Multiplexing of Services in Broadcasting

FIELD OF INVENTION

The present invention relates broadly to a method and system for multiplexing a first set of PLPs (Physical Layer Pipes) and a second set of PLPs in a PL (Physical Layer) frame, and to a method and system for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF (Radio Frequency) channels.

BACKGROUND

With the increased capacity needs of HDTV (High Definition TeleVision), the DVB (Digital Video Broadcasting) project is in the process of developing a second generation terrestrial transmission system . According to the DVB-T2 Call for Technologies [See DVB SB 1644R1, Page 1, 16 April 2007], three phases of work have been identified. The first phase is targeted primarily at fixed and portable receivers using existing aerials and down-leads. Such compatibility requirements may rule out the most significant performance improvements that could be gained by introducing MIMO (Multiple Input Multiple Output) technologies. In the second phase, the focus should be on technology that enables higher payloads and do not necessarily use existing aerial installations. This implies the possibility of MIMO solutions in the second phase. Further, in the third phase where mobile reception is addressed, MIMO technologies appear to provide promising solutions. The above three phases will be regarded separately, and not just as different profiles of one specification.

Although DVB-T2 (i.e., the first phase) only supports single antenna reception, it does not rule out the possibility of deploying multiple transmit antennas. This implies that MISO (Multiple Input Single Output) technologies are a viable option for DVB-T2. Considering the possibility of MIMO transmission being employed in next generation systems (i.e., the 2nd and/or 3rd phases), MIMO-enabled next-generation receivers will

co-exist alongside single-antenna DVB-T2 receiver for a considerable transition period. To cope with this transition period, next generation systems should consider the possibility of multiplexing both services carried by MIMO transmission and services carried by MISO transmission in a PL (Physical Layer) frame. MIMO-enabled next generation receivers would be able to decode all the services, whilst single-antenna DVB-T2 receivers would be able to decode MISO services only. A potential problem of multiplexing MIMO and MISO services in a PL frame is that a MIMO data cell and a MISO data cell may be MISO coded.

Therefore there exists a need for developing efficient methods for multiplexing MIMO and MISO services in a PL frame.

SUMMARY

In accordance with a first aspect of the present invention, there is provided a method for multiplexing a first set of PLPs (Physical Layer Pipes) and a second set of PLPs in a PL (Physical Layer) frame, wherein said PL frame comprises a predetermined number of RF (Radio Frequency) channels, the method comprising the steps of obtaining respective data slices from each of the first and second sets of PLPs; dividing each data slice into a number of subslices, wherein the number of subslices is equal to the number of predetermined RF channels; allocating the subslices to the RF channels such that none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

The method of allocating the subslices to the RF channels may further comprise allotting the subslices of one data slice to the RF channels such that the subslices overlap in time on the RF channels; and cyclically shifting the subslices in time such that a time shift from one RF channel to the next is equal to a predetermined time period.

The time period may correspond to an integer number of OFDM symbols.

The method of allotting the subslices may comprise distributing the subslices onto the RF channels such that a sequence of subslices on each of the RF channels, as determined by the data slice the subslices are divided from, is the same for each RF channel.

The method wherein the step of allotting the subslices may further comprise merging the subslices of the first and second sets of PLPs such that, on each RF channel, the subslices of each set are grouped together.

For each RF channel, a boundary between a last one of the subslices of the first set of PLPs and a first one of subslices of the second set of PLPs may fall onto an OFDM symbol boundary.

One or more dummy cells may be added to the end of the last one of the subslices of the first set of PLPs such that the boundary between the last one of the subslices of the first set of PLPs and the first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

The said first set of PLPs may be transmitted by one of MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output); and said second set of PLPs, may be transmitted by the other.

The said first set of PLPs may be transmitted by one of MIMO and SISO (Single Input Single Output); and said second set of PLPs may be transmitted by the other.

The said first set of PLPs may be transmitted by one of MISO and SISO; and said second set of PLPs may be transmitted by the other.

The said time shift period may be determined using the steps of deriving an initial estimate by dividing a predetermined size of said PL frame by the predetermined number of RF channels; computing a remainder of said initial estimate divided by a predetermined OFDM symbol duration. Determining said time shift amount to be equal to said initial estimate if said remainder is equal to zero; otherwise determining said time shift amount to be equal to said initial estimate minus said remainder.

