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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

ETSI TC SES is producing standards and other deliverables for Satellite Digital Radio (SDR) systems. An SDR system enables broadcast to fixed and mobile receivers through satellites and complementary terrestrial transmitters. Functionalities, architecture and technologies of such systems are described in TR 102 525 [1].

Several existing and planned ETSI standards specify parts of the ETSI SDR system, with the aim of interoperable implementations. These parts can be used all together in SDR compliant equipment, or in conjunction with other existing and future specifications.

The physical layer of the radio interface (air interface) is divided up into the outer physical layer, the inner physical layer with a single carrier transmission, and the inner physical layer with multiple carriers transmission. It is specified by a set of standards consisting of TS 102 550 [2], TS 102 551-1 [3] and TS 102 551-2 [4].

The present document contains guidelines for the use of the ETSI SDR physical layer standards.

1 Scope

The present document concerns the radio interface of ETSI Satellite Digital Radio (SDR) broadcast receivers. TS 102 550 [2], TS 102 551-1 [3] and TS 102 551-2 [4] specify the physical layer of the radio interface. The present document is a Technical Report (TR) with guidelines for the use of the ETSI SDR physical layer standards.

2 References

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2.1 Informative references

[1] ETSI TR 102 525: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) service; Functionalities, architecture and technologies".

[2] ETSI TS 102 550: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Outer Physical Layer of the Radio Interface ".

[3] ETSI TS 102 551-1: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface; Part 1: Single carrier transmission".

[4] ETSI TS 102 551-2: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface; Part 2: Multiple Carrier Transmission".

[5] ETSI TR 101 154: "Digital Video Broadcasting (DVB); Implementation guidelines for the use of MPEG-2 Systems, Video and Audio in satellite, cable and terrestrial broadcasting applications".

[6] ETSI EN 300 468: "Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems".

[7] ETSI ETR 289: "Digital Video Broadcasting (DVB); Support for use of scrambling and Conditional Access (CA) within digital broadcasting systems".

[8] ETSI TS 102 005: "Digital Video Broadcasting (DVB); Specification for the use of Video and Audio Coding in DVB services delivered directly over IP protocols".

[9] ISO/IEC 13818-1:2000: "Information technology - Generic coding of moving pictures and associated audio information: Systems".

[10] ISO/IEC 13818-2:2000: "Information technology - Generic coding of moving pictures and associated audio information: Video".

[11] ISO/IEC 13818-3:1998: "Information technology - Generic coding of moving pictures and associated audio information - Part 3: Audio".

[12] ISO/IEC 14496-10:2005: "Information technology - Coding of audio-visual objects - Part 10: Advanced Video Coding".

[13] IETF RFC 3550: "RTP: A Transport Protocol for Real-Time Applications".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

C band: frequency band between 4 GHz and 8 GHz

Ku band: frequency band between 12 GHz and 18 GHz

L-band: frequency band between 1 GHz and 2 GHz

S-band: frequency band between 2 GHz and 4 GHz

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BER	Bit Error Rate
CCC	Complementary Code Combining
CNR	Carrier to Noise Ratio
C-TS	Channel Transport Stream
DAB	Digital Audio Broadcast
dB	Decibels
DMB	Digital Media Broadcast
DVB	Digital Video Broadcast
Eb/No	Energy per bit / Noise
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FSS	Fixed Satellite Service
GEO	GEostationary Orbit
GPS	Global Positioning System
HEO	Highly Elliptical Orbit
HM	Hierarchical Modulation
HP	High Priority (part of HM signal)
IP	Internet Protocol
IPL	Inner Physical Layer
IPL-MC	Inner Physical Layer Multiple Carrier
IPL-SC	Inner Physical Layer Single Carrier
IU	Interleaver Units
LLR	Log Likelihood Ratio
LNA	Low Noise Amplifier
LP	Low Priority (part of HM signal)
MC	Multi-Carrier
MPEG	Moving Picture Expert Group
MTU	Maximum Transfer Unit

OFDM	Orthogonal Frequency Division Multiplex
OPL	Outer Physical Layer
PFIW	Physical layer FEC Infomation Word
PSI	Program Specific Information
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RTP	Real-time Transport Protocol
SC	Single carrier
SC-TS	Service Component Transport Stream
SDR	Satellite Digital Radio
SFN	Single Frequency Network
SL	Service Layer
SL/PL	Service Layer to Physical Layer
SNR	Signal to Noise Ratio
S-TS	Service Transport Stream
UDP	User Datagram Protocol

4 SDR Design Guidelines Overview

A typical SDR system (see figure 4.1) is based on an architecture combining one or more satellite broadcasts and, where necessary, complementary terrestrial transmitters to ensure seamless reception for receivers when satellite signal(s) are blocked by obstructions, especially in urban zones.

