

Overview of frequency hopping algorithm

Hopping rate

Each bearer will change frequency channel, or hop, once per frame, i.e. the bearer hopping rate is 100 hops/second.

In the case of a traffic bearer this means that in a particular frame, both the down-link and up-link slots will use the same frequency channel.

With 4 active traffic bearers, each hopping at 100 hops/sec, there will be 800 frequency changes/second. However, because down-link and up-link use the same channel, this is only actually 400 channels/second.

Hopping Sequence

There are two methods employed for generating the hopping sequences: tables and random number generators (RNGs). Tables are hand-crafted to have specific properties and reverse table-lookup can be used to deduce the position in the table. RNGs generate very long period sequences which are less prone to 'sequence collision'. Both methods are employed in the EDCT system.

A. Hopping pattern base-table

A dummy bearer or combined dummy/traffic bearer uses a table-generated hop sequence.

A single base-table is constructed containing a permutation of the channel numbers 0, 1, 2, ..., 74 (there are no repeats in the sequence). An extract is shown in the following table where 'i' is the index, and 'F₀' is the base-table sequence.

i	F ₀ (i)
0	0
1	27
2	38
3	14
...	...
7	44
4	

(This is only an extract; the full base table is shown in "Appendix B – Base-Table Hopping Sequence").

From this one base-table, additional sequences are generated using the formula:

$$F_x(i) = (F_0(i) + x) \bmod 75$$

The sequence index 'i' in the above formula is incremented, modulo 75, each frame. The value 'x' is used to select the required pattern. Due to the modulus there are 75 unique patterns permuted from this single base-table.

The following table shows an extract of the patterns.

i	F ₀ (i)	F ₁ (i)	F ₂ (i)	F ₃ (i)	...	F ₇₄ (i)
0	0	1	2	3	...	74
1	27	28	29	30	...	26
2	38	39	40	41	...	37
3	14	15	16	17	...	13
...	...	...	...	...	...	...
8	73	74	0	1	...	72
...	...	...	...	...	...	...
7	44	45	46	47	...	43
4						

The base-table is hand-crafted to meet the following criteria:

- Pseudo-random.
- When any pattern is time-shifted with respect to any other pattern, the number of direct and adjacent channel collisions is minimised. In this context, because of the expected RF performance, adjacent should be taken to mean within 3 channels or less.

- When any pattern is time-shifted with respect to any other pattern, the number of direct or adjacent channel collisions on consecutive hops is minimised. Collisions are minimised for 2, 3 and 4 (or more) consecutive hops.
- Successive channels in the sequence are separated sufficiently to avoid microwave oven interference. In this context, a minimum channel separation of 6 or 8 MHz should be considered sufficient.

B. LCG random number generator

Traffic bearers use a pseudo-random number generated hop sequence. The random number generator (RNG) is a Linear Congruential Generator (LCG). The general form of an LCG is:

$$R_{n+1} = (a \times R_n + c) \bmod m$$

A channel number in the range 0...74 is obtained by applying:

$$\text{Channel number} = (75 \times R_n) / m$$

In the above formula integer division is used. A particular LCG is denoted by LCG(m, a, c, R₀). The proposed RNG for EDCT is LCG(3000, (2×3×4×5×7+1) = 841, 787, R₀):

The modulus (m) is less than 2¹⁶ so that the 'state' can be stored in a single word (16 bits).

This is a full period generator, with a period of 3000, equivalent to 30 seconds and is also a multiple of 75.

As such, all channels are used equally and all channels are used equally over a 30 second period.

The full 3000-long sequence is shown in "Appendix C – LCG Random Hopping Sequence".