The predetermined number of RF channels may be one or more.

In accordance with a second aspect of the present invention, there is provided, a method for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF channels, the method comprising the steps of receiving subslices divided from respective data slices from each of the first and second sets of PLPs on the RF channels, wherein none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

In accordance with a third aspect of the present invention, there is provided a system for multiplexing a first set of PLPs and a second set of PLPs in a PL frame, wherein said PL frame comprises a predetermined number of RF channels, the system comprising a time interleaving unit for obtaining respective data slices from each of the first and second sets of PLPs, a physical layer framing unit for dividing each data slice into a number of subslices, wherein the number of subslices is equal to the number of predetermined RF channels, and allocating the subslices to the RF channels such that none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels

The physical layer framing unit may allocate the subslices to the RF channels by allotting the subslices of one data slice to the RF channels such that the subslices overlap in time on the RF channels; and cyclically shifting the subslices in time such that a time shift from one RF channel to the next is equal to a predetermined time period.

The time period in the system may correspond to an integer number of OFDM symbols.

The physical framing unit may allot the subslices by distributing the subslices onto the RF channels such that a sequence of subslices on each of the RF channels, as determined by the data slice the subslices are divided from, is the same for each RF channel.

The physical framing unit may further allot the subslices by merging the subslices of the first and second sets of PLPs such that, on each RF channel, the subslices of each set are grouped together.

For each RF channel, a boundary between a last one of the subslices of the first set of PLPs and a first one of subslices of the second set of PLPs may fall onto an OFDM symbol boundary.

The physical framing unit may add one or more dummy cells to the end of the last one of the subslices of the first set of PLPs such that the boundary between the last one of the subslices of the first set of PLPs and the first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

The said first set of PLPs may be transmitted by one of MIMO and MISO; and said second set of PLPs may be transmitted by the other in the system.

The said first set of PLPs may be transmitted by one of MIMO and SISO; and said second set of PLPs may be transmitted by the other in the system.

The said first set of PLPs may be transmitted by one of MISO and SISO; and said second set of PLPs may be transmitted by the other in the system.

The physical framing unit may determine the time shift period by deriving an initial estimate by dividing a predetermined size of said PL frame by the predetermined number of RF channels; computing a remainder of said initial estimate divided by a predetermined OFDM symbol duration. Determining said time shift amount to be equal to said initial estimate if said remainder is equal to zero; otherwise determining said time shift amount to be equal to said initial estimate minus said remainder.

The said predetermined number of RF channels may be one or more in the system.

In accordance with a fourth aspect of the present invention, there is provided a system for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF channels, the system comprising a receiver for receiving subslices divided from respective data slices from each of the first and second sets of PLPs on the RF channels, wherein none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

BRIEF DESCRIPTION OF THE DRAWINGS

It will be recognized that some or all of the figures are schematic representations for purposes of illustration and do not necessarily depict the actual relative sizes or locations of the elements shown. The figures are provided for the purpose of illustrating one or more embodiments of the invention with the explicit understanding that they will not be used to limit the scope or the meaning of the claims.

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 is a schematic block diagram showing an exemplary transmission system for digital terrestrial broadcasting.

Figure 2 is a schematic diagram showing an exemplary BaseBand frame.

Figure 3 is a schematic diagram showing an exemplary Forward Error Correction block.

Figure 4 is a schematic flowchart showing a method for multiplexing the first and second sets of Physical Layer Pipes according to a first embodiment of the present invention.

Figure 5a is a schematic diagram illustrating a method of merging and allocating data from the first set of Physical Layer Pipes to successive subslices for each RF channel in the same sequence, followed by the data for the second set of Physical Layer Pipes.

Figure 5b is a schematic diagram illustrating subslice allocations after cyclic shifting.

Figure 6 is a schematic flowchart showing a method for determining the time shift period in the method of Figure 4.

Figure 7 is a schematic flowchart showing a method for multiplexing the first and second sets of Physical Layer Pipes according to a second embodiment of the present invention.

Figure 8 is a schematic diagram illustrating a method of merging and allocating data from the first set of Physical Layer Pipes to successive subslices for a RF channel in the same sequence, followed by the data for the second set of Physical Layer Pipes.

Figure 9 shows a flowchart illustrating a method of multiplexing a first set of Physical Layer Pipes and a second set of Physical Layer Pipes in a Physical Layer frame according to an example embodiment.