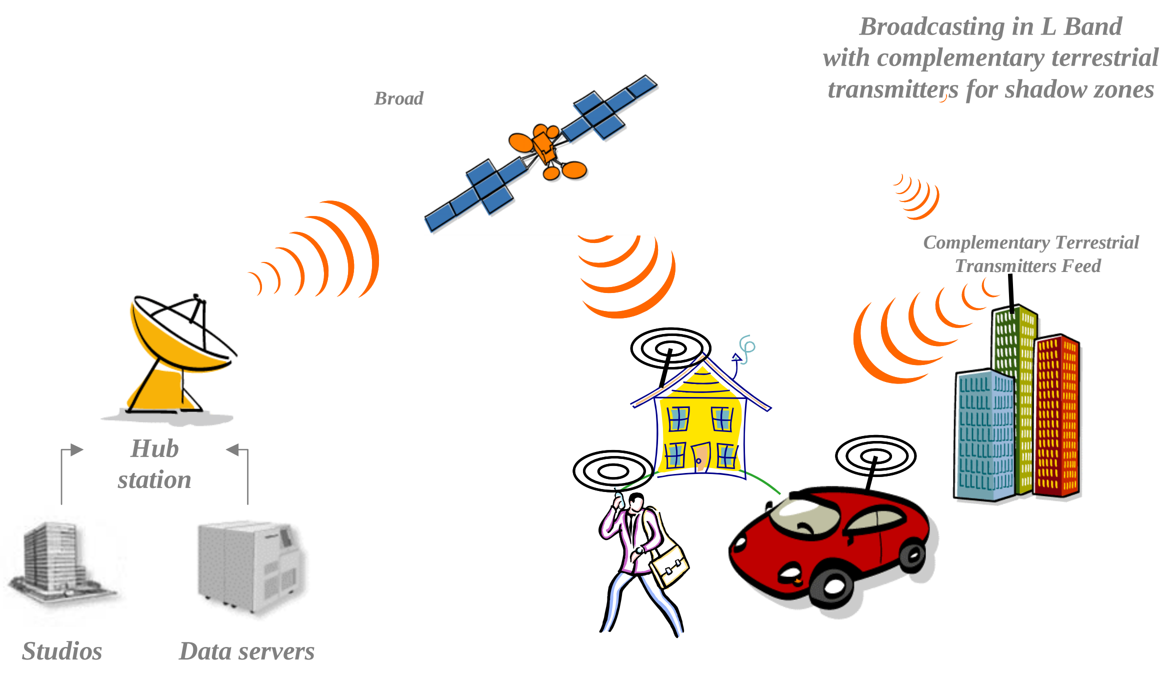

Figure 4.1: Typical SDR system architecture

The satellite signal(s) employ advanced iterative FEC technology along with time diversity techniques to enhance the robustness of signal availability in the mobile environment. These techniques alleviate perceived signal dropage resulting from obstacles momentarily blocking line of sight to the satellite. The resulting user experience provides a consistent quality service in shadowed areas not covered by terrestrial transmitters.

The radio and data programs provided by the service provider are gathered by one or more "hub stations" before being multiplexed and transmitted to Radio Receivers via the satellite(s) path.

The complementary terrestrial segment receives and retransmits content similar to the satellite signal in urban areas. The signal received by this segment may be for example the satellite signal (e.g. around L-band), a signal transmitted from a geostationary FSS satellite (e.g. in C or Ku band), or a wired T1 connection Terrestrial transmission can use one of two modes. The first mode using a different carrier frequency and modulation scheme than the satellite transmission. The second mode using the same carrier frequency and modulation as the satellite.

The general signal path from the service component creation to the user experience is shown in figure 4.2.

