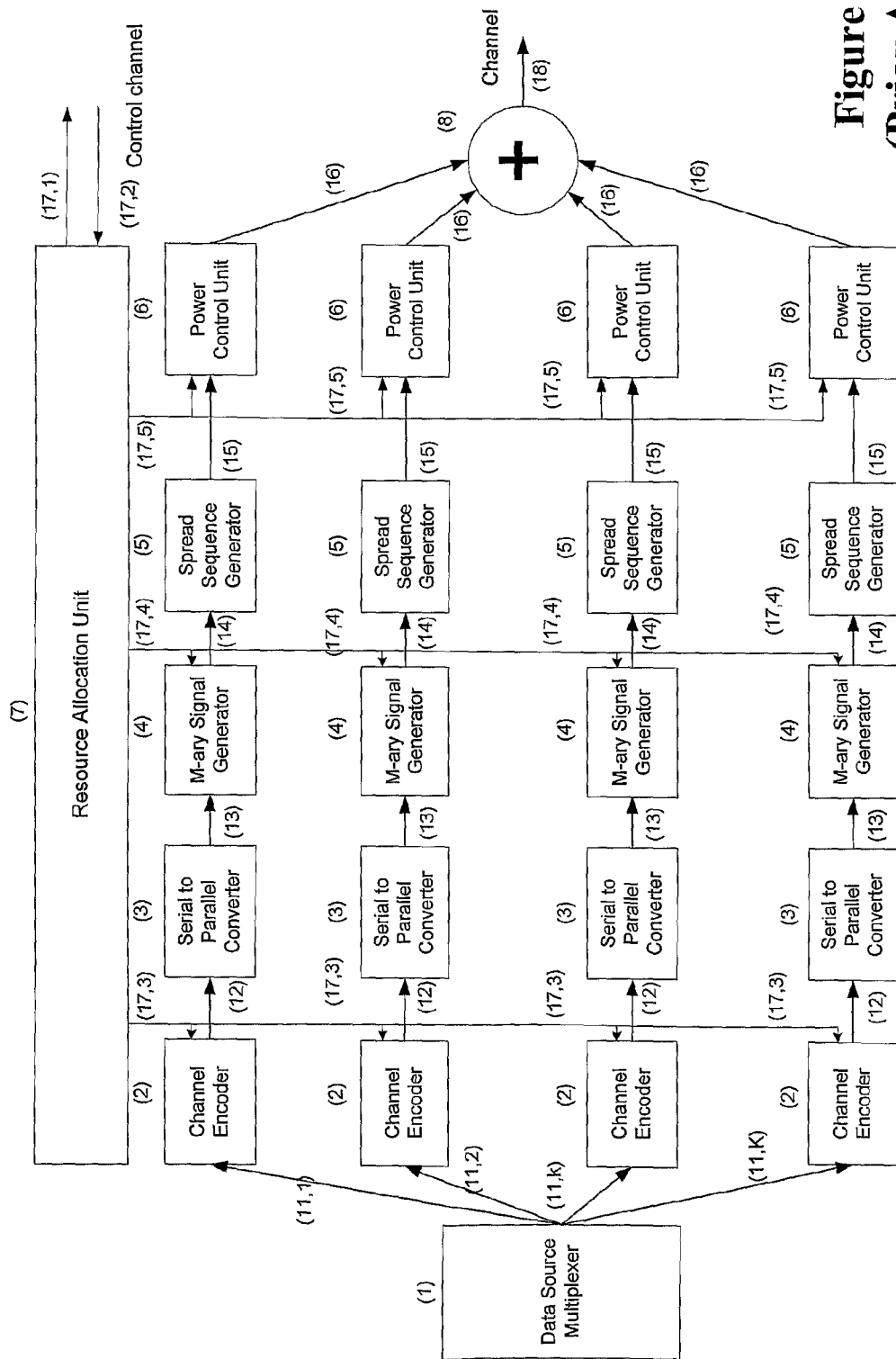
11. A method as claimed in Claim 9 or Claim 10, further comprising *CRC* testing the block of data decoded using the Turbo decoder to verify the integrity of the received data.