DETAILED DESCRIPTION

Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "estimating", "merging", "determining", "allocating", "shifting", "generating", "deriving" "computing", "dividing", "obtaining", or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data

represented as physical quantities within the computer system into other data similarly represented as physical quantities within the computer system or other information storage, transmission or display devices.

Embodiments of the present invention provide a transmission system for carrying multimedia services over terrestrial digital broadcasting networks in an efficient manner based on multi-carrier OFDM (Orthogonal Frequency Division Multiplexing). The primary advantage of OFDM over single-carrier schemes is its potential ability to cope with frequency-selective fading due to multipath. The transmission system of the example embodiments may also deploy two or more transmit antennas, which enables MIMO/MISO transmission. MIMO/MISO can offer significant increases in data throughput and/or link reliability without additional bandwidth or transmit power.

In the example embodiments of the present invention, the system inputs may be one or more transport stream(s) and/or one or more generic stream(s). An input pre-processor may be required to organize input transport streams/generic streams into a number of PLPs (Physical Layer Pipes) characterized by specific performance, e.g., bit-rate capacities, error protection levels, and delay, etc. Each PLP may carry a syntactically correct transport stream or a generic stream. Some PLPs may be specifically designed to carry upper-layer signalling data. As programme data in input transport streams may be variable bit rate, padding the PLP transport stream with null packets may be necessary such that it has a standard and constant packet rate.

Further, the transmission system in the example embodiments of the present invention can operate in either TFS (Time Frequency Slicing) or TS (Time Slicing) mode. In TFS mode, a complete multiplex of multiple PLPs may be organised as sequential bursts covering multiple RF (Radio Frequency) channels in PL (Physical Layer) frames. In a PL frame of the example embodiment, data for a particular PLP is sent evenly in multiple bursts, which are distributed over different RF channels. There is a time shift between adjacent bursts of a particular PLP, which enables reception of a particular PLP with a single tuner since the receiver has time to retune between adjacent bursts. The OFDM symbols and data cells allocated to a particular PLP in a PL frame are collectively termed a slice. The slice is divided into subslices with each subslice comprising the OFDM symbols and data cells for each available RF channel. The slice size for a

particular PLP depends on the instantaneous bit rates of services mapped to the PLP and the coding and modulation parameters specific to the PLP. Thus, the slice sizes may vary among PLPs. PL frame durations, however, are fixed. In summary, a TFS transmission system may be of high capacity since it may enable efficient statistical multiplexing of services and increases frequency diversity. In TS mode, a complete multiplex of multiple PLPs is organised as sequential bursts covering only a single RF channel in PL frames. Thus, a TS transmission system may be viewed as a unique case of TFS.

Figure 1 is a schematic block diagram of an example embodiment of a transmission system 100 for digital broadcasting. The input to the transmission system 100 is in the form of a predetermined number of PLPs 101, which are classified into two sets. The first set of PLPs is transmitted by MISO known as MISO PLPs, while the second set of PLPs transmitted by MIMO are termed MIMO PLPs. Alternatively, the first set of PLPs may be transmitted by MIMO, and the second set of PLPs may be transmitted by MISO. The transmission system 100 comprises a ISP (Input Stream Processing) unit 102 comprising a plurality of ISP modules 103; a BICM (Bit Interleaved Coding Modulation) unit 104 comprising a plurality of BICM modules 105, and time interleaving unit 106 comprising a plurality of time interleaving modules 107; each module for operations on a PLP. Since there are separated ISP modules, BICM modules, and time interleavers for individual PLPs, different PLPs may be assigned different coding, modulation and time-interleaving formats and may provide unequal error protection. The transmission system 100 further comprises a PL framing module 108, a MIMO/MISO processing module 110, a frequency interleaver 112, and an OFDM modulator 114. The transmitted information is then received by a MIMO/MISO receiver 116.

