(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 October 2005 (13.10.2005)

PCT

(10) International Publication Number
WO 2005/096519 A1

(51) International Patent Classification[7]: H04B 7/06, H04J 11/00, H03M 13/05

(21) International Application Number: PCT/CA2005/000504

(22) International Filing Date: 4 April 2005 (04.04.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/558,566	2 April 2004 (02.04.2004)	US
60/563,802	21 April 2004 (21.04.2004)	US
60/566,009	28 April 2004 (28.04.2004)	US

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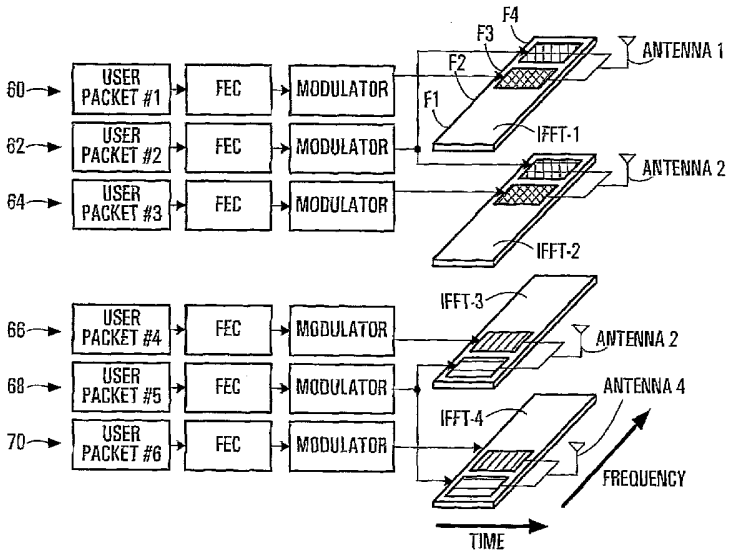
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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) Title: SPACE-TIME TRANSMIT DIVERSITY SYSTEMS AND METHODS FOR OFDM APPLICATIONS



(57) Abstract: Embodiments of the invention provide orthogonal Frequency Division Multiplexing-Space-time Block Codes (OFDMSTBC) mappings for code rate 1, 2 and 4 codes for 4 Transmit Antennas. To overcome the innate weakness of known codes, a new class of STBC codes is provided which is particularly suited for OFDM applications, although other applications are also contemplated. Codes for STBC mappings in the time direction, the frequency direction and a combined time frequency mapping for multiple antennas are provided. In OFDM applications, these codes exploit the properties of OFDM and FEC codes to substantially maintain the advantages of Alamouti codes. Furthermore, while the detailed examples given herein focus on four antenna applications, they can be easily extended to systems with more than four antennas.

WO 2005/096519 A1

European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Published:

— *with international search report*

Space-Time Transmit Diversity Systems and Methods for OFDM Applications

Related Applications

This application claims the benefit of U.S. Provisional Patent Application No. 60/558,566 filed on April 2, 2004, U.S. Provisional Patent No. 60/563,802 filed on April 21, 2004, and U.S. Provisional Patent Application Application No. 60/566,009 filed on April 28, 2004.

Field of the Invention

The invention relates to space-time transmit diversity systems and methods for OFDM (orthogonal frequency division multiplexing) applications.

Background of the Invention

For open-loop fading channels, diversity is often considered the only choice to mitigate the fading effects and improve the system reliability. While FEC (forward error correction) coding provides valuable time diversity, for a slow fading environment, space diversity/polarization proves to be more effective. The objective of the so-called space-time *codes* is to maximize the diversity gain.

There are basically two kinds of space-time codes: trellis codes and block codes. While trellis codes provide additional coding gain, they have drawbacks, namely: the decoder is more complex (since these codes work on the QAM symbols), and it is difficult to concatenate trellis space-time codes with powerful soft-decoding FEC codes, such as Turbo codes and convolutional codes. Space-time block codes (STBC) do not provide coding gain, but they are simple to decode (especially for those complex orthogonal design codes), and

they can be naturally combined with other soft-decoding FEC codes. It is for these reasons that STBC (space-time block codes) are more practical and are widely adopted by numerous standards.

The best known STBC code was invented by Alamouti and Tarokh (US 6,185,258) where the code matrix is presented as in Table 1 below.

Table 1 - The Alamouti code

	Time t	Time $(t+T)$
Antenna 1	s_1	s_2
Antenna 2	$-s_2^*$	s_1^*

This code has several properties, which makes it perfect for space diversity. The signals are orthogonal; hence full diversity is achieved at the receiver side. The transmit power is balanced between the two antennas (and the two time slots); hence a low cost power amplifier can be used, which in turn reduces the modem cost. Its code rate is 1; hence no throughput is sacrificed. Its maximum likelihood decoder is very simple, which makes the cost of an optimal decoder negligible.

Unfortunately, it was proven later that there are no such orthogonal codes existing for a system with more than two transmitter antennas. Therefore, the focus was shifted to the following two areas: designing orthogonal STBC codes with a code rate smaller than 1; and designing quasi-orthogonal STBC codes to maintain the property of code rate 1. While the first approach sacrifices the system throughput, the second approach sacrifices signal quality due to a loss of orthogonality.

There are several variations of the codes falling into the above categories, with focus on other areas such as power balancing and code rate manipulation; but no codes with the beauty of the Alamouti have been found.

Table 2 below is a first example of an STBC code for 4 transmit antennas (code-A). This is an orthogonal code having code rate 3/4. This code strives to maintain the orthogonality of the codes, thereby the diversity order and signal quality.

Table 2 - Code rate 3/4 orthogonal code (Code-A)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	$-s_3^*$	×
Antenna 2	s_2	s_1^*	×	s_3^*
Antenna 3	s_3	×	s_1^*	$-s_2^*$
Antenna 4	×	$-s_3$	s_2	s_1

With this code, each received signal has a diversity order of 4. However, one weakness of this code is its code rate loss, which must be compensated in FEC codes. In other words, due to the rate loss in STBC, the code rate in FEC must be higher. This can cause problem for those powerful trellis codes at higher code rate, whose coding gain loss becomes significant when punctuation becomes excessive. Note that this code does not achieve full power balance across transmit antennas. There are other codes available that are able to overcome this weakness.

Table 3 contains a second example of an STBC code for 4 antenna applications (Code-B). This is a code rate 1 non-orthogonal code. This code strives to maintain the throughput of the system; thereby no coding gain will be lost at the FEC stage.

Table 3 - Code rate 1 non-orthogonal code (Code-B)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	s_3	$-s_4^*$
Antenna 2	s_2	s_1^*	s_4	s_3^*
Antenna 3	s_3	$-s_4^*$	s_1	$-s_2^*$
Antenna 4	s_4	s_3^*	s_2	s_1^*

Since Code-B is no longer an orthogonal code, its determinant suffers from mutual interference. Defining the equivalent channel matrix Q as

$$Q = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_2^* & -h_1^* & h_4^* & -h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ h_4^* & -h_3^* & h_2^* & -h_1^* \end{bmatrix}, \quad (1)$$

then

$$\vec{r} = Q\vec{s}, \quad (2)$$

where $\vec{r} = [r_1 \quad r_2^* \quad r_3 \quad r_4^*]^T$, and $\vec{s} = [s_1 \quad s_2 \quad s_3 \quad s_4]^T$. The determinant of Q is given by

$$|Q| = A^2 - B^2, \quad (3)$$

where $A = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2$, and $B = 2\left(\mathrm{Re}(h_1 h_3^*) + \mathrm{Re}(h_2 h_4)\right)$. The element of B^2 represents the loss due to the loss of orthogonality. Since $B^2 \geq 0$, it always contributes negatively to the code performance.

Summary of the Invention

According to an aspect of the present invention, there is provided a method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by; during n pairs of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during the n pairs of consecutive transmission intervals and only one pair of antennas is active during a given transmission interval.

According to another aspect of the present invention, there is provided a method for mapping a rate one space-time block code for a 2n antenna transmitter where n>=2, the method comprising transmitting 2n transmission symbols on each sub-carrier of a plurality of sub-carriers in an OFDM spectrum by: for each transmission interval: on each of n pairs of adjacent OFDM sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all sub-carriers are used and only one pair of antennas is active during a given transmission interval for a given sub-carrier.

According to another aspect of the present invention, there is provided a method for mapping a space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by: during two consecutive transmission intervals, transmitting a respective Alamouti code

block containing two transmission symbols on a respective pair of antennas.

According to another aspect of the present invention, there is provided a method for mapping a space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by: for each transmission interval; on a pair of adjacent OFDM sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas.

According to another aspect of the present invention, there is provided a method for mapping a space-time block code for a 2n+1 antenna transmitter where n >=1, the method comprising transmitting transmission symbols by: during k pairs of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during at least one of the k pairs of consecutive transmission intervals and at least one transmit antenna is used during two of the k pairs of consecutive transmission intervals.

According to another aspect of the present invention, there is provided a method for mapping a space-time block code for a 2n+1 antenna transmitter where n >=1 adapted to transmit transmission symbols by: for each transmission interval: on k pairs of sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during at least one of the k pairs of consecutive transmission intervals and at least one transmit antenna is used during two of the k pairs of sub-carriers.

According to another aspect of the present invention, there is provided a method for mapping a space-time block code

for a 4 antenna transmitter, the method comprising selecting an appropriate code rate code from a code set of available code rate codes, wherein the code set is:

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0
	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$	Time $(t+4T)$	Time $(t+5T)$
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*
	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

or

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}

	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

According to another aspect of the present invention, there is provided a method for mapping a space-time block code for a 4 antenna transmitter, the method comprising selecting an appropriate code rate code from a code set of available code rate codes, wherein the code set is:

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0
	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

,

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3	Sub-carrier k+4	Sub-carrier k+5
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*

	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

or

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}
	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

According to another aspect of the present invention, there is provided a method for mapping a rate 3/4 space-time block code for a 4 antenna transmitter, the method comprising transmitting 3 transmission symbols by: during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a first respective pair of antennas on a given sub-carrier and transmitting a respective Alamouti code block containing one transmission symbol on a second respective pair of antennas on a same sub-carrier such that all antennas are used during the pair of consecutive transmission intervals.

According to another aspect of the present invention, there is provided a method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by: during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission

symbols on a respective pair of antennas on a given sub-carrier such that all antennas are used during the pair of consecutive transmission intervals and each pair of antennas is active on a different sub-carrier.

According to another aspect of the present invention, there is provided a method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 4n transmission symbols by: during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing n transmission symbols on a respective pair of antennas on a given sub-carrier such that all antennas are used during the pair of consecutive transmission intervals.