C. Logical and physical channel numbers

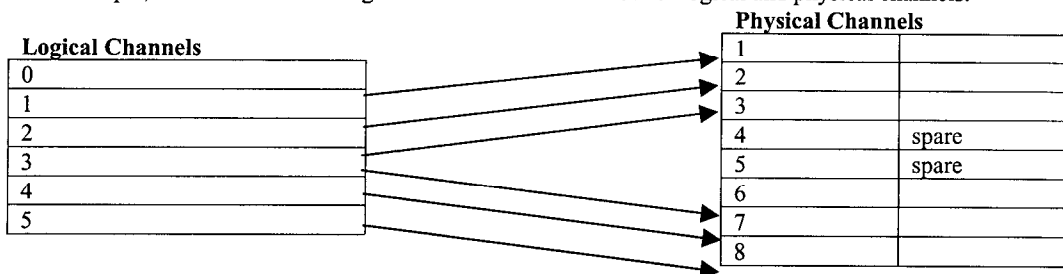
The techniques described so far generate channel numbers in the range 0...74. The EDCT system can use a total of 87 hopping channels (numbered from 1... 88, avoiding channel 71,). This results in 12 channels that are not part of the normal sequence and these are reserved as 'spare channels'.

The spare channels are used to adapt the hop sequence, which is a method used by EDCT to avoid noisy frequency channels (see later).

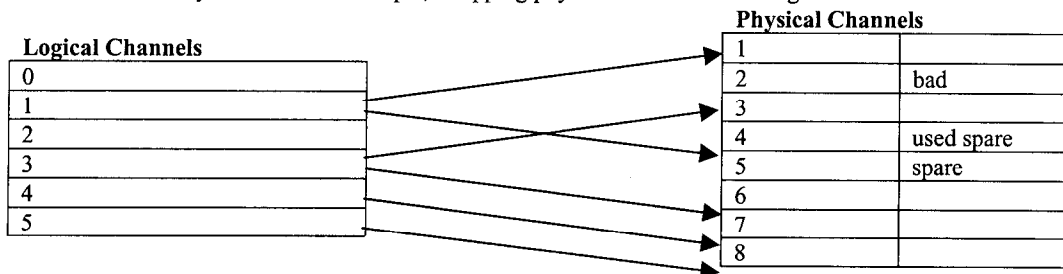
A mapping table is used to convert the 'logical channel number' (in the range 0 ... 74) given by the hopping sequence to the 'physical channel number' (in the range 1 ... 88) that is actually used.

An important feature of the mapping table is that it is always a one-to-one mapping, i.e. a physical channel is only ever 'mapped-onto' by one logical channel. In this way the channel usage characteristics of the hop sequence are preserved.

For example, consider the following scenario for a small number of logical and physical channels:



Noisy channels can be adapted out of the sequence by 'channel swapping', i.e. swapping a good spare channel for a noisy channel. For example, swapping physical channels 1 and 3 gives:



Obviously, the above mapping table is an example.. It satisfies the following criteria:

It maps the 75 logical channels onto 87 physical channels, with a one-to-one mapping. This leaves 12 spare channels that are not used in the unadapted hopping sequence.



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The spare channels are only positioned around the 2.45 GHz area. The reason for this is that interference from microwave ovens is most likely¹ to be centred on 2.45 GHz.

To facilitate robust 'sequence adaption' a requirement is that the basic underlying pattern should be changed as little as possible. This is achieved by always ensuring that the channels are swapped back to their original positions when the channel stops being noisy.

Appendix B – Base-Table Hopping Sequence

The following table, arranged as an 8×10 grid, is the base table for the hopping sequence. The sequence is 75 hops long.

	0	1	2	3	4	5	6	7	8	9
0	0	27	38	14	26	49	13	33	73	55
10	16	1	11	54	8	64	2	48	28	61
20	4	40	65	6	23	67	57	42	12	29
30	62	36	47	5	71	43	32	56	21	59
40	39	15	53	18	45	37	74	63	46	3
50	51	31	72	58	9	70	35	69	25	34
60	50	60	68	22	52	24	41	7	17	30
70	19	10	20	66	44					

Appendix C – LCG Random Hopping Sequence

The following table, is the random channel sequence produced by the LCG random number generator. The sequence is 3000 hops long.