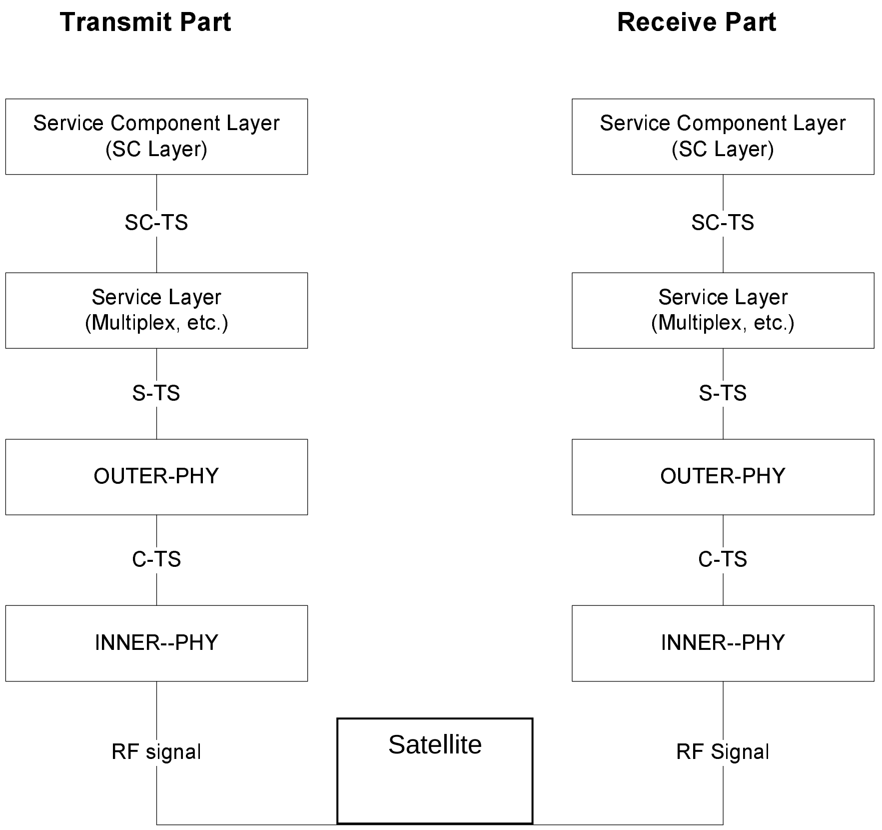

Figure 4.2: Signal path

The present document detailed examples for the outer and inner physical layers for different SDR systems.

4.1 Overview outer physical layer

The outer phsycial layer provides time division multiplexing of service components along with channel encoding. In addition, the outer physical layer introduces time slicing for handheld power optimization. The channel coding provides flexible advanced FEC and time dispersing options enabling system adjustment for maximum performance and throughput. Figure 4.3 shows the various outer physical layer function. The physical layer output waveform is organized in fixed SDR OPL packets made up of one or more flexible "pipes". These smaller "pipes" can be optimized for overall performance. Examples of various "pipe" structures will be covered in following clause.

The signalling pipe contains all the information that the SDR receiver requires to perform channel decoding of the SDR waveform. The signalling pipe indicates what type of time disperser profile and FEC is associtated with each "pipe" in the SDR OPL frame.