12. A method as claimed in any preceding claim, wherein the coding scheme has an outer and inner code, the method comprising the steps of:
- (a) supplying an outer encoder with a total of  $x$  incoming packets of  $L$  digits and operating it to generate an additional packet of  $L$  digits, wherein:
- (i) each packet of  $L$  digits is generated using the digits of the incoming packet; and
- (ii) the additional packet is generated by an EXCLUSIVE-OR combination of the  $x$  incoming packets;
- the outer encoder achieving a rate  $\frac{x}{x+1}$  by taking a total of  $x$  incoming packets;
- the group of  $x+1$  packets forming a Coded Parity Packets group;
- (b) encoding each packet using a Turbo encoder; and
- (c) transmitting the data from the Turbo encoder at a rate  $\frac{x}{x+1} r_I b$
- where  $r_I$  is the Turbo encoder rate and  $b$  is the number of bits carried by the modulation scheme.
13. A method as claimed in Claim 12 wherein, in step (a)(i), each packet of  $L$  digits also includes cyclic redundancy digits appended to the incoming digits.
14. A method as claimed in Claim 12 or Claim 13, further comprising an iterative message passing and channel decoding method which operates between the packets belonging to a Coded Parity Packets group, the method comprising decoding the packets in the said Coded Parity Packets group using a combination of the soft information of the other packets in the said Coded Parity Packets group.
15. A method as claimed in Claim 14, further comprising iteratively repeating the



decoding process until each packet is correctly decoded or until the iteration number reaches a predetermined value.

16. A transmitter configured to implement a method in accordance with any preceding claim.
17. A receiver configured to implement a method in accordance with any of claims 1 to 15.
18. A telecommunications system comprising a transmitter as claimed in Claim 16, and one or more receivers as claimed in Claim 17.
19. A method of transmitting data substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.
20. Transmitter apparatus substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.
21. Receiver apparatus substantially as herein described with reference to and as illustrated in any combination of the accompanying drawings.