	0	1	2	3	4	5	6	7	8	9
0	0	19	66	20	60	68	73	29	43	69
10	61	51	68	66	2	55	29	31	15	10
20	48	8	69	38	19	41	61	33	61	27
30	35	39	71	10	35	28	18	34	33	44
40	22	71	73	57	52	15	50	36	5	61
50	8	28	0	28	69	2	6	38	52	2
60	70	60	1	0	11	63	38	40	23	19
70	57	16	3	47	27	50	70	41	70	36
80	44	48	5	19	44	37	27	43	42	53
90	30	5	7	65	61	24	58	45	14	69
100	17	37	8	37	3	10	15	47	60	11
110	4	68	10	9	19	72	47	48	32	28
120	66	25	12	56	36	59	4	50	4	45
130	52	57	14	27	53	46	35	52	51	61
140	39	14	15	74	70	32	67	54	22	3
150	26	45	17	46	11	19	24	55	69	20
160	13	2	19	18	28	6	56	57	41	37
170	74	34	21	64	45	68	12	59	13	53
180	61	66	22	36	62	54	44	61	59	70
190	48	22	24	8	3	41	1	62	31	12
200	35	54	26	55	20	28	33	64	3	29
210	21	11	28	26	37	15	64	66	50	45
220	8	43	29	73	54	1	21	68	21	62
230	70	74	31	45	70	63	53	69	68	4
240	57	31	33	17	12	50	10	71	40	21
250	43	63	35	63	29	37	41	73	12	37
260	30	20	36	35	46	23	73	0	58	54
270	17	51	38	7	62	10	30	1	30	71
280	4	8	40	54	4	72	62	3	2	13
290	65	40	42	25	21	59	18	5	49	29
300	52	72	43	72	38	45	50	7	20	46
310	39	28	45	44	54	32	7	8	67	63
320	26	60	47	16	71	19	39	10	39	5
330	12	17	49	62	13	6	70	12	11	21
340	74	49	50	34	30	67	27	14	57	38
350	61	5	52	6	46	54	59	15	29	55



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360	48	37	54	53	63	41	16	17	1	72
370	34	69	56	24	5	28	47	19	48	13
380	21	26	57	71	22	14	4	21	19	30
390	8	57	59	43	38	1	36	22	66	47
400	70	14	61	15	55	63	68	24	38	64
410	56	46	63	61	72	50	24	26	10	5
420	43	3	64	33	14	36	56	28	56	22
430	30	34	66	5	30	23	13	29	28	39
440	17	66	68	52	47	10	45	31	0	56
450	3	23	70	23	64	72	1	33	47	72
460	65	55	71	70	6	58	33	35	18	14
470	52	11	73	42	22	45	65	36	65	31
480	39	43	0	14	39	32	22	38	37	48
490	25	0	2	60	56	19	53	40	9	64
500	12	32	3	32	73	5	10	42	55	6
510	74	63	5	4	14	67	42	43	27	23
520	61	20	7	51	31	54	74	45	74	40
530	47	52	9	22	48	41	30	47	46	56
540	34	9	10	69	65	27	62	49	17	73
550	21	40	12	41	6	14	19	50	64	15
560	8	72	14	13	23	1	51	52	36	32
570	69	29	16	59	40	63	7	54	8	48
580	56	61	17	31	57	49	39	56	54	65
590	43	17	19	3	73	36	71	57	26	7
600	30	49	21	50	15	23	28	59	73	24
610	16	6	23	21	32	10	59	61	45	40
620	3	38	24	68	49	71	16	63	16	57
630	65	69	26	40	65	58	48	64	63	74
640	52	26	28	12	7	45	5	66	35	16
650	38	58	30	58	24	32	36	68	7	32
660	25	15	31	30	41	18	68	70	53	49
670	12	46	33	2	57	5	25	71	25	66
680	74	3	35	49	74	67	57	73	72	8
690	60	35	37	20	16	54	13	0	44	24
700	47	67	38	67	33	40	45	2	15	41
710	34	23	40	39	49	27	2	3	62	58
720	21	55	42	11	66	14	34	5	34	0
730	7	12	44	57	8	1	65	7	6	16
740	69	44	45	29	25	62	22	9	52	33
750	56	0	47	1	41	49	54	10	24	50
760	43	32	49	48	58	36	11	12	71	67
770	29	64	51	19	0	23	42	14	43	8
780	16	21	52	66	17	9	74	16	14	25
790	3	52	54	38	33	71	31	17	61	42
800	65	9	56	10	50	58	63	19	33	59
810	51	41	58	56	67	45	19	21	5	0
820	38	73	59	28	9	31	51	23	51	17
830	25	29	61	0	25	18	8	24	23	34
840	12	61	63	47	42	5	40	26	70	51
850	73	18	65	18	59	67	71	28	42	67
860	60	50	66	65	1	53	28	30	13	9
870	47	6	68	37	17	40	60	31	60	26
880	34	38	70	9	34	27	17	33	32	43
890	20	70	72	55	51	14	48	35	4	59