According to another aspect of the present invention, there is provided a method of transmitting a MIMO OFDM signal expressed in the form Y=HF(S), where Y^{1xM} is an output of a MIMO channel, H^{MxNT} is a matrix of MIMO channel characteristics, F(s) denotes a space-time coding matrix for a complex input symbol $S=[s_1 \ s_2 \ \ldots \ s_L]$ which is grouped as $S_1=[s_1 \ s_2 \ s_3 \ s_4]$, $S_2=[s_5 \ s_6 \ s_7 \ s_8]$ and $S_3=[s_9 \ s_{10} \ s_{11} \ s_{12}]$, the method comprising selecting an appropriate code for a wireless terminal adapted to receive the MIMO OFDM signal transmitted by a multi-antenna transmitter depending on a number of receiver antenna at the wireless terminal.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

Brief Description of the Drawings

Preferred embodiments of the invention will now be described with reference to the attached drawings in which:

Figure 1A - A schematic diagram of a 4 antenna transmitter supporting MIMO-OFDM communication for use with embodiments provided by the invention;

Figure 1B - A schematic diagram of a multi-antenna transmitter and receiver supporting MIMO-OFDM communication for use with embodiments provided by the invention;

Figure 1C - A schematic diagram of another multi-antenna transmitter supporting MIMO-OFDM communication for use with embodiments provided by the invention;

Figure 1D - A schematic diagram of a further multi-antenna transmitter supporting MIMO-OFDM communication for use with embodiments provided by the invention;

Figure 1E - A schematic diagram of yet another multi-antenna transmitter supporting MIMO-OFDM communication for use with embodiments provided by the invention;

Figure 2 - A schematic diagram representing transmission of STBC blocks on multiple sub-carriers for space-time coding in the time direction;

Figure 3 - A graphical illustration of improved performance of a code mapping embodiment provided by the invention compared to an existing code mapping;

Figure 4 - A graphical illustration of improved high mobility speed performance of a code mapping embodiment provided by the invention compared to an existing code mapping;

Figure 5 - A graphical illustration of improved low mobility speed performance of a code mapping embodiment

provided by the invention compared to an existing code mapping; and

Figure 6 - A schematic diagram representing transmission of STBC blocks on multiple sub-carriers for space-time coding in the time direction.

Detailed Description of the Preferred Embodiments

In accordance with embodiments of the invention, methods are provided for mapping users to a multi-antenna transmit resource that enables the network to exploit the time-frequency diversity and multi-user diversity. In addition, the mapping also allows flexible radio resource management/allocation and provides different QoS based services. Within the same framework, SISO, MISO, MIMO capable users can be supported.

By way of overview, each user can be mapped onto a different OFDM resource which might be a sub-channel, e.g. the AMC sub-channel and/or a diversity sub-channel. For MIMO users, preferably, multiple different space-time coding schemes are supported such as SM (spatial multiplexing) and STTD (space-time transmit diversity).

On a continuous basis, there is a stream of OFDM symbols associated with each transmit antenna. Each user may be first mapped onto one or multiple OFDM symbols and each OFDM symbol may then be mapped onto its associated antenna. Such mapping also allows per-antenna rate control (PARC) to be performed in some embodiments.

Each OFDM symbol may be mapped onto its associated antenna in the sub-carrier domain. For certain sub-carriers,

if no specific user data is mapped, then a null assignment to such sub-carrier maybe fed into the corresponding antenna.

A very simple example of what might be transmitted at a specific instant in time as a result of a particular OFDM symbol and antenna mapping is shown in Figure 1A. Figure 1A shows a four antenna transmit system that, in the instance depicted, is being used to transmit six user packets 60,62,64,66,68,70 each of which undergoes FEC (forward error correction) and modulation. A specific mapping of the six packets of six users is shown for a particular time instant. Over time, the number of users, and/or the manner in which the user packets are mapped are preferably dynamically changing.

For the particular time instant, the OFDM bandwidth is allocated in four distinct frequency bands F1,F2,F3,F4. These might for example be considered AMC sub-channels. A similar approach can be employed for diversity sub-channels.

Each packet is to be mapped onto the four antennas using a selected mapping scheme. Various space-time mapping schemes are described in detail below. In some embodiments, multiple different schemes are available or a given number of transmit antennas and receive antennas. For example, for a 2x2 system, preferably STTD or SM (BLAST - Bell Labs Layer Space Time) can be selected. In other embodiments only a single scheme is implemented for each antenna permutation. Single antenna users use a single input single output (SISO) (which may involve PARC - Per-antenna rate control) transmission scheme.

The first packet 60 is transmitted using only antenna 1 on band F3 implying a 1x1 SISO transmission.

The second packet 62 is transmitted on both antennas 1 and 2 in band F4 implying a 2x1, 2x2 or 2x4 MIMO transmission.

The third packet 64 is transmitted only on antenna 2 in band F3, again implying a 1x1 SISO transmission.

The fourth packet 66 is transmitted on band F2 over antenna 3.

The fifth packet 68 is transmitted on band F1 on both of antennas 3 and 4.

Finally, packet 70 is transmitted on only band F2 of antenna 4.

Generally, each packet can be mapped individually to some or all of the antennas. This enables MIMO and non-MIMO users to be mixed. In the above example, packets 60, 64, 66 and 70 are for non-MIMO users. Packets 62 and 64 are for MIMO users.

Please note that the flexible mapping of MIMO and non-MIMO users applied both in the context of "partial utilization" and "full utilization". With partial utilization, a given base station only has access to part of the overall OFDM band. In this case, the sub-bands F1,F2,F3,F4 defined for the example of Figure 1A would fall within the defined part of the overall band. With partial utilization, different base stations that are geographically proximate may be assigned different bands. With full utilization, each base station uses the entire OFDM band. With such an implementation, for the particular example of Figure 1A the sub-bands F1,F2,F3,F4 would map to the entire band.

For SISO users, a single band on a single antenna will be used. For a MIMO user the configuration is denoted as N_T x N_R.

The flexible structure illustrated by way of example in Figure 1A can be used for both STTD and BLAST. For example, the packet 62 may be transmitted using the band F4 on antennas 1 and 2 using either BLAST or STTD.

The particular example shown in Figure 1A is designed to show the co-existence of SISO and MIMO be it STTD and/or BLAST. Of course the number of sub-bands, and their shape, size, location, etc., within the OFDM band are implementation specific details. The mapping can be done on a per OFDM symbol basis, or for multiple OFDM symbols.

Details of a method of performing transmitting from a plurality of antennas are defined in applicants' co-pending application no. <attorney docket 71493-1330 entitled _____> hereby incorporated by reference in its entirety. The method generally involves:

dividing an available OFDM bandwidth of each antenna into sub-channels;

defining a plurality of regions, each region being defined by a respective set of sub-channels and a defined number of OFDM symbols;

defining a respective antenna mapping for each region and selecting one or more of the plurality of antennas to use for the region, the antenna mappings including at least one MIMO mapping;

mapping content for at least one user to each of the regions using the respective antenna mapping;

transmitting each region on the one or more antennas selected for the region.

Another way to think of this is that each time-frequency block that is defined can have its own matrix. Once the matrix is specified, the number of antennas at the output is defined. For example, a 2x2 matrix requires two antennas; a 4x4 matrix requires four antennas. The matrix also determines, not necessarily uniquely, the number of different users that can be mapped. Particular examples are given in the tables below.

The content for multiple users of course needs to be mapped in a manner that is consistent and non-conflicting. Also, each user needs to be informed of where/when its content will be transmitted.

For each individual user, the antenna mapping enables STTD, SM and PARC transmissions for either the AMC sub-channel or the diversity sub-channel. In one embodiment, any one of six different mapping configurations can be applied to each individual user there including three 4-transmit antenna mappings, 2-transmit antenna mappings and a single antenna mapping.

The uplink may include, for example, two modes: (1) STTD for dual transmit antenna capable SS and (2) Virtual-MIMO for single transmit antenna capable SS.

Referring now to Figures 1B,1C,1D and 1E shown are specific transmitter configurations. In a preferred embodiment, the transmitter is dynamically reconfigurable to enable transmission to multiple users using respective transmission formats. The particular examples of Figures 1B,1C,1D, and 1E below can be considered "snapshots" of such a reconfigurable transmitter. These configurations can also

exist simultaneously for different sub-bands of an overall OFDM band that is being employed. For example, the configuration of Figure 1B might be used for a first set of sub-channels or a first OFDM band and associated user(s); the configuration of Figure 1C might be used for a second set of sub-channels or a second OFDM band and associated user(s) and so on. Of course, many of the components that are shown as being replicated would not need to be physically replicated. For example, a single IFFT and associated transmit circuitry can be used per antenna with the different mappings being performed and then input to appropriate sub-carriers of the IFFT.

Figure 1B shows an example configuration with a matrix that performs STTD encoding based on a single input stream, and with horizontal encoding for two, three or four transmit antennas. An input stream 1000 is encoded and modulated and then STC encoded in space time encoder 1002 having two, three or four outputs that are then fed to respective transmit chains and transmitted. A corresponding receiver structure is indicated generally at 1004. In this case, matrix F_{4x1} or F_{4x2} defined below can be used for four transmit antennas, depending upon receiver capabilities, or F_{2x1} defined below can be used for two transmit antennas. These are all STTD matrices, that might for example be employed; other matrices are possible.

Figure 1C shows an example configuration with a matrix that performs STTD encoding for multiple input streams, and with horizontal encoding for two, three or four transmit antennas. Input streams 1006,1008 (only two shown, more possible) are encoded and modulated and then STC encoded in space time encoder 1010 having two, three or four outputs that are then fed to respective transmit chains and transmitted. In this case, matrix F_{4x1} or F_{4x2} defined below can be used for four

transmit antennas, depending upon receiver capabilities, or F_{2x1} defined below can be used for two transmit antennas. These are all STTD matrices, that might for example be employed; other matrices are possible.

Figure 1D shows an example configuration with a matrix that performs SM (e.g. BLAST) encoding for a single input stream. Input stream 1012 is encoded and modulated and then demultiplexed into two, three or four streams 1012,1014 that are fed to respective transmit chains and transmitted. In this case, matrix F_{4x4} might be used for four transmit antennas or $F_{2x2,2x4}$ for two transmit antennas, both defined below, both of which are SM matrices, that might for example be employed; other matrices are possible. This is an example of so-called "vertical encoding" where the input symbols of a given input stream are vertically distributed (i.e. simultaneous in time) between the multiple antennas.

Figure 1E shows an example configuration with a matrix that performs SM (e.g. BLAST) encoding for multiple input streams. Input streams 1020, 1022 (only two shown, more possible) are encoded and modulated fed to respective transmit chains and transmitted. In this case, matrix F_{4x4} might be used for four transmit antennas or $F_{2x2,2x4}$ for two transmit antennas, both defined below, both of which are SM matrices, that might for example be employed; other matrices are possible. This is an example of so-called "horizontal encoding" where the input symbols of a given input stream are horizontally distributed (i.e. sequentially in time) on a single antenna.

Specific Antenna Mapping Example

A more specific example of a quasi-Orthogonal Space-Time Coding Flexible mode Assignment for SISO, STTD and SM based on the above will now be detailed.

Downlink open loop transmission with multiple antennas at a base station (BS) can be configured by several transmission modes. Assuming that N_T is the number of transmit antennas at the BS and N_R is the number of receive antennas at a terminal subscriber station (SS), a MIMO configuration is denoted as $N_T x N_R$. Note that for SISO transmissions only one of the available transmit antennas is used. Any existing SISO code structure can be employed.

Index	1	2	3	4	5
FEC	R=1/5	R=1/3	R=1/2	R=2/3	R=4/5
Modulation	QPSK	16 QAM	64 QAM		

For MIMO down link transmission, space-time coding is preferably employed. In one embodiment, a 4x4 quasi-orthogonal space-time transmit diversity (QOSTTD) code is used as a mother code for space-time coding, and can be punctured in time to optimize for different receive antenna configurations. The MIMO transmission and reception can be expressed by Y=HF(S), where Y^{1xM} is the output of the MIMO channel, H^{MxNT} is a matrix of MIMO channel characteristics, F(s) denotes the space-time coding matrix for a complex input symbol $S=[s_1 \ s_2 \ \ldots \ s_L]$ which is grouped as $S_1=[s_1 \ s_2 \ s_3 \ s_4]$, $S_2=[s_5 \ s_6 \ s_7 \ s_8]$ and $S_3=[s_9 \ s_{10} \ s_{11} \ s_{12}]$, and the rows of coding matrix F(s) are the individual antenna transmission outputs.