**Figure 1**  
**(Prior Art)**

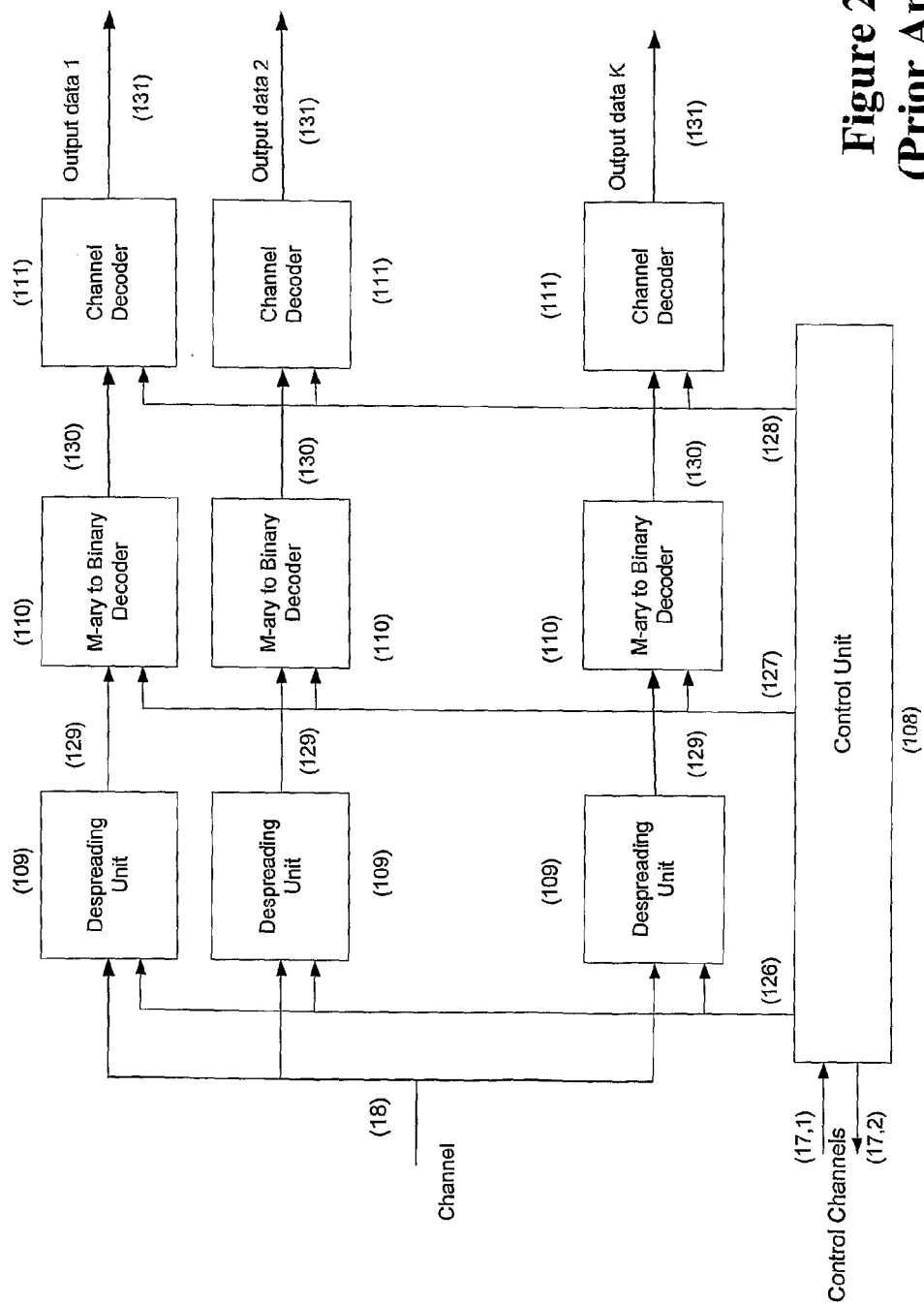


Figure 2  
(Prior Art)