900	7	27	73	27	68	0	5	37	50	1
910	69	58	0	74	9	62	37	38	22	18
920	56	15	2	46	26	49	69	40	69	35
930	42	47	4	17	43	36	25	42	41	51
940	29	4	5	64	60	22	57	44	12	68
950	16	35	7	36	1	9	14	45	59	10
960	3	67	9	8	18	71	46	47	31	27
970	64	24	11	54	35	58	2	49	3	43
980	51	56	12	26	52	44	34	51	49	60
990	38	12	14	73	68	31	66	52	21	2
1000	25	44	16	45	10	18	23	54	68	19
1010	11	1	18	16	27	5	54	56	40	35
1020	73	33	19	63	44	66	11	58	11	52
1030	60	64	21	35	60	53	43	59	58	69
1040	47	21	23	7	2	40	0	61	30	11
1050	33	53	25	53	19	27	31	63	2	27
1060	20	10	26	25	36	13	63	65	48	44
1070	7	41	28	72	52	0	20	66	20	61
1080	69	73	30	44	69	62	52	68	67	3
1090	55	30	32	15	11	49	8	70	39	19
1100	42	62	33	62	28	35	40	72	10	36
1110	29	18	35	34	44	22	72	73	57	53
1120	16	50	37	6	61	9	29	0	29	70
1130	2	7	39	52	3	71	60	2	1	11
1140	64	39	40	24	20	57	17	4	47	28
1150	51	70	42	71	36	44	49	5	19	45
1160	38	27	44	43	53	31	6	7	66	62
1170	24	59	46	14	70	18	37	9	38	3
1180	11	16	47	61	12	4	69	11	9	20
1190	73	47	49	33	28	66	26	12	56	37
1200	60	4	51	5	45	53	58	14	28	54
1210	46	36	53	51	62	40	14	16	0	70
1220	33	68	54	23	4	26	46	18	46	12
1230	20	24	56	70	20	13	3	19	18	29
1240	7	56	58	42	37	0	35	21	65	46
1250	68	13	60	13	54	62	66	23	37	62
1260	55	45	61	60	71	48	23	25	8	4
1270	42	1	63	32	12	35	55	26	55	21
1280	29	33	65	4	29	22	12	28	27	38
1290	15	65	67	50	46	9	43	30	74	54
1300	2	22	68	22	63	70	0	32	45	71
1310	64	53	70	69	4	57	32	33	17	13
1320	51	10	72	41	21	44	64	35	64	30
1330	37	42	74	12	38	31	20	37	36	46
1340	24	74	0	59	55	17	52	39	7	63
1350	11	30	2	31	71	4	9	40	54	5
1360	73	62	4	3	13	66	41	42	26	22
1370	59	19	6	49	30	53	72	44	73	38
1380	46	51	7	21	47	39	29	46	44	55
1390	33	7	9	68	63	26	61	47	16	72
1400	20	39	11	40	5	13	18	49	63	14
1410	6	71	13	11	22	0	49	51	35	30
1420	68	28	14	58	39	61	6	53	6	47
1430	55	59	16	30	55	48	38	54	53	64