A code suitable for a 4x1 configuration is: (STC Code Rate = 1)

$$F_{4x1}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & -s_2^* & -s_3^* & s_4 & s_5 & -s_7^* & -s_8^* & s_6 & s_9 & -s_{12}^* & -s_{10}^* & s_{11} \\ s_2 & s_1^* & -s_4^* & -s_3 & s_6 & s_8^* & s_7^* & s_5 & s_{10} & -s_{11}^* & s_9^* & -s_{12} \\ s_3 & -s_4^* & s_1^* & -s_2 & s_7 & s_5^* & -s_6^* & -s_8 & s_{11} & s_{10}^* & s_{12}^* & s_9 \\ s_4 & s_3^* & s_2^* & s_1 & s_8 & -s_6^* & s_5^* & -s_7 & s_{12} & s_9^* & -s_{11}^* & -s_{10} \end{bmatrix}.$$

A code suitable 4x2 configuration (STC Code Rate = 2, STTD), in-time puncturing the columns 3&4, 7&8 and 11&12 of $F_{4x1}(S_1,S_2,S_3)$ gives:

$$F_{4x2}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* & s_9 & -s_{12}^* \\ s_2 & s_1^* & s_6 & s_8^* & s_{10} & -s_{11}^* \\ s_3 & -s_4^* & s_7 & s_5^* & s_{11} & s_{10}^* \\ s_4 & s_3^* & s_8 & -s_6^* & s_{12} & s_9^* \end{bmatrix}.$$

A code suitable a 4x4 configuration (STC Code Rate = 4, spatial multiplexing), columns 1, 3 and 5 of $F_{4x2}(S_1,S_2,S_3)$, are preferably punctured, gives:

$$F_{4x4}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & s_5 & s_9 \\ s_2 & s_6 & s_{10} \\ s_3 & s_7 & s_{11} \\ s_4 & s_8 & s_{12} \end{bmatrix}.$$

In a four transmit antenna system, an SS is preferably configured to receive the transmission of space-time coding of 4x1, 4x2 or 4x4 configurations (F_{4x1} F_{4x2} F_{4x4}, given above being specific examples) with respect to different receive antenna capabilities of the SS classes. These three modes can be applied to the AMC sub-channel and diversity sub-channel. In addition, a fast feedback channel to support the mode selection and adaptation for both the DL and UL is preferably provided.

For two transmit antennas, two transmission modes are preferably supported: space-time transmit diversity and spatial multiplexing.

For a 2x1 configuration the following is an example of a code structure: (STC Code Rate = 1)

$F_{2x1}(S_1,S_2)=\begin{bmatrix} s_1 & -s_2^* & s_3 & -s_4^* \\ s_2 & s_1^* & s_4 & s_3^* \end{bmatrix}$, which is the Alamouti space-time transmit diversity (STTD).

For 2x2, 2x4 configuration: (STC Code Rate = 2), puncturing the even columns of F_{2x1} gives:

$F_{2x2,2x4}(S_1,S_2)=\begin{bmatrix} s_1 & s_3 \\ s_2 & s_4 \end{bmatrix}$. This is the spatial multiplexing (a.k.a. BLAST).

In a preferred embodiment, the SS is configured to receive transmission of space-time coding of 2x1, 2x2 or 2x4 configurations, (F_{2x1}, $F_{2x2,2x4}$ given above being specific examples) with respect to different receive antenna capabilities of SS classes. These two modes can be applied to the AMC sub-channel and diversity sub-channel. In addition, a fast feedback channel to support mode selection and adaptation for both the DL and UL is preferably provided.

Details of the above codes and of example implementations of the fast feedback channel can be found in Applicant's co-pending application < Attorney Docket 71493-1329> filed _____, entitled "Methods for Supporting MIMO Transmission in OFDM Applications" hereby incorporated by reference in its entirety.

A first embodiment of the invention provides a code rate 1 OFDM-STBC mapping for 4 Transmit Antennas. To overcome

the innate weakness of the above two kinds of codes, a new class of STBC codes is provided which is particularly suited for OFDM applications, although other applications are also contemplated. In OFDM applications, these codes exploit the properties of OFDM and FEC codes to substantially maintain the advantages of Alamouti codes. Furthermore, while the detailed examples given here focus on four antenna applications, they can be easily extended to systems with more than four antennas.

One property of FEC codes is their diversity effect within the code block. With this knowledge, the diversity order on each Quadrature Amplitude modulation (QAM) symbol can be relaxed to within one code block. Code rate 1 orthogonal STBC code designs need to achieve full diversity per QAM symbol, something which is difficult, if not impossible for a larger number of antennas than two. However, this is not necessary when the system is concatenated with soft-decoding based FEC codes.

Therefore, new STBC codes are provided so as to provide a diversity order of two per QAM symbol, while still achieving full diversity with the help of FEC codes. Diversity order two means that each QAM symbol travels through two independently (multipath) fading channels. An example of a new STBC code is presented in Table 4 below (Code-C).

Table 4 OFDM-STBC code rate 1 orthogonal code (Code C)
(*Antenna Hopping Pattern-1*)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0

Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

In Table 5A, another arrangement of an alternative antenna hopping pattern different than Table 4 is shown. Antenna hopping refers to a reordering of the mapping such that the same coding is performed, but that symbols are transmitted by different antennas. For example, in antenna hopping pattern 1 shown in Table 4 above, Antenna 2 is assigned s_2 at time t, s_1* at time t+T and a null assignment at times t+2T and t+3T. However, in antenna hopping pattern 2 in Table 5A below, Antenna 3 is assigned s_2 at time t, s_1* at time t+T and a null assignment at times t+2T and t+3T. It is to be understood that these are two examples of antenna hopping patterns, but there are others that are valid and considered to be within the scope of the invention as well. Table 5B shows a further alternative code mapping.

Table 5A - OFDM-STBC code rate 1 orthogonal code (Code C)
(*Antenna Hopping Pattern-2*)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

Table 5B - OFDM-STBC code rate 1 orthogonal code (Code C)
(*Antenna Hopping Pattern-3*)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

In a preferred embodiment, multiple different patterns are employed over time, such as the above-introduced "hopping pattern-1" and "hopping pattern-2". The effect of this is that for each group of symbols s_1, s_2, s_3, s_3, the antenna used for s_1 for example, changes over time.

Preferably, for the above embodiment, the mappings are used on a per OFDM sub-carrier basis.

With Alamouti codes hopping across the transmit antennas, each QAM symbol has a diversity order of 2; with FEC coding being applied across all the STBC blocks, full diversity order is achieved. The STBC code rate is one, and each code STBC block is orthogonal.

In order to achieve power imbalance for all the transmit antenna in time-domain, from Table 4, it can be noticed that at each instant only two transmitters are transmitting, which means for a constant power of P, each power amplifier (PA) can be designed to have 3 dB more dynamic range

than when power balanced codes are used. Here, properties of OFDM can be employed.

Preferably, different patterns are used for different sub-carriers such that an overall power balancing is achieved. This is detailed further below. For the specific example above, a first set of sub-carriers could be used to transmit pattern-1, and a second set of sub-carriers used to transmit pattern-2 at the same time.

An OFDM signal has multiple sub-carriers, with each sub-carrier being treated as a flat fading channel. Figure 2 is an illustrative example of an OFDM signal wherein the sub-carriers are indicated in the frequency domain in columns k,k+1,k+2,k+3...,k+(n-3),k+(n-2),k+(n-1),k+n and time intervals are indicated in the time domain in rows t,t+T,t+2T,t+3T in which STBC blocks 20 are represented.

After IFFT processing occurs, of the type described in the examples of Figures 1A-E above, energy of each sub-carrier is superimposed in the time domain, which is then amplified by a respective power amplifier. For sub-carrier k, at time t and t+T, only Antennas 1 and 2 are used for transmission and for sub-carrier k+1, at the same time, only Antenna 3 and 4 are used for transmission. In other words, when looked at from the time domain, all the antennas are transmitting simultaneously, but for different sub-carriers. Thus the average transmitting power per antenna is in fact balanced. This concept is illustrated in Figure 2.

In Figure 2, each vertical set of four symbols is transmitted on a single sub-carrier over four transmission intervals, and represents two STBC blocks 20 as defined in Table 4. During the first two transmit intervals, t and t+T, Antennas 1 and 2 transmit an Alamouti block on the sub-carrier, k+1, and during the next two transmit intervals, t+2T and t+3T,

Antennas 3 and 4 transmit an Alamouti block. This structure is then repeated for multiple sub-carriers (the horizontal direction in Figure 2).

In some embodiments, the mapping code on a first set of sub-carriers have the mapping described above and a second set of sub-carriers will have a mapping that is an inverse of the described mapping, that is the location of the Alamouti blocks switch location in the time interval/antenna mapping shown in Tables 4, 5A and 5B. For example, on a first sub-carrier, during the first two transmit intervals, t and t+T, Antennas 1 and 2 transmit an Alamouti block and during the next two transmit intervals, t+2T and t+3T, Antennas 3 and 4 transmit an Alamouti block. On a second sub-carrier, during the first two transmit intervals, t and t+T, Antennas 3 and 4 transmit an Alamouti block and during the next two transmit intervals, t+2T and t+3T, Antennas 1 and 2 transmit an Alamouti block.

In the illustrated example, during a given pair of transmit intervals, all of the odd sub-carriers $k,k+2,\ldots,k+(n-3),k+(n-1)$ of one pair of antennas are active, and all of the even sub-carriers $k+1,k+3,\ldots,k+(n-2),k+n$ of the other pair of antennas are active. This then reverses for the following pair of transmission intervals. This is only one way to map the single sub-carrier solution onto a set of sub-carriers.

In some embodiments different antennas are used for different sub-carriers (in frequency) to achieve power balancing in the time domain. This is OFDM specific, and is one of the reasons that the new code designs are attractive for practical implementation.

A performance advantage in terms of SNR gain of OFDM-STBC Code-C is provided in some embodiments is shown in Figure

3 over the prior art non-orthogonal, code rate 1 Code-B described previously.

In addition to performance improvements achieved by the new codes, they also possess other additional merits. In some embodiments, the solution is particularly adaptable to OFDM arrangements, but may be suitable for other systems if the resulting power imbalance is acceptable. In some embodiments, such a construction is optimum and can be generalized to 2n transmit antennas (no other R=1 full diversity code is known to date). This code also utilizes soft-decoding FEC codes to realize full diversity for the whole FEC code block. It is from STBC code-rate 1, full orthogonality of each STBC code block, and full diversity of the whole FEC code block point of view, that optimality is achieved. It was proven that the optimum code with code-rate 1, full orthogonality of each STBC code block, and full diversity for each transmitted symbol does not exist. In some embodiments, since in OFDM applications there are now three dimensions to map the Alamouti structure (essentially a 2 dimensional mapping), the time span for Alamouti mapping can be reduced by alternating the antenna or frequency dimension.