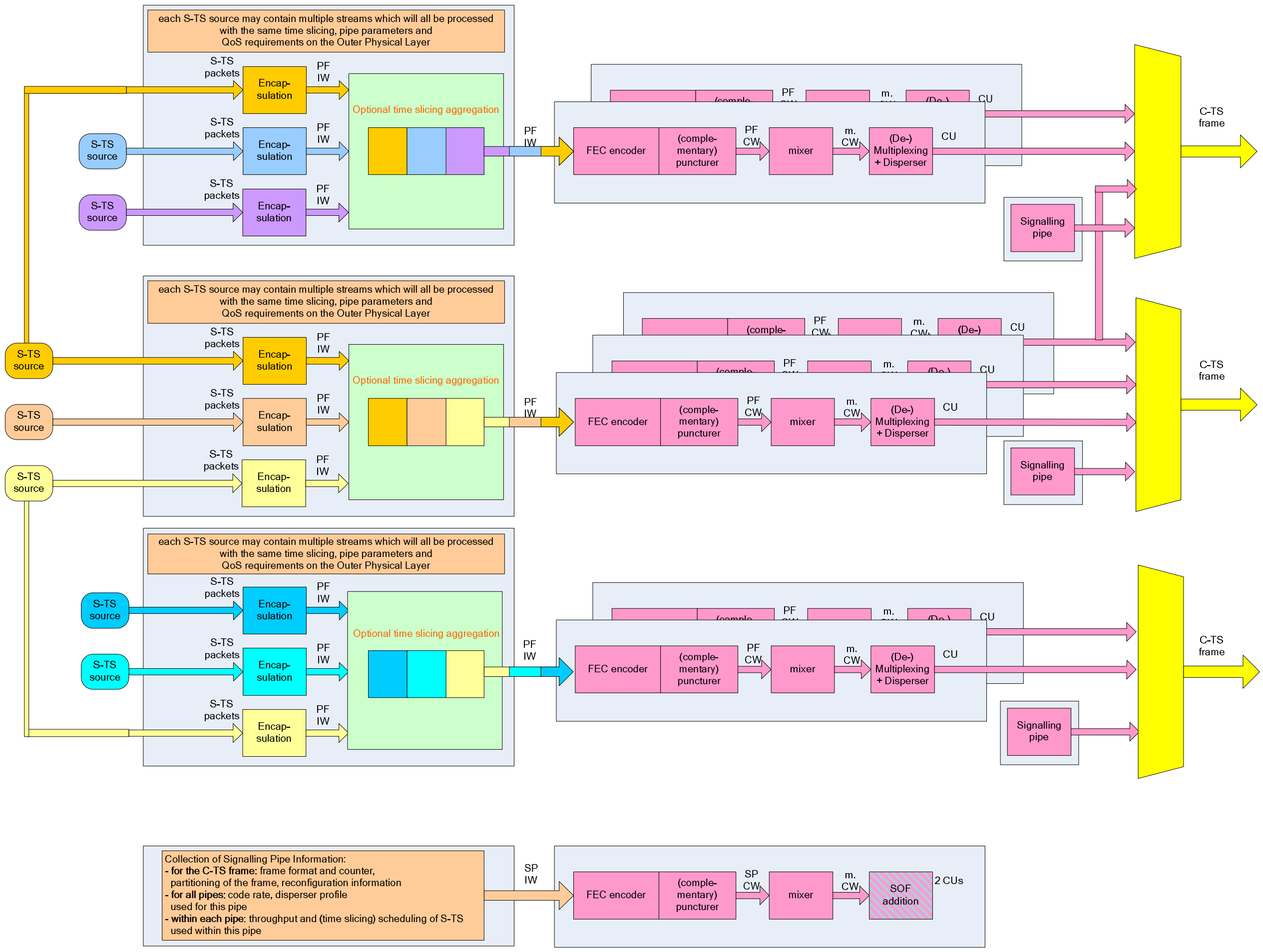

Figure 4.3: Outer physical layer function

4.1.1 Overview S-TS mutliplex/encapsulation

The encapsulation process converts each type of service packet type into a fixed PFIW (physical layer FEC info word). There are 4 possible service types for encapsulation. Each PFIW is 12 282 bits after encapsulation. Table 4.1 shows the frame length for various SDR profiles. The minimum PFIW rate is 12 282 bits/frame_length.

Table 4.1: SDR mode vs. frame length

Profile	IPL-SC-A	IPL-SC-A	IPL-SC-A	IPL-SC-A	IPL-SC-B	IPL-SC-B
Mode	1	1	1	1	2	2
Frame_length (ms)	432	487,42	438,68	432	432	432

Table 4.2 shows the S-TS types.

Table 4.2: S-TS type vs. payload size

S-TS Type	S-TS Type ID	S-TS payload packet Size in bytes	Suffix length in bits	Comment
Dummy packet	0	0	26	Used for asynchronous SL/PL interface. Is discarded in receiver.
Transparent	1	1 532	26	SL has to decide what to do with this data.
MPEG-TS	2	1 504	250	Payload packet is 8 MPEG packets of 188 bytes each; additionally, a BCH code of 196 bit is applied.
IP stream	3	1 504	250	MTU of IP = 4 095 bytes with 2 bytes additional header per packet.

4.1.2 Overview S-TS ID

Each service transport stream has a unique identifier for all signal sources for a given system operator. This allows for seamless transmission using various signal sources. A maximum of 256 S-TS IDs are available to each system operator ID. An operator ID is located in the signalling pipe. A S-TS is the smallest transmitted block available to the physical layer. The S-TS may include many smaller services which are processed by the service layer. There are four basic S-TS streams.

4.1.3 Overview S-TS type 0 (dummy packet)

This dummy S-TS is used to synchronize the service layer with the physical layer. When the service layer and physical layer are asynchronous, overruns and underruns are possible. In the case of an overrun, an S-TS packet is dropped. Whereas an underrun is corrected by a dummy S-TS insertion. Buffering should be used between the service layer input and encapsulation to minimize dropped S-TS packets.