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1440	42	16	18	2	72	35	70	56	25	6
1450	28	48	20	48	14	22	26	58	72	22
1460	15	5	21	20	31	8	58	60	43	39
1470	2	36	23	67	47	70	15	61	15	56
1480	64	68	25	39	64	57	47	63	62	73
1490	50	25	27	10	6	44	3	65	34	14
1500	37	57	28	57	23	30	35	67	5	31
1510	24	13	30	29	39	17	67	68	52	48
1520	11	45	32	1	56	4	24	70	24	65
1530	72	2	34	47	73	66	55	72	71	6
1540	59	34	35	19	15	52	12	74	42	23
1550	46	65	37	66	31	39	44	0	14	40
1560	33	22	39	38	48	26	1	2	61	57
1570	19	54	41	9	65	13	32	4	33	73
1580	6	11	42	56	7	74	64	6	4	15
1590	68	42	44	28	23	61	21	7	51	32
1600	55	74	46	0	40	48	53	9	23	49
1610	41	31	48	46	57	35	9	11	70	65
1620	28	63	49	18	74	21	41	13	41	7
1630	15	19	51	65	15	8	73	14	13	24
1640	2	51	53	37	32	70	30	16	60	41
1650	63	8	55	8	49	57	61	18	32	57
1660	50	40	56	55	66	43	18	20	3	74
1670	37	71	58	27	7	30	50	21	50	16
1680	24	28	60	74	24	17	7	23	22	33
1690	10	60	62	45	41	4	38	25	69	49
1700	72	17	63	17	58	65	70	27	40	66
1710	59	48	65	64	74	52	27	28	12	8
1720	46	5	67	36	16	39	59	30	59	25
1730	32	37	69	7	33	26	15	32	31	41
1740	19	69	70	54	50	12	47	34	2	58
1750	6	25	72	26	66	74	4	35	49	0
1760	68	57	74	73	8	61	36	37	21	17
1770	54	14	1	44	25	48	67	39	68	33
1780	41	46	2	16	42	34	24	41	39	50
1790	28	2	4	63	58	21	56	42	11	67
1800	15	34	6	35	0	8	13	44	58	9
1810	1	66	8	6	17	70	44	46	30	25
1820	63	23	9	53	34	56	1	48	1	42
1830	50	54	11	25	50	43	33	49	48	59
1840	37	11	13	72	67	30	65	51	20	1
1850	23	43	15	43	9	17	21	53	67	17
1860	10	0	16	15	26	3	53	55	38	34
1870	72	31	18	62	42	65	10	56	10	51
1880	59	63	20	34	59	52	42	58	57	68
1890	45	20	22	5	1	39	73	60	29	9
1900	32	52	23	52	18	25	30	62	0	26
1910	19	8	25	24	34	12	62	63	47	43
1920	6	40	27	71	51	74	19	65	19	60
1930	67	72	29	42	68	61	50	67	66	1
1940	54	29	30	14	10	47	7	69	37	18
1950	41	60	32	61	26	34	39	70	9	35
1960	28	17	34	33	43	21	71	72	56	52
1970	14	49	36	4	60	8	27	74	28	68