It is noted that one basic assumption of STBC is that the channel does not change from one transmission to the next transmission. For the prior art codes describe above, each QAM symbol is transmitted four times, and this can cause performance loss in the case of mobility, where the basic assumption becomes less and less true. Obviously, the longer the time (or frequency) that elapses between the first and the last transmission, the greater the loss that will be resulted in. The new codes are well suited for this case, for each QAM symbol is only transmitted twice, consecutively.

Figures 4 and 5 show that the performance of embodiments of OFDM-STBC code-C is consistently better than the prior art codes presented above pertaining to performance for high mobility speed and performance for low mobility speed, respectively.

The above described code mappings are examples resulting from of a more general method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2. 2n transmission symbols are transmitted during n pairs of consecutive transmission intervals, by transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during the n pairs of consecutive transmission intervals and only one pair of antennas is active during a given transmission interval. In some embodiments, this method is performed on a per-OFDM sub-carrier basis. Furthermore, the different antenna hopping patterns generally serve to map transmission symbols to the antennas using different patterns for different transmission periods.

CODE RATE 2 OFDM-STBC FOR 4 TRANSMIT ANTENNAS

The fully orthogonal structure for a four antenna transmit case does not exist when the space-time coding rate is 2. However, a sub-optimal code structure can be constructed, as shown in Table 6. Table 7A and Table 7B provide alternative antenna hopping variants. Furthermore, while the detailed examples given here focus on four antenna applications, they can be easily extended to systems with more than four antennas.

Table 6 - OFDM-STBC code rate 2 orthogonal code (Code-D)
(*Antenna Hopping Pattern-1*)

	Time *t*	Time

		$(t+T)$
Antenna 1	s_1	$-s_2^*$
Antenna 2	s_2	s_1^*
Antenna 3	s_3	$-s_4^*$
Antenna 4	s_4	s_3^*

Table 7A - OFDM-STBC code rate 2 orthogonal code (Code-D)
(*Antenna Hopping Pattern-2*)

	Time t	Time $(t+T)$
Antenna 1	s_1	$-s_3^*$
Antenna 2	s_2	$-s_4^*$
Antenna 3	s_3	s_1^*
Antenna 4	s_4	s_2^*

Table 7B - OFDM-STBC code rate 2 orthogonal code (Code-D)
(*Antenna Hopping Pattern-3*)

	Time t	Time $(t+T)$
Antenna 1	s_1	$-s_4^*$
Antenna 2	s_2	$-s_3^*$
Antenna 3	s_3	s_2^*

Antenna 4	s_4	s_1^*

The above described code mappings are examples resulting from of a more general method for mapping a space-time block code for a 2n antenna transmitter where n >=2. 2n transmission symbols are transmitted during two consecutive transmission intervals, by transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas.

The three code rate 2 "hopping pattern" codes can be combined in various different ways to form a code set.

EXTENSION TO THE FREQUENCY DIRECTION MAPPING

The above STBC code construction is provided in the form that maps the Alamouti structure in the time direction, however, such an arrangement can be also mapped onto the frequency direction.

Similar to the mapping in the time direction, an example of a power balance arrangement for the mapping for the frequency direction is shown in Figure 6. In Figure 6, the sub-carriers are indicated in the frequency domain in columns k,k+1,k+2,k+3,...,k+(n-3)k+(n-2),k+(n-1),k+n and time intervals are indicated in the time domain in rows t,t+T,t+2T,t+3T in which STBC blocks 30 are represented. During the first two sub-carriers, k and k+1, Antennas 1 and 2 transmit an Alamouti block on the time interval t, and during the next two sub-carriers, k+2 and k+3, Antennas 3 and 4 transmit an Alamouti block. This structure is then repeated for subsequent time intervals (the vertical direction in Figure 6). In the illustrated example, on a given pair of sub-carriers, during the odd time intervals t,t+2T,...,t+(n-1)T one pair of antennas

is active, and during the even time intervals t+T,t+3T,...,t+mT the other pair of antennas is active. This then reverses for the following pair of sub-carriers. This is only one of many ways to map the single sub-carrier solution onto a set of sub-carriers.

Examples of STBC codes for mapping the Alamouti structure in the frequency direction are listed in Table 8, Table 9A and Table 9B for code rate 1 and Table 10 and Table 11 are for code rate 2.

Furthermore, while the detailed examples given here focus on four antenna applications, they can be easily extended to systems with more than four antennas.

Table 8 - OFDM-STBC code rate 1 orthogonal code

(Antenna Hopping Patter-1)

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

Table 9A - OFDM-STBC code rate 1 orthogonal code

(Antenna Hopping Pattern-2)

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3

Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

Table 9B - OFDM-STBC code rate 1 orthogonal code (*Antenna Hopping Pattern-3*)

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

The above described code mappings are examples resulting from of a more general method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2. 2n transmission symbols are transmitted on each sub-carrier of a plurality of sub-carriers in an OFDM spectrum, for each transmission interval, on each of n pairs of adjacent OFDM sub-carriers, by transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all sub-carriers are used and only one pair of antennas is active during a given transmission interval for a given sub-carrier. In some embodiments, during a given

transmit interval, sub-carriers are active in pairs, alternating between pairs of transmit antennas. Furthermore, the different antenna hopping patterns generally serve to map transmission symbols to the antennas using different patterns for different sub-carriers.

Table 10 - OFDM-STBC code rate 2 orthogonal code (*Antenna Hopping Pattern-1*)

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$
Antenna 2	s_2	s_1^*
Antenna 3	s_3	$-s_4^*$
Antenna 4	s_4	s_3^*

Table 11A - OFDM-STBC code rate 2 orthogonal code (*Antenna Hopping Pattern-2*)

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_3^*$
Antenna 2	s_2	$-s_4^*$
Antenna 3	s_3	s_1^*
Antenna 4	s_4	s_2^*

Table 11B - OFDM-STBC code rate 2 orthogonal code (*Antenna Hopping Pattern-3*)

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_4^*$
Antenna 2	s_2	$-s_3^*$
Antenna 3	s_3	s_2^*
Antenna 4	s_4	s_1^*

The above described code mappings are examples resulting from of a more general method for mapping a space-time block code for a 2n antenna transmitter where n >=2. 2n transmission symbols are transmitted for each transmission interval on a pair of adjacent OFDM sub-carriers, by transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas.

Extension to 3 transmit antennas

The new codes can be extended to odd numbers of transmit antennas as well. Table 12 and Table 13 are embodiments of the transmit antenna OFDM-STBC code in the time direction and in frequency direction, respectively for an example with three antennas. In these embodiments the code rate is reduced to 2/3, however, however full orthogonality is achieved.

Table 12 - OFDM-STBC code rate 2/3 orthogonal code (*Antenna Hopping Pattern-1*)

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*

Table 13 - OFDM-STBC code rate 2/3 orthogonal code (*Antenna Hopping Pattern-2*)

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*

CODE RATE 4 OFDM-STBC FOR 4 TRANSMIT ANTENNAS

Code rate 4 arrangements become the typical parallel spatial multiplexing known as BLAST. In Table 14 and Table 15 embodiments of a mapping of 4 transmit antenna BLAST in time and in frequency are listed. Furthermore, while the detailed examples given here focus on four antenna applications, they can be easily extended to systems with more than four antennas.

Table 14 - OFDM-STBC code rate 4 orthogonal code

	Time t	Time $(t+T)$

Antenna 1	s_1	s_5
Antenna 2	s_2	s_6
Antenna 3	s_3	s_7
Antenna 4	s_4	s_8

Table 15 - OFDM-STBC code rate 4 orthogonal code

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	s_5
Antenna 2	s_2	s_6
Antenna 3	s_3	s_7
Antenna 4	s_4	s_8

OFDM-STBC CODE SETS WITH ANTENNA HOPPING

Various embodiments of 4 antenna transmit ODFM-STBC code sets, are listed in Tables 16A, 16B, and 16C.

Table 16A - Code Set Rate 1

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0

	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

Table 16B - Code Set Rate 2

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$	Time $(t+4T)$	Time $(t+5T)$
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*
	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

Table 16C - Code Set Rate 4

Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}
	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

Tables 16A, 16B, and 16C are embodiments of code sets for space-time mappings in the time direction. Similarly, the space-time mappings could be expressed in the frequency direction as well, as shown in Tables 16D, 16E, and 16F.

Table 16D - Code Set Rate 1

		Sub-	Sub-	Sub-	Sub-

		carrier k	carrier k+1	carrier k+2	carrier k+3
Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0
	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

Table 16E - Code Set Rate 2

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3	Sub-carrier k+4	Sub-carrier k+5
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*
	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

Table 16F - Code Set Rate 4

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}

	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

A specific Alamouti coded has been used in the examples. It is to be understood that any code having the Alamouti structure can be employed.

DECODER COMPLEXITY

A decoder complexity for the 4 transmit STBC of Code-C compared with the prior art codes is listed in Table 17. It can be seen that the complexity of the OFDM-STBC Code-C is 16 times less than the prior art codes.

Table 17 - Complexity Comparison

	Code-A	Code-B	Code-C	
	Rate = 1	Rate = 1	Rate = 1	Rate = 2
Complexity	64	64	4	64

Space-Time Frequency Mapping for Multiple Transmit Antennas

As described above, the space-time coding can be mapped onto either the time direction or the frequency direction. In other embodiments, a mapping is provided that utlizes both time and frequency mapping, while providing for the entire antenna transmission on each sub-carrier based on the code format. Advantages of this combined time-frequency mapping include minimizing the time-frequency span to ensure the space-time code span is within both a coherent-time and coherent-frequency range. The following examples are provided in particular for 4 transmit antennas, but it is to be

understood that the space-time frequency mapping approach can be generalized for systems with a different number of transmit antennas.

Table 18 - OFDM-Space-Time Frequency BC code rate 3/4

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	$-s_3^*$	×
Antenna 2	s_2	s_1^*	×	s_3^*
Antenna 3	s_3	×	s_1^*	$-s_2^*$
Antenna 4	×	$-s_3$	s_2	s_1

Table 19 - OFDM-Space-Time Frequency BC code rate 1
(*Antenna Hopping Pattern-1*)

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

Table 20 - OFDM-Space-Time Frequency BC code rate 1
(*Antenna Hopping Pattern-2*)

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

Table 21 - OFDM-Space-Time Frequency BC code rate 1
(*Antenna Hopping Pattern-3*)

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

Table 22 - OFDM-Space-Time Frequency BC code rate 2
(*Antenna Hopping Pattern-1*)

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$
Antenna 2	s_2	s_1^*	s_6	$-s_8^*$
Antenna 3	s_3	$-s_4^*$	s_7	s_5^*
Antenna 4	s_4	s_3^*	s_8	s_6^*

Table 23 - OFDM-Space-Time Frequency BC code rate 2 (*Antenna Hopping Pattern-2*)

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$
Antenna 2	s_2	s_1^*	s_7	s_5^*
Antenna 3	s_3	$-s_4^*$	s_6	$-s_8^*$
Antenna 4	s_4	s_3^*	s_8	s_6^*

Table 24 - OFDM-Space-Time Frequency BC code rate 4

	Time t Sub-	Time t+T Sub-carrier	Time t Sub-carrier	Time t+T Sub-

	carrier k	k	k+1	carrier k+1
Antenna 1	s_1	s_5	s_9	s_{13}
Antenna 2	s_2	s_6	s_{10}	s_{14}
Antenna 3	s_3	s_7	s_{11}	s_{15}
Antenna 4	s_4	s_8	s_{12}	s_{16}

Numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practised otherwise than as specifically described herein.