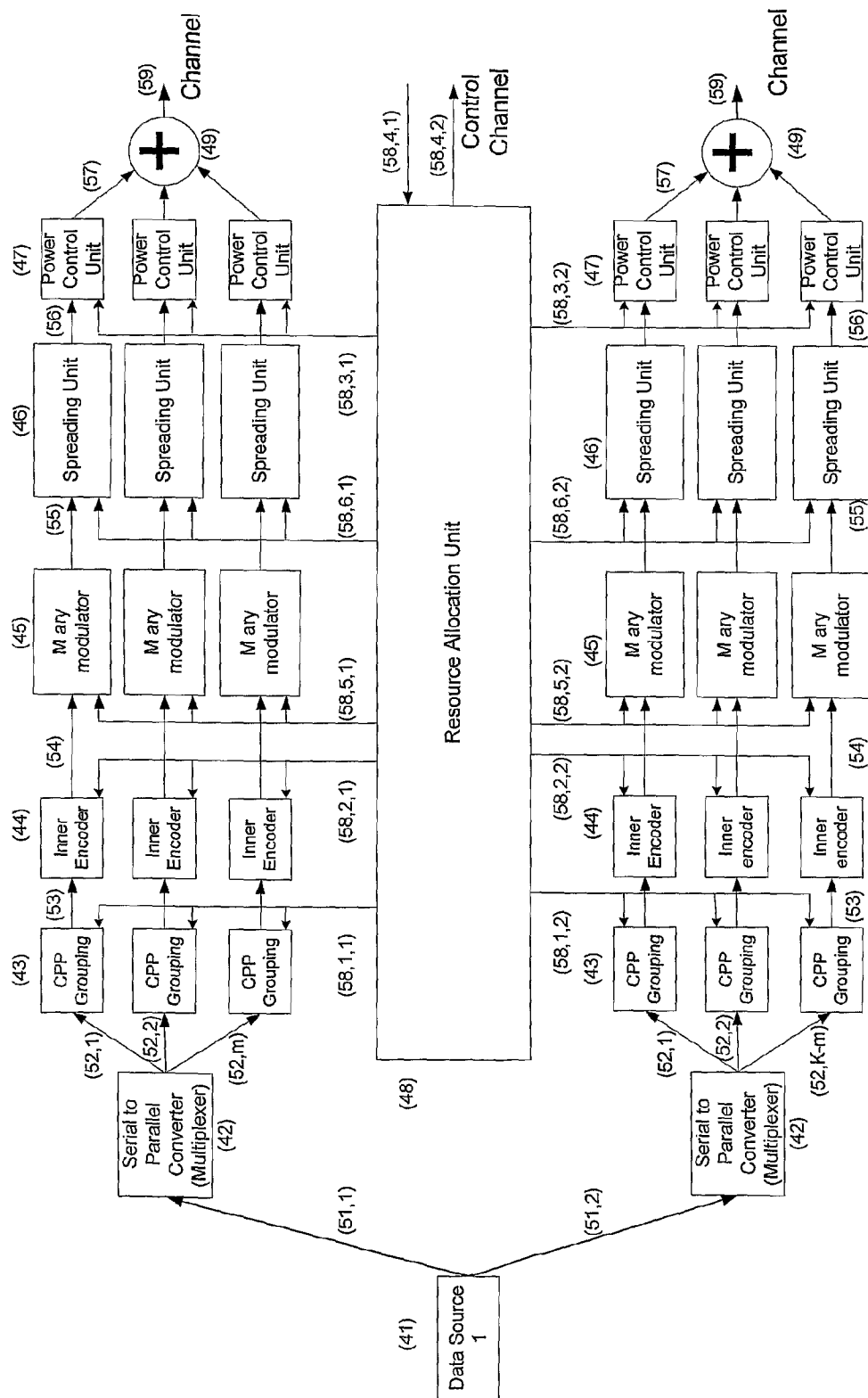


Figure 3

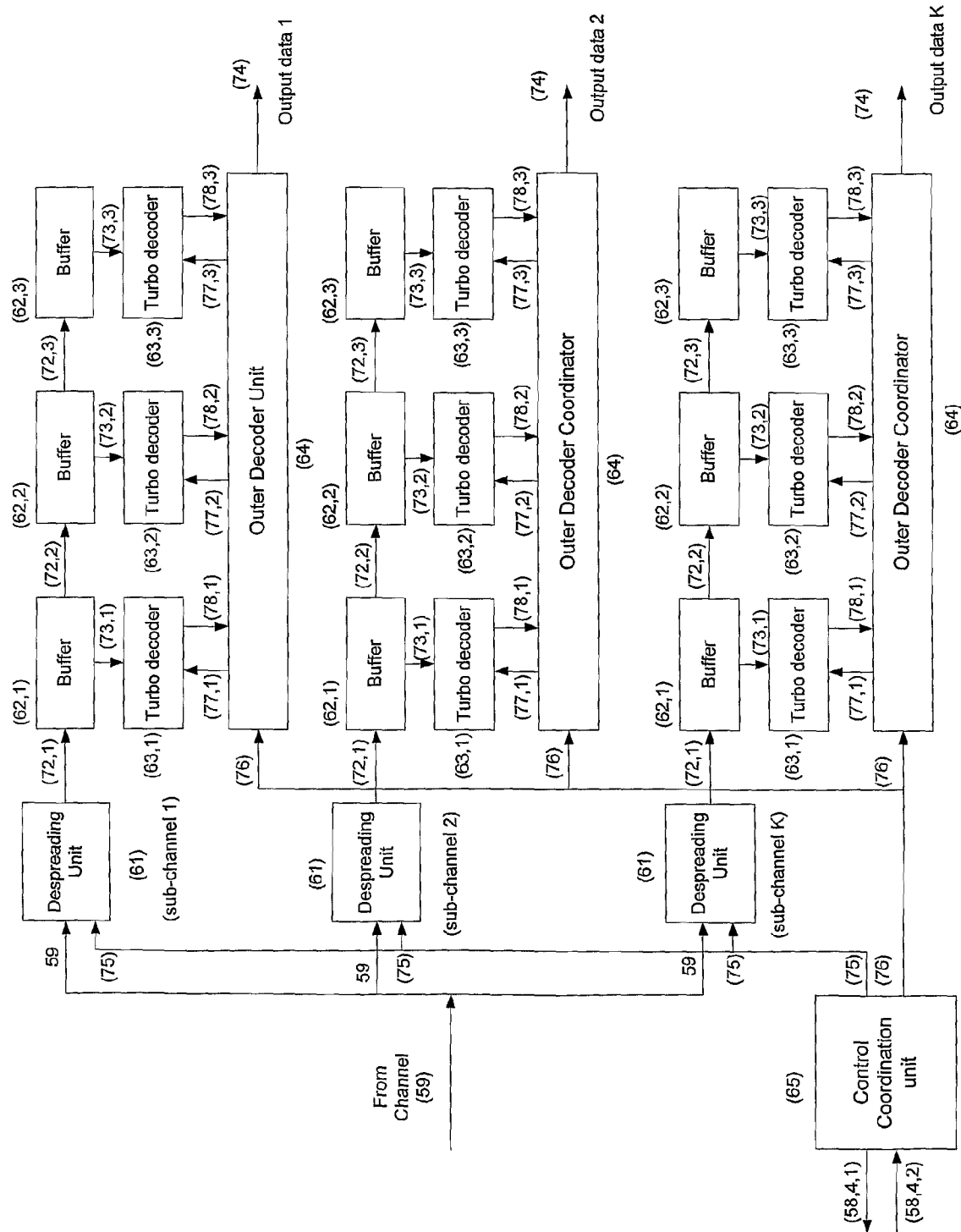


Figure 4