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1980	1	6	37	51	2	69	59	1	74	10
1990	63	37	39	23	18	56	16	2	46	27
2000	50	69	41	70	35	43	48	4	18	44
2010	36	26	43	41	52	30	4	6	65	60
2020	23	58	44	13	69	16	36	8	36	2
2030	10	14	46	60	10	3	68	9	8	19
2040	72	46	48	32	27	65	25	11	55	36
2050	58	3	50	3	44	52	56	13	27	52
2060	45	35	51	50	61	38	13	15	73	69
2070	32	66	53	22	2	25	45	16	45	11
2080	19	23	55	69	19	12	2	18	17	28
2090	5	55	57	40	36	74	33	20	64	44
2100	67	12	58	12	53	60	65	22	35	61
2110	54	43	60	59	69	47	22	23	7	3
2120	41	0	62	31	11	34	54	25	54	20
2130	27	32	64	2	28	21	10	27	26	36
2140	14	64	65	49	45	7	42	29	72	53
2150	1	20	67	21	61	69	74	30	44	70
2160	63	52	69	68	3	56	31	32	16	12
2170	49	9	71	39	20	43	62	34	63	28
2180	36	41	72	11	37	29	19	36	34	45
2190	23	72	74	58	53	16	51	37	6	62
2200	10	29	1	30	70	3	8	39	53	4
2210	71	61	3	1	12	65	39	41	25	20
2220	58	18	4	48	29	51	71	43	71	37
2230	45	49	6	20	45	38	28	44	43	54
2240	32	6	8	67	62	25	60	46	15	71
2250	18	38	10	38	4	12	16	48	62	12
2260	5	70	11	10	21	73	48	50	33	29
2270	67	26	13	57	37	60	5	51	5	46
2280	54	58	15	29	54	47	37	53	52	63
2290	40	15	17	0	71	34	68	55	24	4
2300	27	47	18	47	13	20	25	57	70	21
2310	14	3	20	19	29	7	57	58	42	38
2320	1	35	22	66	46	69	14	60	14	55
2330	62	67	24	37	63	56	45	62	61	71
2340	49	24	25	9	5	42	2	64	32	13
2350	36	55	27	56	21	29	34	65	4	30
2360	23	12	29	28	38	16	66	67	51	47
2370	9	44	31	74	55	3	22	69	23	63
2380	71	1	32	46	72	64	54	71	69	5
2390	58	32	34	18	13	51	11	72	41	22
2400	45	64	36	65	30	38	43	74	13	39
2410	31	21	38	36	47	25	74	1	60	55
2420	18	53	39	8	64	11	31	3	31	72
2430	5	9	41	55	5	73	63	4	3	14
2440	67	41	43	27	22	60	20	6	50	31
2450	53	73	45	73	39	47	51	8	22	47
2460	40	30	46	45	56	33	8	10	68	64
2470	27	61	48	17	72	20	40	11	40	6
2480	14	18	50	64	14	7	72	13	12	23
2490	0	50	52	35	31	69	28	15	59	39
2500	62	7	53	7	48	55	60	17	30	56
2510	49	38	55	54	64	42	17	18	2	73