CLAIMS:

1. A method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by:

during n pairs of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during the n pairs of consecutive transmission intervals and only one pair of antennas is active during a given transmission interval.

2. The method of claim 1 further comprising:

mapping transmission symbols to the antennas using at least two different patterns for different transmission periods.

3. The method of claim 1 wherein the mapping achieves a diversity order 2 per transmission symbol, the method further comprising performing FEC coding before the mapping such that between the FEC coding and the mapping a full diversity is provided.

4. The method of claim 1 applied in an OFDM transmitter on a per-OFDM sub-carrier basis.

5. The method of claim 4 further comprising:

mapping transmission symbols to the antennas using at least two different patterns for different transmission periods.

6. The method of claim 1 wherein n=2.

7. The method of claim 1, wherein the mapping is one of:

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

or

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

8. The method of claim 4, wherein power balancing is achieved by mapping the Alamouti blocks to sub-carriers such that during a given transmission interval, each antenna has a substantially similar number of active sub-carriers.

9. The method of claim 8, wherein during each pair of transmission intervals for a first set of sub-carriers a first mapping is employed, and for a second set of sub-carriers a second mapping is employed that is the inverse of that first mapping.

10. The method of claim 9, wherein the first mapping is one of:

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0

Antenna 4	0	0	s_4	s_3^*

or

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

11. The method of claim 9, wherein the first set of sub-carriers are odd sub-carriers or even sub-carriers and the second set of sub-carriers are the remaining sub-carriers.

12. The method of claim 4, wherein the active antennas of a given sub-carrier alternate every transmission interval.

13. A method for mapping a rate one space-time block code for a 2n antenna transmitter where n>=2, the method comprising transmitting 2n transmission symbols on each sub-carrier of a plurality of sub-carriers in an OFDM spectrum by:

for each transmission interval:

on each of n pairs of adjacent OFDM sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all sub-carriers are used and only one pair of antennas is active during a given transmission interval for a given sub-carrier.

14. The method of claim 13, wherein during a given transmit interval, sub-carriers are active in pairs, alternating between pairs of transmit antennas.

15. The method of claim 14, wherein there are four transmit antennas, and during a given transmit interval even pairs of sub-carriers are active on a first pair of transmit antennas, and odd pairs of sub-carriers are active on a second pair of transmit antennas.

16. The method of claim 15, wherein in each transmit interval, the active sub-carriers are switched between the pairs of antennas.

17. The method of claim 15, wherein the active antennas of a given sub-carrier alternate every transmission interval.

18. The method of claim 13 further comprising:

mapping transmission symbols to the antennas using at least two different patterns for different active sub-carriers.

19. The method of claim 13, wherein the mapping is one of:

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

or

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

20. The method of claim 14, wherein for each pair of sub-carriers for a first pair of time intervals a first mapping is employed, and for a second pair of time intervals a second mapping is employed that is the inverse of that first mapping.

21. The method of claim 20, wherein the first mapping is one of:

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier

				k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

,

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

or

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

22. A method for mapping a space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by:

during two consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas.

23. The method of claim 22 applied in an OFDM transmitter on a per-OFDM sub-carrier basis.

24. The method of claim 22 further comprising:

mapping transmission symbols to the antennas using at least two different patterns for different transmission periods.

25. The method of claim 22, wherein the mapping is one of:

	Time t	Time $(t+T)$
Antenna 1	s_1	$-s_2^*$
Antenna 2	s_2	s_1^*
Antenna 3	s_3	$-s_4^*$
Antenna 4	s_4	s_3^*

	Time t	Time $(t+T)$
Antenna 1	s_1	$-s_3^*$

Antenna 2	s_2	$-s_4^*$
Antenna 3	s_3	s_1^*
Antenna 4	s_4	s_2^*

or

	Time t	Time $(t+T)$
Antenna 1	s_1	$-s_4^*$
Antenna 2	s_2	$-s_3^*$
Antenna 3	s_3	s_2^*
Antenna 4	s_4	s_1^*

26. A method for mapping a space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by:

for each transmission interval;

on a pair of adjacent OFDM sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas.

27. The method of claim 26, further comprising:

mapping transmission symbols to the antennas using at least two different patterns for different transmission periods.

28. The method of claim 26, wherein the mapping is one of:

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$
Antenna 2	s_2	s_1^*
Antenna 3	s_3	$-s_4^*$
Antenna 4	s_4	s_3^*

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_3^*$
Antenna 2	s_2	$-s_4^*$
Antenna 3	s_3	s_1^*
Antenna 4	s_4	s_2^*

or

	Sub-carrier k	Sub-carrier k+1
Antenna 1	s_1	$-s_4^*$
Antenna 2	s_2	$-s_3^*$
Antenna 3	s_3	s_2^*
Antenna 4	s_4	s_1^*

29. A method for mapping a space-time block code for a 2n+1 antenna transmitter where n >=1, the method comprising transmitting transmission symbols by:

during k pairs of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used during at least one of the k pairs of consecutive transmission intervals and at least one transmit antenna is used during two of the k pairs of consecutive transmission intervals.

30. The method of claim 29 applied on a per-sub-carrier basis to an OFDM application.

31. The method of claim 29, wherein the mapping is:

	Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*

32. A method for mapping a space-time block code for a 2n+1 antenna transmitter where n >=1 adapted to transmit transmission symbols by:

for each transmission interval:

on k pairs of sub-carriers, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas such that all antennas are used

during at least one of the k pairs of consecutive transmission intervals and at least one transmit antenna is used during two of the k pairs of sub-carriers.

33. The method of claim 32, wherein the mapping is:

	Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*

34. A method for mapping a space-time block code for a 4 antenna transmitter, the method comprising selecting an appropriate code rate code from a code set of available code rate codes, wherein the available code rate codes are generated using any one of claims 1-28.

35. A method for mapping a space-time block code for a 4 antenna transmitter, the method comprising selecting an appropriate code rate code from a code set of available code rate codes, wherein the code set is one of:

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0
	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$	Time $(t+4T)$	Time $(t+5T)$
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*
	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

or

		Time t	Time $(t+T)$	Time $(t+2T)$	Time $(t+3T)$
Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}
	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

36. A method for mapping a space-time block code for a 4 antenna transmitter, the method comprising selecting an appropriate code rate code from a code set of available code rate codes, wherein the code set is one of:

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3

Code Rate = 1	Antenna 1	s_1	$-s_2^*$	0	0
	Antenna 2	s_2	s_1^*	0	0
	Antenna 3	0	0	s_3	$-s_4^*$
	Antenna 4	0	0	s_4	s_3^*

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3	Sub-carrier k+4	Sub-carrier k+5
Code Rate = 2	Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$	s_9	$-s_{12}^*$
	Antenna 2	s_2	s_1^*	s_6	$-s_8^*$	s_{10}	$-s_{11}^*$
	Antenna 3	s_3	$-s_4^*$	s_7	s_5^*	s_{11}	s_{10}^*
	Antenna 4	s_4	s_3^*	s_8	s_6^*	s_{12}	s_9^*

or

		Sub-carrier k	Sub-carrier k+1	Sub-carrier k+2	Sub-carrier k+3
Code Rate = 4	Antenna 1	s_1	s_5	s_9	s_{13}
	Antenna 2	s_2	s_6	s_{10}	s_{14}
	Antenna 3	s_3	s_7	s_{11}	s_{15}
	Antenna 4	s_4	s_8	s_{12}	s_{16}

37. A method for mapping a rate 3/4 space-time block code for a 4 antenna transmitter, the method comprising transmitting 3 transmission symbols by:

during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a first respective pair of antennas on a given sub-carrier and transmitting a respective Alamouti code block containing one transmission symbol on a second respective pair of antennas on a same sub-carrier such that all antennas are used during the pair of consecutive transmission intervals.

38. The method of claim 37, wherein the mapping is:

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	$-s_3^*$	×
Antenna 2	s_2	s_1^*	×	s_3^*
Antenna 3	s_3	×	s_1^*	$-s_2^*$
Antenna 4	×	$-s_3$	s_2	s_1

39. A method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 2n transmission symbols by:

during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing two transmission symbols on a respective pair of antennas on a given sub-carrier such that all antennas are used during the

pair of consecutive transmission intervals and each pair of antennas is active on a different sub-carrier.

40. The method of claim 39, wherein the mapping is one of:

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	s_2	s_1^*	0	0
Antenna 3	0	0	s_3	$-s_4^*$
Antenna 4	0	0	s_4	s_3^*

5

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	0	0	s_4	s_3^*
Antenna 4	s_2	s_1^*	0	0

or

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	0	0
Antenna 2	0	0	s_3	$-s_4^*$
Antenna 3	s_2	s_1^*	0	0
Antenna 4	0	0	s_4	s_3^*

41. A method for mapping a rate one space-time block code for a 2n antenna transmitter where n >=2, the method comprising transmitting 4n transmission symbols by:

during a pair of consecutive transmission intervals, transmitting a respective Alamouti code block containing n transmission symbols on a respective pair of antennas on a given sub-carrier such that all antennas are used during the pair of consecutive transmission intervals.

42. The method of claim 41, wherein the mapping is one of:

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$
Antenna 2	s_2	s_1^*	s_6	$-s_8^*$

Antenna 3	s_3	$-s_4^*$	s_7	s_5^*
Antenna 4	s_4	s_3^*	s_8	s_6^*

or

	Time t Sub-carrier k	Time t+T Sub-carrier k	Time t Sub-carrier k+1	Time t+T Sub-carrier k+1
Antenna 1	s_1	$-s_2^*$	s_5	$-s_7^*$
Antenna 2	s_2	s_1^*	s_7	s_5^*
Antenna 3	s_3	$-s_4^*$	s_6	$-s_8^*$
Antenna 4	s_4	s_3^*	s_8	s_6^*

43. A method of transmitting a MIMO OFDM signal expressed in the form Y=HF(S), where Y^{1xM} is an output of a MIMO channel, H^{MxNT} is a matrix of MIMO channel characteristics, F(s) denotes a space-time coding matrix for a complex input symbol $S=[s_1 \ s_2 \ \ldots \ s_L]$ which is grouped as $S_1=[s_1 \ s_2 \ s_3 \ s_4]$, $S_2=[s_5 \ s_6 \ s_7 \ s_8]$ and $S_3=[s_9 \ s_{10} \ s_{11} \ s_{12}]$, the method comprising selecting an appropriate code for a wireless terminal adapted to receive the MIMO OFDM signal transmitted by a multi-antenna transmitter depending on a number of receiver antenna at the wireless terminal.