The ISP modules 102 in the example embodiment adapt the set of PLPs 101 to the BB (BaseBand) frame formats. Figure 2 shows an exemplary BB frame 200, which consists of a BB header section 202, a data field section 204, and a padding section 206. The ISP modules 102 (Figure 1) have an input interface function to perform null packet deletion. The ISP modules 102 also have a mode adaptation function for slicing packet data into data fields, inserting BB header 202, and inserting timing information etc. In addition, the ISP modules 102 may need a stream adaptation function to provide

padding to complete a BB frame 200 and to scramble BB frame 200 data. The input processing methods are understood in the art and will not be discussed in detail here. For one example of the input processing methods, reference is made to DVB-S2 standard, contents of which are included by cross reference ETSI EN 302 307 V1.1.2, Page 14 – Page 19, June 2006.

The BICM modules 104 (Figure 1) perform FEC (Forward Error Correction) encoding, bit interleaving, and de-multiplexing bits into cell words in sequence. The FEC encoding is applied to BB frames to generate FEC blocks. In the example embodiment, the FEC encoding is a concatenation of a BCH (Bose, Ray-Chaudhuri, Hocquenghem) outer codes and a LDPC (Low Density Parity Check) inner codes. Figure 3 shows an exemplary FEC block 300, which consists of a BB frame section 302, a BCH FEC section 304, and a LDPC FEC section 306. The size of the FEC block 300 is fixed during a PL frame, e.g., 64800 bits or 16200 bits. The FEC encoding methods are understood in the art and will not be discussed in detail here. For one example of the FEC encoding methods, reference is made to DVB-S2 standard, contents of which are included by cross reference ETSI EN 302 307 V1.1.2, Page 19 – Page 23, June 2006. The bit interleaving is applied to the output of an FEC encoder by using a block interleaver to scramble the coded bits within the FEC block 300. The method of bit interleaving depends on the FEC block size, code rate, and modulation type. The bit interleaving methods are understood in the art and will not be discussed in detail here. For one example of the bit interleaving methods, reference is made to DVB-S2 standard, contents of which are included by cross reference ETSI EN 302 307 V1.1.2, Page 23 – Page 24, June 2006. The purpose of de-multiplexing bits into cell words is to group the bits of FEC block 300 into words which have a length appropriate to the modulation type. For example, 64-QAM requires 6-bit words and 256-QAM requires 8-bit words.

With the time interleavers 106 (Figure 1), block-based time interleaving may be applied to FEC blocks for the purpose of spreading data for individual PLPs across their respective slices in a PL frame. For this purpose, in front of the time interleavers 106, FEC block buffers (not shown in Figure 1) may be used to buffer FEC blocks of individual PLPs over a frame period. FEC block buffers may also be used to inform the PL framing module 108 of the number of FEC blocks accumulated over a frame period for individual PLPs.

The PL framing module 108 forms frame structure by inserting preamble symbols, continual and scattered pilots, PL signalling, etc. Another function of the PL framing module 108 is to allocate time interleaved data for the first and second sets of PLPs 101 to subslices in a PL frame according to a predetermined multiplexing method. Since the TFS frame structure is different from TS frame structure, the PL framing module 108 operates differently when in either TFS or TS mode. The methods for multiplexing the first and second sets of PLPs in a PL frame at both TFS and TS modes are discussed in further detail later.

The MIMO/MISO processing module 110 of the example embodiment applies MISO coding to data cells for the first set of PLPs; and applies MIMO coding to data cells for the second set of PLPs. With MISO processing, the data cells can be duplicated in a second stream and processed according to a predetermined MISO coding scheme. These MISO coding schemes understood in the art and will not be discussed in detail here. For one example of MISO coding schemes, reference is made to the Alamouti scheme, contents of which are included by cross reference in US Pat. No. 6185258 B1. With MIMO processing, independent data cells, rather than related data cells as discussed in Alamouti, may be transmitted from the two transmitters according to a predetermined MIMO coding scheme. MIMO coding schemes are understood in the art and will not be discussed in detail here. For one example of MIMO coding schemes, reference is made to BLAST (Bell Laboratories Layered Space-Time) scheme, contents of which are included by cross reference "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas" [Bell Laboratories Technical Journal, Page 41 – Page 59, Autumn 1996].

In the example embodiment, the frequency interleaver 112 may evenly spread the effect of selective fading over data cells within an OFDM symbol. Note that the frequency interleaver 112 may be swapped with the MIMO/MISO processing module 110. The main functions of the OFDM modulation module 114 include bit mapping into I/Q constellations, IFFT (Inverse Fast Fourier Transform), guard interval insertion, digital to analogue conversion, and analogue anti-aliasing filtering, etc. Frequency interleaving and ODFM modulation techniques are understood in the art and will not be discussed in detail here. For one example frequency interleaving and ODFM modulation techniques,

reference is made to DVB-T standard, contents of which are included by cross reference ETSI EN 300 744 V1.5.1, Page 19 – Page 25, November 2004.