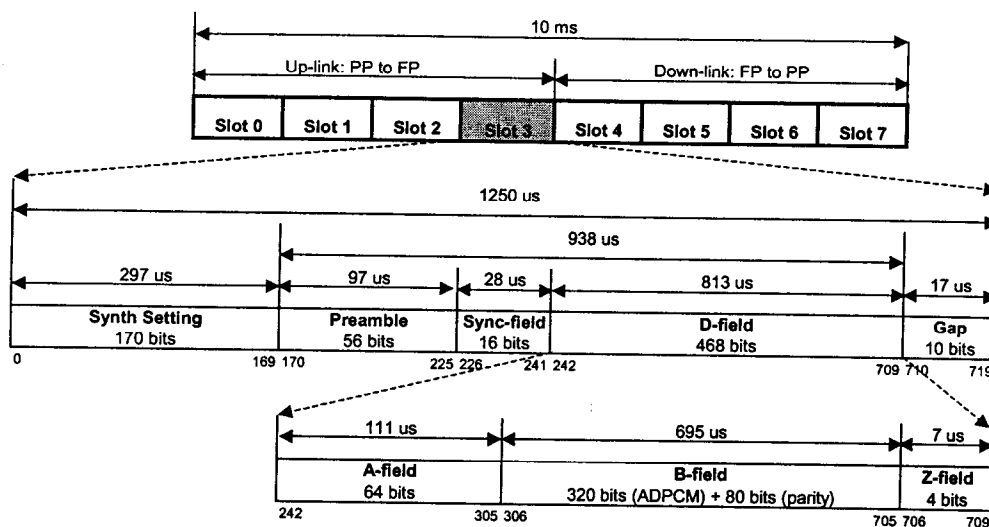


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2520	36	70	57	26	6	29	49	20	49	15
2530	22	27	59	72	23	16	5	22	21	31
2540	9	59	60	44	40	2	37	24	67	48
2550	71	15	62	16	56	64	69	25	39	65
2560	58	47	64	63	73	51	26	27	11	7
2570	44	4	66	34	15	38	57	29	58	23
2580	31	36	67	6	32	24	14	31	29	40
2590	18	67	69	53	48	11	46	32	1	57
2600	5	24	71	25	65	73	3	34	48	74
2610	66	56	73	71	7	60	34	36	20	15
2620	53	13	74	43	24	46	66	38	66	32
2630	40	44	1	15	40	33	23	39	38	49
2640	27	1	3	62	57	20	55	41	10	66
2650	13	33	5	33	74	7	11	43	57	7
2660	0	65	6	5	16	68	43	45	28	24
2670	62	21	8	52	32	55	0	46	0	41
2680	49	53	10	24	49	42	32	48	47	58
2690	35	10	12	70	66	29	63	50	19	74
2700	22	42	13	42	8	15	20	52	65	16
2710	9	73	15	14	24	2	52	53	37	33
2720	71	30	17	61	41	64	9	55	9	50
2730	57	62	19	32	58	51	40	57	56	66
2740	44	19	20	4	0	37	72	59	27	8
2750	31	50	22	51	16	24	29	60	74	25
2760	18	7	24	23	33	11	61	62	46	42
2770	4	39	26	69	50	73	17	64	18	58
2780	66	71	27	41	67	59	49	66	64	0
2790	53	27	29	13	8	46	6	67	36	17
2800	40	59	31	60	25	33	38	69	8	34
2810	26	16	33	31	42	20	69	71	55	50
2820	13	48	34	3	59	6	26	73	26	67
2830	0	4	36	50	0	68	58	74	73	9
2840	62	36	38	22	17	55	15	1	45	26
2850	48	68	40	68	34	42	46	3	17	42
2860	35	25	41	40	51	28	3	5	63	59
2870	22	56	43	12	67	15	35	6	35	1
2880	9	13	45	59	9	2	67	8	7	18
2890	70	45	47	30	26	64	23	10	54	34
2900	57	2	48	2	43	50	55	12	25	51
2910	44	33	50	49	59	37	12	13	72	68
2920	31	65	52	21	1	24	44	15	44	10
2930	17	22	54	67	18	11	0	17	16	26
2940	4	54	55	39	35	72	32	19	62	43
2950	66	10	57	11	51	59	64	20	34	60
2960	53	42	59	58	68	46	21	22	6	2
2970	39	74	61	29	10	33	52	24	53	18
2980	26	31	62	1	27	19	9	26	24	35
2990	13	62	64	48	43	6	41	27	71	52

TDMA frames structure

The EDCT TDMA frame structure is shown below:



The basic, repeating, frame structure is 10 ms long. It is sub-divided into 8 slots, each 1250 μ s long. The active transmission time is 937.5 μ s. The first 4 slots form the 'up-link', when the PPs transmit to the FP. The last 4 slots form the 'down-link', when the FP transmits to the PPs.

EDCT uses TDD to carry a two-way voice communication. This is always by using slot-pairs: 0 and 4, 1 and 5, 2 and 6, 3 and 7. In this way the down-link transmission of the duplex communication is always 5ms after the corresponding up-link transmission.

There is only one transceiver in FP or PP therefore in any single slot, the FP or PP can only ever be receiving or transmitting.