44. The method of claim 43, wherein a STC code rate 1 code suitable for a 4 transmitter antenna, 1 receiver antenna (4x1) configuration is:

$$F_{4x1}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & -s_2^* & -s_3^* & s_4 & s_5 & -s_7^* & -s_8^* & s_6 & s_9 & -s_{12}^* & -s_{10}^* & s_{11} \\ s_2 & s_1^* & -s_4^* & -s_3 & s_6 & s_8^* & s_7^* & s_5 & s_{10} & -s_{11}^* & s_9^* & -s_{12} \\ s_3 & -s_4^* & s_1^* & -s_2 & s_7 & s_5^* & -s_6^* & -s_8 & s_{11} & s_{10}^* & s_{12}^* & s_9 \\ s_4 & s_3^* & s_2^* & s_1 & s_8 & -s_6^* & s_5^* & -s_7 & s_{12} & s_9^* & -s_{11}^* & -s_{10} \end{bmatrix}$$

45. The method of claim 43, wherein a STC code rate 2 code suitable for a 4 transmitter antenna, 2 receiver antenna (4x2) configuration is:

$$F_{4x2}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* & s_9 & -s_{12}^* \\ s_2 & s_1^* & s_6 & s_8^* & s_{10} & -s_{11}^* \\ s_3 & -s_4^* & s_7 & s_5^* & s_{11} & s_{10}^* \\ s_4 & s_3^* & s_8 & -s_6^* & s_{12} & s_9^* \end{bmatrix},$$

46. The method of claim 43, wherein a STC Code Rate 4 code suitable for a 4 transmitter antenna, 4 receiver antenna (4x4) configuration is:

$$F_{4x4}(S_1,S_2,S_3)=\begin{bmatrix} s_1 & s_5 & s_9 \\ s_2 & s_6 & s_{10} \\ s_3 & s_7 & s_{11} \\ s_4 & s_8 & s_{12} \end{bmatrix}.$$

47. The method of claim 43, wherein a STC Code Rate 1 code suitable for a 2 transmitter antenna, 1 receiver antenna (2x1) configuration is:

$$F_{2x1}(S_1,S_2)=\begin{bmatrix} s_1 & -s_2^* & s_3 & -s_4^* \\ s_2 & s_1^* & s_4 & s_3^* \end{bmatrix}.$$

48. The method of claim 43, wherein a STC Code Rate 2 code suitable for a 2 transmitter antenna, 2 or 4 receiver antenna (2x2,2x4) configuration is:

$$F_{2x2,2x4}(S_1,S_2)=\begin{bmatrix} s_1 & s_3 \\ s_2 & s_4 \end{bmatrix}.$$

49. The method of any preceding claim further comprising employing an FEC code across a code block such that at a receiver, full diversity for the whole FEC code block is achieved.

50. The method of any preceding claim wherein each pair of antennas is spatially adjacent.

51. The method of any preceding claim wherein each pair of antennas is not spatially adjacent.

52. A coder for performing the method of any preceding claim.

53. A transmitter for an OFDM communications system comprising a coder for performing the method of any preceding claim.

54. An OFDM communication system comprising a transmitter adapted to perform the method of any preceding claim.

55. An OFDM communication system comprising a transmitter, the transmitter comprising a coder adapted to perform the method of any preceding claim.

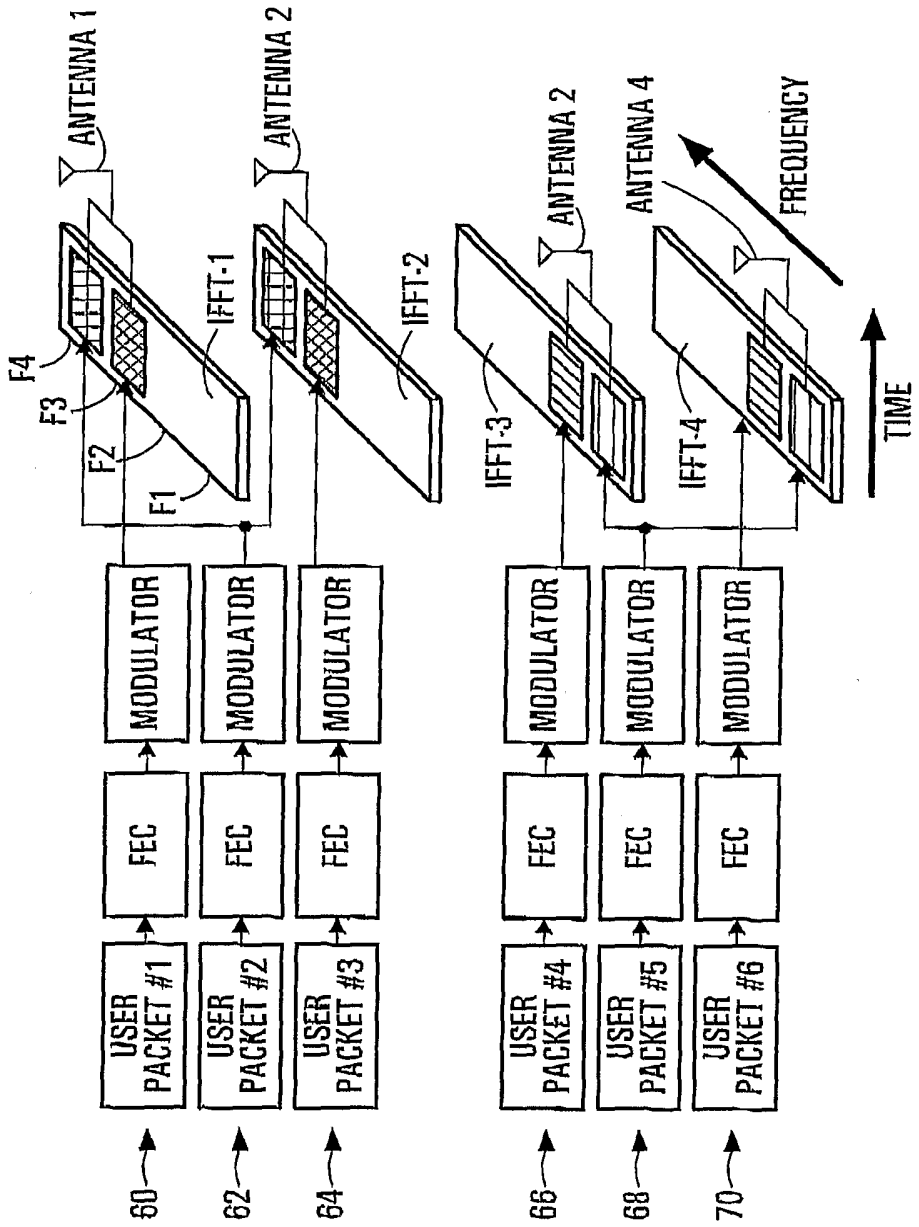

ANTENNA 1
ANTENNA 2
ANTENNA 2
ANTENNA 4
FREQUENCY
TIME
F4
F3
F2
F1
IFFT-1
IFFT-2
IFFT-3
IFFT-4
MODULATOR
FEC
USER PACKET #1
USER PACKET #2
USER PACKET #3
USER PACKET #4
USER PACKET #5
USER PACKET #6
60
62
64
66
68
70

FIG. 1A

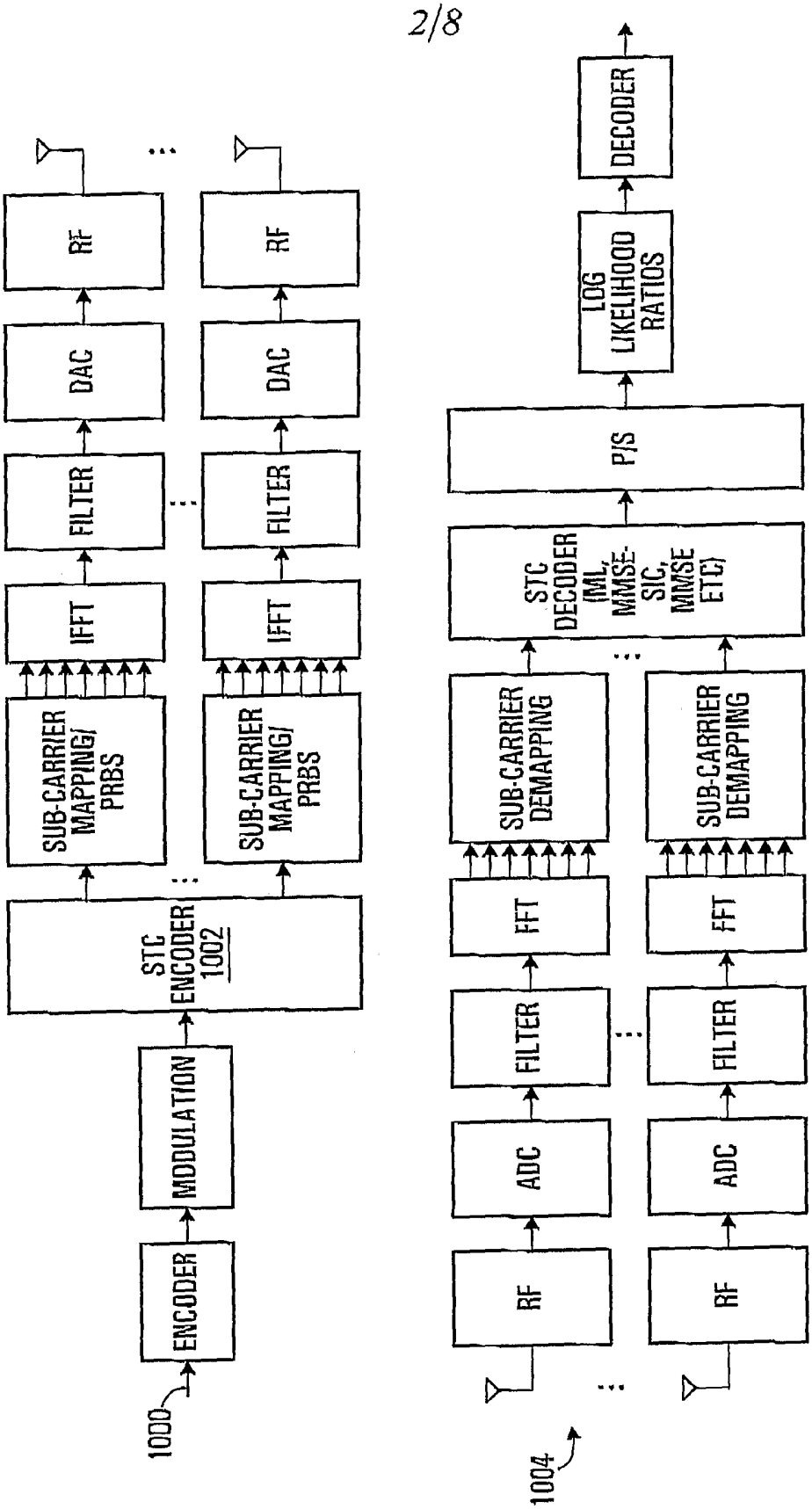

1000
ENCODER
MODULATION
STC ENCODER 1002
SUB-CARRIER MAPPING/ PRBS
IFFT
FILTER
DAC
RF
1004
RF
ADC
FILTER
FFT
SUB-CARRIER DEMAPPING
STC DECODER (ML, MMSE-SIC, MMSE ETC)
P/S
LOG LIKELIHOOD RATIOS
DECODER