Figure 4 is a schematic flowchart showing a method 400 for multiplexing the first and second sets of PLPs in a PL frame according to a first embodiment of the present invention, which may be applicable to TFS transmission system. The method 400 starts at Step 402. At Step 404, the number of required cells per RF channel is estimated for each PLP according to the predetermined number of RF channels and the number of FEC blocks accumulated by FEC block buffers for a frame period for that PLP.

At Step 406, according to their respective numbers of required cells per RF channel, the time-interleaved data for the first set of PLPs are merged and allocated to successive subslices in the same sequence for each RF channel, followed by the data for the second set of PLPs. Note that for each of the first and second sets of PLPs, the number of subslices per RF channel is predetermined, and the size of subslices can be estimated according to the number of required cells per RF channel and the number of subslices per RF channel. The total number of subslices per PLP depends on the number of RF channels. For example, in the case of three RF channels, the number of subslices per RF channel may be two, and thus the total number of subslices per PLP may be six.

Further, at Step 406, for each RF channel, an OFDM symbol can be shared between two adjacent subslices for the first set of PLPs or between two adjacent subslices for the second set of PLPs. However, OFDM symbols are not shared between a subslice for the first set of PLPs and a subslice for the second set of PLPs. Dummy cells may be used at the end of both the last OFDM symbol allocated to the first set of PLPs and the last OFDM symbol allocated to the second set of PLPs to complete a PL frame. Since there may exist hundreds of PLPs in a typical transmission system, the number of dummy cells inserted at the end of the first set of PLPs may be negligible when viewed with respect to the total number of valid information cells.

Figure 5(a) is a schematic diagram illustrating the Step 406 as described in Figure 4. In the example embodiment, a total of eight input PLPs, from the Time Interleaving Module 106 (Figure 1) are shown, four of which are MIMO PLPs, and four of

which are MISO PLPs. The data of each of the eight PLPs are obtained and further divided into data slices for processing and transmission. Data slices (511 to 518) are shown, four of which are MISO data slices 512, 513, 515, 517 and the remaining four are MIMO data slices 511, 514, 516, 518. Data slices for each of the PLPs (511 to 518) are then separated into their respective types (MIMO or MISO) and further divided into a number of subslices equal to the number of RF channels, with each subslice allotted to a different RF channel. For example, MISO data slice 512 is divided into subslices 5121, 5122 and 5123 for RF channels 1, 2 and 3 respectively. Similarly, for the remaining MISO data slices 513, 515, 517, subslices, 5131, 5151, 5171 are allotted to RF channel 1; 5132, 5152, 5172 are allotted to RF channel 2; and 5133, 5153, 5173 are allotted to RF channel 3. In this way, the MISO subslices in each of the RF channels are grouped together.

The four MIMO data slices 511, 514, 516, 518 are manipulated in the same way. The four MIMO data slices 511, 514, 516, 518 are divided into four subslices 5111, 5141, 5161, and 5181 for RF channel 1, four subslices 5112, 5142, 5162, and 5182 for RF channel 2, and four subslices 5113, 5143, 5163, and 5183 for RF channel 3. As described earlier, the two sets of data subslices (MISO and MIMO) are segregated and merged on each of the RF channels. For each RF channel, successive MISO data subslices occupy a first portion of the frame 500, while successive MIMO data occupy the remainder portion of the frame 500. In the example embodiment, successive MISO subslices 5121, 5131, 5151 and 5171, and successive MIMO subslices 5111, 5141, 5161, 5181, are transmitted over the RF channel 1.

As shown in Figure 5(a), two neighbouring MISO subslice 5131 and 5151 can share the OFDM symbol 520, and two neighbouring MIMO subslice 5141 and 5161 can share the OFDM symbol 530, but the MISO subslice 5171 and the MIMO subslice 5111 do not share the OFDM symbol 524. The intersection of the last OFDM symbol of MISO subslice 5171 and first OFDM symbol of MIMO subslice 5111 falls on an OFDM symbol boundary. Dummy cells may be used at the end of the OFDM symbol 524 and at the end of the OFDM symbol 534.

At Step 408 of Figure 4, the subslices are cyclically shifted in time such that the time shift from one RF channel to the next is equal to a predetermined period. Figure

5(b) is a schematic diagram illustrating the subslice allocations of the frame 500 of Figure 5(a) after Step 408 of Figure 4. Subslices on RF channel 1 are kept as they were. However, subslices on RF channel 2 are cyclically shifted by a pre-determined time period, while the subslices on RF channel 3 are cyclically shifted by twice the pre-determined time period to produce new subslice sequences on RF channels 2 and 3. Notice that some subslices may be fragmented into further separated subslices, such that one subslice is in the beginning and one in the end of the frame, e.g., sub-slice 5142. Also, the subslices of a data slice do not overlap in time on the RF channels. The method 400 terminates at Step 410.

Figure 6 is a schematic flowchart showing a method 600 for determining the time shift amount in step 408 of the method 400 (Figure 4) in the example embodiment. The method 600 starts at Step 602. At Step 604, an initial estimate is derived by dividing the predetermined frame size by the predetermined number of RF channels. Because the frame size covers an integer number of OFDM symbols, the initial estimate is a maximum possible time shift between subslices in different RF channels. At Step 606, the remainder of the initial estimate divided by the predetermined OFDM symbol duration is computed. At Step 608, if the remainder is equal to zero, Step 610 is performed and the time shift amount is determined to be equal to the first estimate. Otherwise Step 612 is performed and the time shift amount is determined to be equal to the initial estimate minus the remainder obtained in Step 606. The method 600 terminates at Step 614.

A receiver may then follow the following procedure to receive the slice 512 (Figure 5b) of a particular PLP:

- tune to RF channel 1 (Figure 5b);
- demodulate the subslice 5121 (Figure 5b);
- retune to RF channel 2 (Figure 5b);
- demodulate the subslice 5122 (Figure 5b);
- retune to RF channel 3 (Figure 5b); and
- demodulate the subslice 5123 (Figure 5b).

The time shift period in step 408 of the method 400 (Figure 4) covers an integer number of OFDM symbols. If this is not satisfied, a subslice for the first set of PLPs and a subslice for the second set of PLPs may share an OFDM symbol after cyclically time shifting. In addition, the time shift period takes into account that the receiver has time to retune between adjacent sub-slices.

Figure 7 is a schematic flowchart showing a method 700 for multiplexing the first and second sets of PLPs in a PL frame according to a second embodiment of the present invention, which may be applicable to TS transmission system. This embodiment differs from the earlier embodiment (Figure 4) in that the cyclic shifting step is omitted. At Step 702, the method 700 starts. At Step 704, the number of required cells for each PLP in a PL frame is estimated according to the number of FEC blocks accumulated by FEC block buffers for a frame period for that PLP. At Step 706, the time-interleaved data for the first set of PLPs are merged and allocated to successive subslices according to their respective numbers of required cells, followed by the data for the second set of PLPs. Notice that for each of the first and second sets of PLPs, the number of subslices is predetermined, and the size of subslices is estimated according to the number of required cells and the predetermined number of subslices. At Step 706, an OFDM symbol can be shared between two adjacent subslices for the first set of PLPs or between two adjacent subslices for the second set of PLPs, and but an OFDM symbol is not shared between a subslice for the first set of PLPs and a subslice for the second set of PLPs. Dummy cells may be used at the end of both the last OFDM symbol allocated to the first set of PLPs and the last OFDM symbol allocated to the second set of PLPs to complete a PL frame. The method 700 stops at Step 708.

Figure 8 is a schematic diagram illustrating the Step 706 as described in Figure 7. In the example embodiment, a total of eight input PLPs, from the Time Interleaving Module 106 (Figure 1) are shown, four of which are MIMO PLPs, and four of which are MISO PLPs. The data of each of the eight PLPs are further divided into data slices for processing and transmission. Data slices (811 to 818) are shown, four of which are MISO data slices 812, 813, 815, 817 and the remaining four are MIMO data slices 811, 814, 816, 818. Data slices for each of the PLPs (811 to 818) are then separated into their respective types (MIMO or MISO) and allocated into the RF channel as subslices

(8111 to 8181). For example, MISO data slices 812, 813, 815, 817 are allocated into the RF channel as subslices 8121, 8131, 8151, 8171.