FIG. 1B

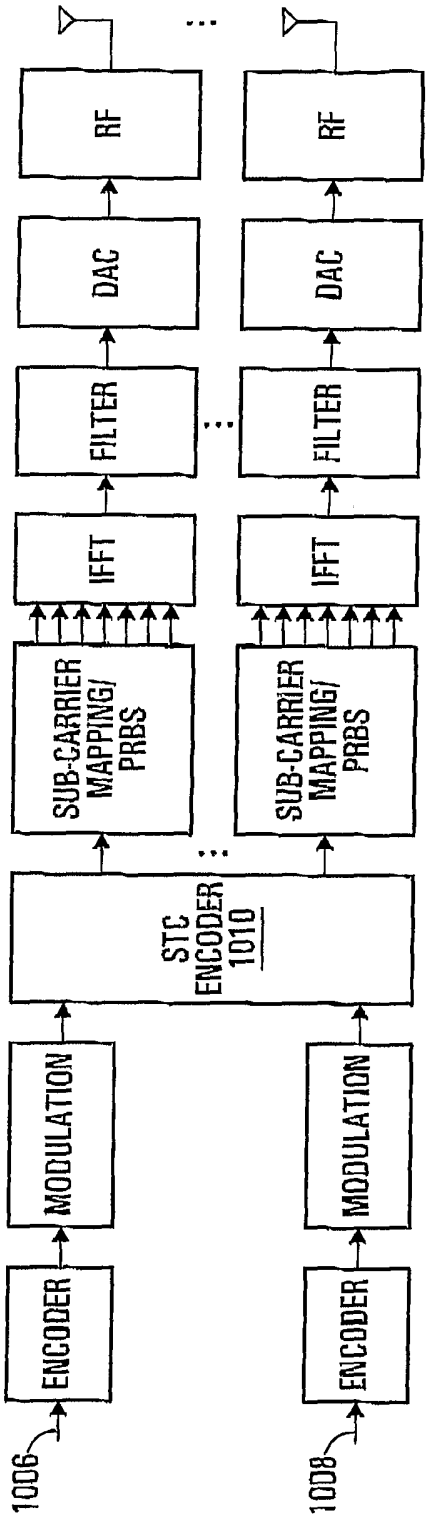

1006
1008
ENCODER
ENCODER
MODULATION
MODULATION
STC ENCODER 1010
SUB-CARRIER MAPPING/ PRBS
SUB-CARRIER MAPPING/ PRBS
IFFT
IFFT
FILTER
FILTER
DAC
DAC
RF
RF

FIG. 1C

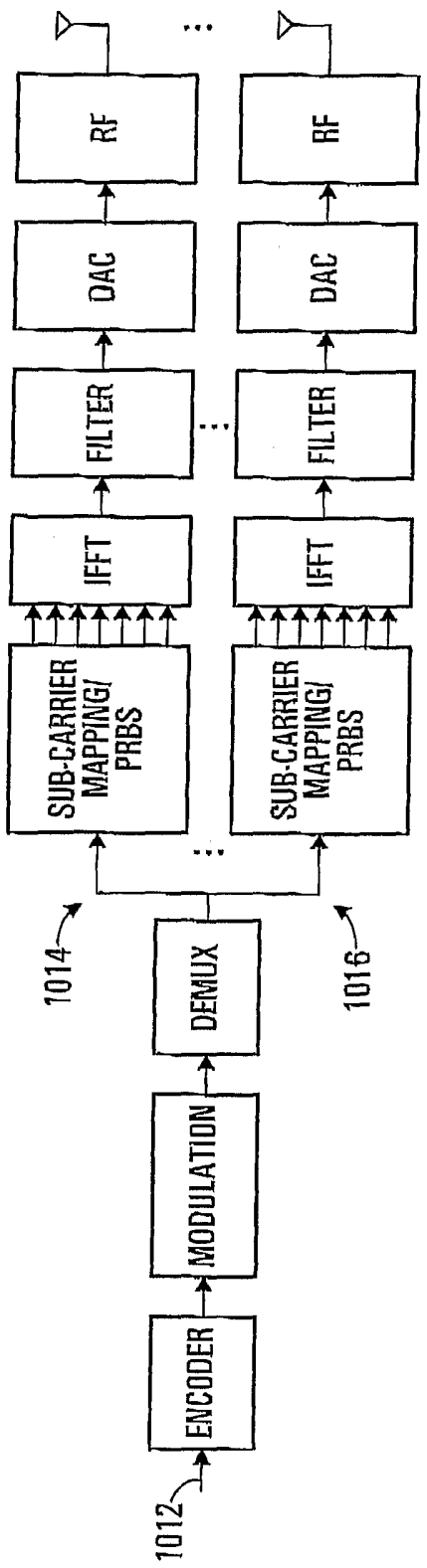

1012
ENCODER
MODULATION
DEMUX
1014
1016
SUB-CARRIER MAPPING/ PRBS
SUB-CARRIER MAPPING/ PRBS
IFFT
IFFT
FILTER
FILTER
DAC
DAC
RF
RF

FIG. 1D

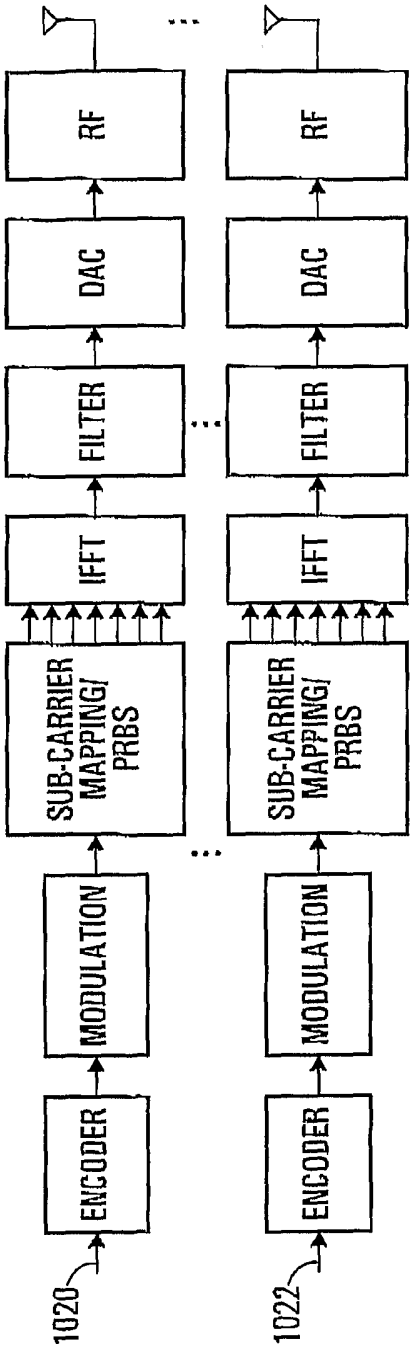

1020
1022
ENCODER
ENCODER
MODULATION
MODULATION
SUB-CARRIER MAPPING/ PRBS
SUB-CARRIER MAPPING/ PRBS
IFFT
IFFT
FILTER
FILTER
DAC
DAC
RF
RF

FIG. 1E

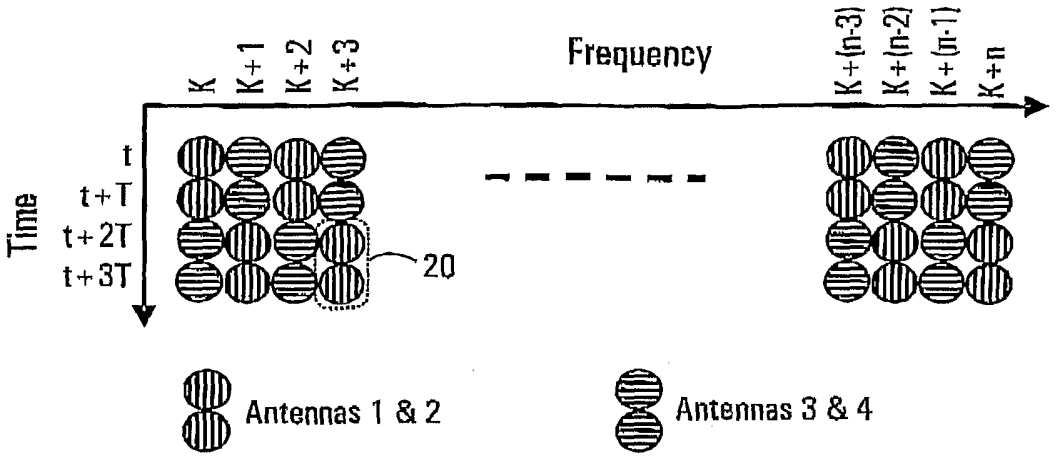

K
K+1
K+2
K+3
Frequency
K+(n-3)
K+(n-2)
K+(n-1)
K+n
Time
t
t+T
t+2T
t+3T
20
Antennas 1 & 2
Antennas 3 & 4

FIG. 2

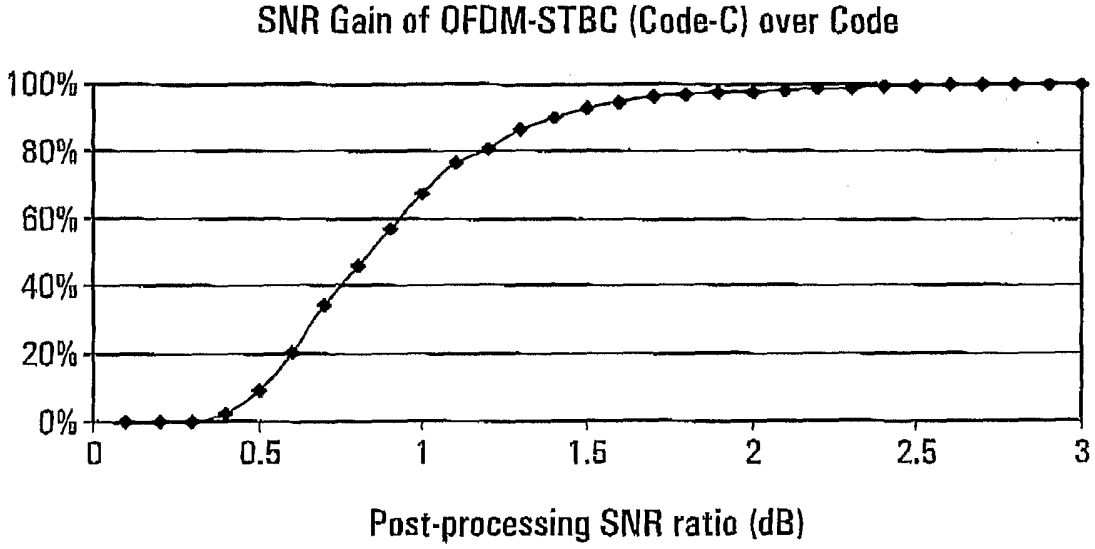

SNR Gain of OFDM-STBC (Code-C) over Code
100%
80%
60%
40%
20%
0%
0
0.5
1
1.5
2
2.5
3
Post-processing SNR ratio (dB)