The four MIMO data slices 811, 814, 816, 818 are allocated into the RF channel as four subslices 8111, 8141, 8161, and 8181. The two sets of data subslices (MISO and MIMO) are segregated on the RF channel. Successive MISO data subslices occupy a first portion of the frame 800, while successive MIMO data occupy the remainder portion of the frame 800. In the example embodiment, successive MISO subslices 8121, 8131, 8151 and 8171, and successive MIMO subslices 8111, 8141, 8161, 8181 are transmitted over the RF channel 1.

In this embodiment of the present invention, data cells of the first set of PLPs and a data cell of the second set of PLPs do not coexist in an OFDM symbol. Therefore, if MISO coding is applied in the frequency domain, the problem that a MIMO data cell and a MISO data cell may be MISO coded is avoided. However, if MISO coding is applied in time domain, a MIMO data cell and a MISO data cell may be MISO coded. Therefore, to address this problem in the case of two transmit antennas deployed at the transmitter, the first set of PLPs is mapped to an even number of OFDM symbols, and the second set of PLPs is also mapped to an even number of OFDM symbols in another example embodiment. As a result, dummy symbol insertion may be used to complete a PL frame.

Figure 9 shows a flowchart 900 illustrating a method of multiplexing a first set of PLPs and a second set of PLPs in a PL frame according to an example embodiment. At step 902, respective data slices from each of the first and second sets of PLPs is obtained. At step 904, each data slice is divided into a number of subslices, wherein the number of subslices is equal to the number of predetermined RF channels. At step 906, subslices are allocated to the RF channels such that none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels

It should be noted that in order to receive a particular PLP, the receiver knows whether the PLP is transmitted by MIMO or MISO. According to the embodiments of the present invention, a signal is used to indicate at which OFDM symbol the first set of PLPs ends or at which OFDM symbol the second set of PLPs starts.

A method for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF channels comprises that subslices divided from respective data slices from each of the first and second sets of PLPs are received on the RF channels, wherein none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

In the abovementioned embodiments, the first set of PLPs is transmitted by MIMO, and the second set of PLPs is transmitted by MISO. It should be noted that there exists different ways of transmitting the first set of PLPs and the second set of PLPs in different embodiments. For example, the first set of PLPs may be transmitted by one of MISO, and the second set of PLPs may be SISO (Single Input Single Output). Alternatively, the first set of PLPs may be transmitted by MIMO, and the second set of PLPs may be transmitted by and SISO.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method for multiplexing a first set of PLPs (Physical Layer Pipes) and a second set of PLPs in a PL (Physical Layer) frame, wherein said PL frame comprises a predetermined number of RF (Radio Frequency) channels, the method comprising the steps of

Obtaining respective data slices from each of the first and second sets of PLPs,

Dividing each data slice into a number of subslices, wherein the number of subslices is equal to the number of predetermined RF channels;

Allocating the subslices to the RF channels such that none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

2. The method as claimed in claim 1, wherein the step of allocating the subslices to the RF channels comprises:

Allotting the subslices of one data slice to the RF channels such that the subslices overlap in time on the RF channels; and

Cyclically shifting the subslices in time such that a time shift from one RF channel to the next is equal to a predetermined time period.

3. The method as claimed in claim 2, wherein the time period corresponds to an integer number of OFDM symbols.

4. The method as claimed in claims 2 or 3, wherein the steps of allotting the subslices comprises:

Distributing the subslices onto the RF channels such that a sequence of subslices on each of the RF channels, as determined by the data slice the subslices are divided from, is the same for each RF channel.

5. The method as claimed in claim 4, wherein the step of allotting the subslices further comprises:

Merging the subslices of the first and second sets of PLPs such that, on each RF channel, the subslices of each set are grouped together.

6. The method as claimed in claim 5, wherein for each RF channel, a boundary between a last one of the subslices of the first set of PLPs and a first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

7. The method as claimed in claim 6, wherein one or more dummy cells are added to the end of the last one of the subslices of the first set of PLPs such that the boundary between the last one of the subslices of the first set of PLPs and the first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

8. The method as claimed in any one of the preceding claims, wherein said first set of PLPs are transmitted by one of MIMO (Multiple Input Multiple Output) and MISO (Multiple Input Single Output); and said second set of PLPs are transmitted by the other.