FIG. 3

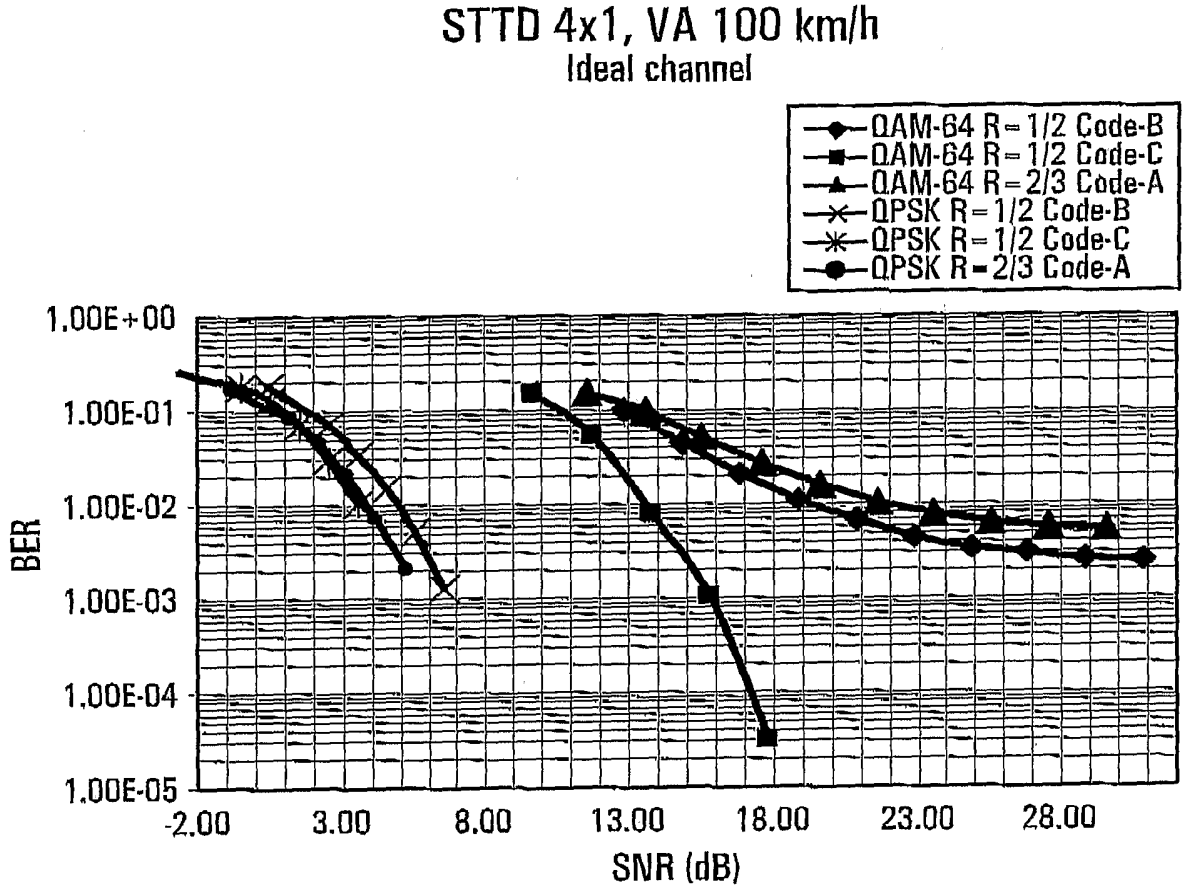

STTD 4x1, VA 100 km/h
Ideal channel
QAM-64 R=1/2 Code-B
QAM-64 R=1/2 Code-C
QAM-64 R=2/3 Code-A
QPSK R=1/2 Code-B
QPSK R=1/2 Code-C
QPSK R=2/3 Code-A
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
BER
-2.00
3.00
8.00
13.00
18.00
23.00
28.00
SNR (dB)

FIG. 4

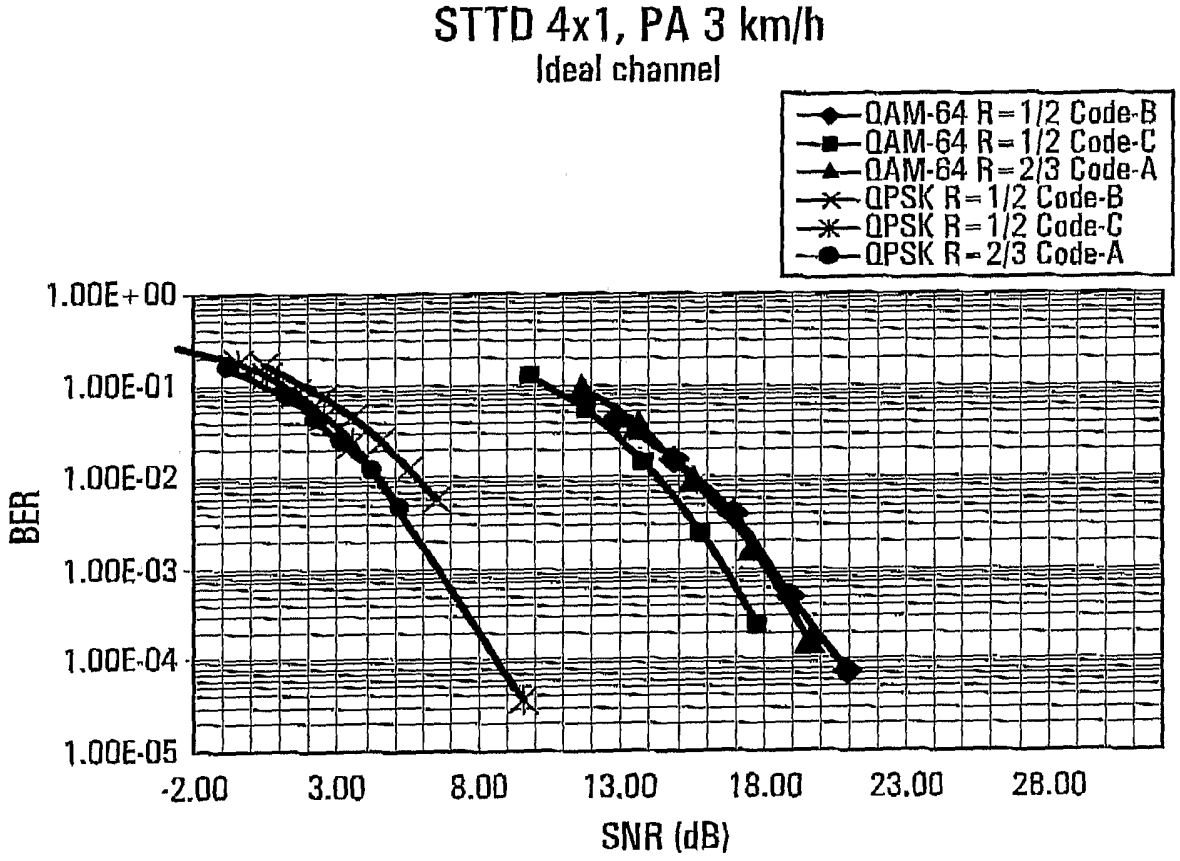

STTD 4x1, PA 3 km/h
Ideal channel
QAM-64 R=1/2 Code-B
QAM-64 R=1/2 Code-C
QAM-64 R=2/3 Code-A
QPSK R=1/2 Code-B
QPSK R=1/2 Code-C
QPSK R=2/3 Code-A
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
BER
-2.00
3.00
8.00
13.00
18.00
23.00
28.00
SNR (dB)

FIG. 5

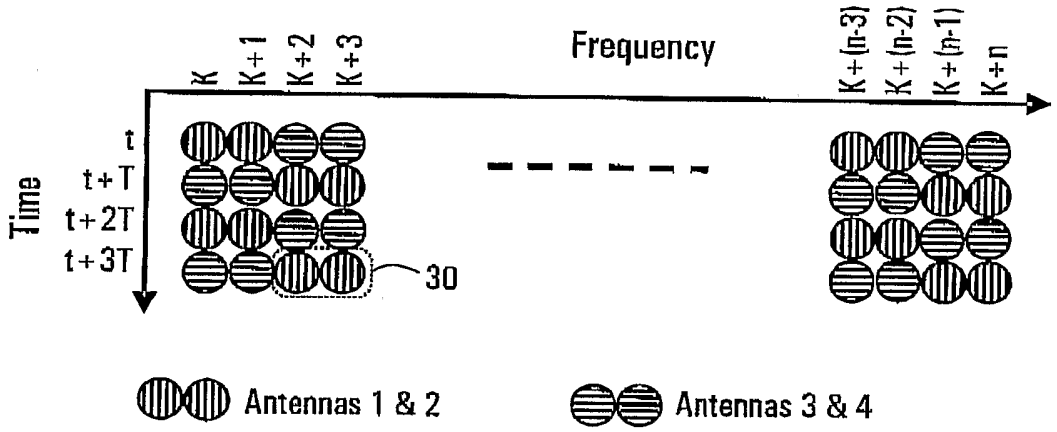

Frequency
K
K+1
K+2
K+3
K+(n-3)
K+(n-2)
K+(n-1)
K+n
Time
t
t+T
t+2T
t+3T
30
Antennas 1 & 2
Antennas 3 & 4

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2005/000504

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7): H04B 7/06, H04J 11/00, H03M 13/05

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(7): H04B 7/06, H04J 11/00, H03M 13/05, H04B-007/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
IEEE Xplore, Delphion, Canadian Database, Questel-Orbit PLUSPAT
space-time, Alamouti, 4 antennas, quasi-orthogonal, sub-carrier, sub-channel, code, orthogonal, OFDM, block code

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2003/0067993 (Viswanathan) 10 April, 2003 (10-04-2003) Abstract; Figure 2; Paragraphs [0005], [0007]-[0010]; Claims 1 - 5	1-3, 6, 7 4, 5, 8-21, 29-36, 39, 40, 49-55
Y	Suto et al. : "Performance Evaluation of Space-Time-Frequency Block Codes over Frequency Selective Fading Channels" Vehicular Technology Conference 2002 vol. 3; September 2002, pages 1466-1470 Section I; Section III; Section IV; Figure 2; Figure 3	4, 5, 8-21, 23, 26-28, 30, 32, 33, 36-42
X Y A	US 6185258 (Alamouti et al.) 06 Feb, 2001 (06-02-2001) Abstract; Figures 1-3; Column 3, line 18 - Column 4, line 52 <cited in the application>	22, 24, 25 23, 26-33, 35, 36, 41-48 1-21, 34, 37-40, 49-55
Y	US 2003/0053487 (Hamalainen et al.) 20 Mar, 2003 (20-03-2003) Abstract; Paragraphs [0017], [0018]	34-36, 43-48

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12-May-2005 (12-05-2005)	27 May 2005 (27-05-2005)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001(819)953-2476	Mark J. Stephens (819) 934-3472

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2005/000504

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Jafarkhani H. : "A Quasi-Orthogonal Space-Time Block Code" IEEE Transactions on Communications	44
A	vol. 49, Issue 1; January 2001, pages 1-4 Section I - Introduction Section II - Quasi-Orthogonal Space-Time Block Code Equation 5	1-43, 45-55
Y	Tirkonnen et al. : "Square-Matrix Embeddable Space-Time Block Codes for Complex Signal Constellations"	37, 38
A	IEEE Transactions on Information Theory vol. 48, Issue 2; February 2002, pages 384-395 Section IV -Unitary Designs Equation 22	1-36, 39-55
A	US 2003/0138058 (Agrawal et al.) 24 Jul, 2003 (24-07-2003) Abstract; Figure 2; Paragraphs [0016] - [0020]	4, 5, 8-21, 23, 26-28, 30, 32, 33, 36-42
A	US 2003/0235149 (Chan et al.) 25 December, 2003 (25-12-2003) Abstract; Paragraphs [0007]-[0009]	13-21, 26-28, 32, 33, 36
A	Tarokh et al. : "Space-Time Block Codes from Orthogonal Designs" IEEE Transactions on Information Theory vol. 45, Issue 5; July 1999, pages 1456-1467 *Whole document*	1-55

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