9. The method as claimed in any one of the preceding claims, wherein said first set of PLPs are transmitted by one of MIMO and SISO (Single Input Single Output); and said second set of PLPs are transmitted by the other.

10. The method as claimed in any one of the preceding claims, wherein said first set of PLPs are transmitted by one of MISO and SISO; and said second set of PLPs are transmitted by the other.

11. The method as claimed in claim claimed in Claim 2, wherein said time shift period is determined using the steps of:

Deriving an initial estimate by dividing a predetermined size of said PL frame by the predetermined number of RF channels;

Computing a remainder of said initial estimate divided by a predetermined OFDM symbol duration.

Determining said time shift amount to be equal to said initial estimate if said remainder is equal to zero; otherwise determining said time shift amount to be equal to said initial estimate minus said remainder.

12. The method as claimed in any one of the preceding claims, wherein said predetermined number of RF channels is one or more.

13. A method for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF channels, the method comprising the steps of

Receiving subslices divided from respective data slices from each of the first and second sets of PLPs on the RF channels,

wherein none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.

14. A system for multiplexing a first set of PLPs and a second set of PLPs in a PL frame, wherein said PL frame comprises a predetermined number of RF channels, the system comprising

A time interleaving unit for obtaining respective data slices from each of the first and second sets of PLPs,

A physical layer framing unit for dividing each data slice into a number of subslices, wherein the number of subslices is equal to the number of predetermined RF channels, and allocating the subslices to the RF channels such that none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels

15. The system as claimed in claim 14, wherein the physical layer framing unit allocates the subslices to the RF channels by:

Allotting the subslices of one data slice to the RF channels such that the subslices overlap in time on the RF channels; and

Cyclically shifting the subslices in time such that a time shift from one RF channel to the next is equal to a predetermined time period.

16. The system as claimed in claim 15, wherein the time period corresponds to an integer number of OFDM symbols.

17. The system as claimed in claims 15 or 16, wherein the physical framing unit allots the subslices by distributing the subslices onto the RF channels such that a

sequence of subslices on each of the RF channels, as determined by the data slice the subslices are divided from, is the same for each RF channel.

18. The system as claimed in claim 17, wherein the physical framing unit allots the subslices by merging the subslices of the first and second sets of PLPs such that, on each RF channel, the subslices of each set are grouped together.

19. The system as claimed in claim 18, wherein for each RF channel, a boundary between a last one of the subslices of the first set of PLPs and a first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

20. The system as claimed in claim 19, wherein the physical framing unit adds one or more dummy cells to the end of the last one of the subslices of the first set of PLPs such that the boundary between the last one of the subslices of the first set of PLPs and the first one of subslices of the second set of PLPs falls onto an OFDM symbol boundary.

21. The system as claimed in any one of the preceding claims 14 to 20, wherein said first set of PLPs are transmitted by one of MIMO and MISO (Multiple Input Single Output); and said second set of PLPs are transmitted by the other.

22. The system as claimed in any one of the preceding claims 14 to 21, wherein said first set of PLPs are transmitted by one of MIMO and SISO and said second set of PLPs are transmitted by the other.

23. The system as claimed in any one of the preceding claims 15 to 22, wherein said first set of PLPs are transmitted by one of MISO and SISO; and said second set of PLPs are transmitted by the other.

24. The system as claimed in claim claimed in Claim 14, wherein the physical framing unit determines the time shift period by:

Deriving an initial estimate by dividing a predetermined size of said PL frame by the predetermined number of RF channels;

Computing a remainder of said initial estimate divided by a predetermined OFDM symbol duration.

Determining said time shift amount to be equal to said initial estimate if said remainder is equal to zero; otherwise determining said time shift amount to be equal to said initial estimate minus said remainder.

25. The system as claimed in any one of the preceding claims 14 to 24, wherein said predetermined number of RF channels is one or more.

26. A system for demultiplexing a first set of PLPs and a second set of PLPs received on a predetermined number of RF channels, the system comprising:

A receiver for receiving subslices divided from respective data slices from each of the first and second sets of PLPs on the RF channels, wherein none of the subslices from the first set of PLPs share an OFDM symbol with a subslice of the second set of PLPs and such that the subslices of one data slice do not overlap in time on the RF channels.