4.1.4 Overview S-TS type 1 (transparent stream)

The transparent S-TS frame is considered a proprietary stream to the service layer. The input S-TS contains a packet structure unknown by the OPL. The transparent stream has a minimum rate of 1 532 bytes or 12 256 bits per C-TS frame. In the event that 1 532 bytes are not available for transmission, a dummy packet (S-TS Type 0) is used. In the event of an over run, there is no mechanism in this frame structure to indicate a lost packet.

4.1.5 Overview S-TS type 2 (MPEG-TS stream)

The MPEG-TS S-TS frame provides for transparent blocks of 8 MPEG-TS packets according to ISO/IEC 13818-1 [9]. Each MPEG-TS packet contains 188 bytes, in the event that less than 8 MPEG-TS packets are available for transmission, missing MPEG-TS packets are replaced with MPEG-TS null packets. An additional error correction/detection is added which uses a shortened BCH code on pairs of MPEG-TS packets.

When no MPEG packet is ready, a dummy packet is inserted.

4.1.6 Overview S-TS type 3 (IP stream)

The IP stream provides transparent transmission of IP packets with a maximum length of 4 095 bytes. During encapsulation, a 2 byte header is added to each IP packet indicating the packet type and length. Both IPv4 and IPv6 types are available. An additional error correction/detection is added which uses a shortened BCH code on each block of 376 bytes of the paylod. In the event no IP data is available or the IP S-TS type is not complete, transmit a dummy packet.

4.1.7 Overview FEC

The FEC configuration for SDR has 14 selections, thus giving the operator the ability to adjust capacity vs. link margin in roughly 12,5 % and 0,75 dB steps. In addition, some FEC selections allow for complementary puncturing. This allows for increased performance in a multiple source system. There are 28 total FEC and puncturing options available to the operator.

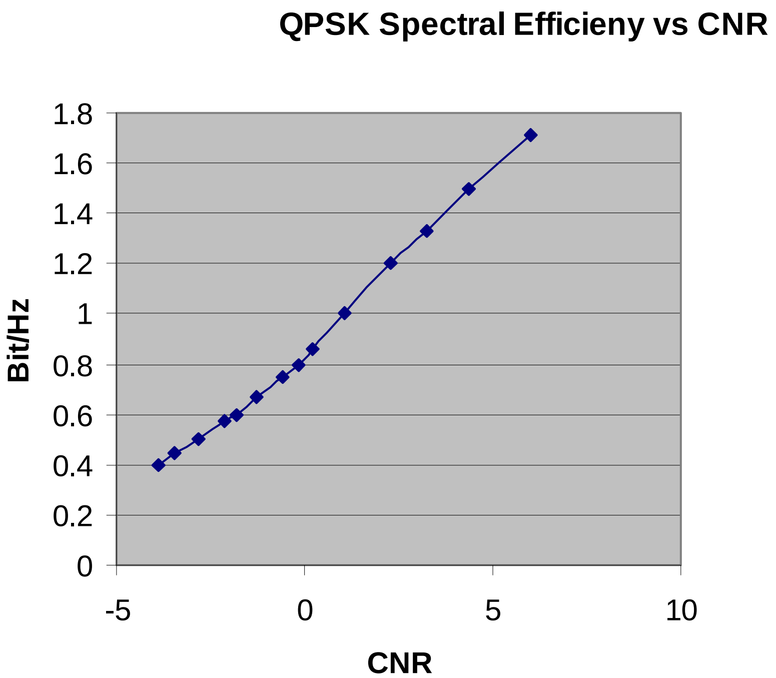

Figure 4.4: Example of QPSK spectral efficiency for 1e-5 BER

The operator has the ability to adjust service quality as well as reception quality after the system has been launched. This allows the system level to obtain optimum user satisfaction.

For any code rate R = 6/N, the puncturing patterns were designed with the following properties:

- For N even, primarily the first generator polynomial (upper parity branch) of the two constituent encoders is used (Y0 and Y'0), or at least the standard code uses primarily this generator polynomial.
- For N odd, primarily the second generator polynomial (lower parity branch) of the two constituent encoders is used (Y1 and Y'1), or at least the standard code uses primarily this generator polynomial.

4.1.7.1 FEC puncturing

After the message bits are output from the Turbo Encoder, the systematic bit X, and the parity bits Y0, Y1, Y'0, and Y'1 is punctured for the selected code rate. The puncturing patterns associated with each code rate, including standard and complementary, is designated by its Punct_Pat_ID and has unique data and tail bit puncturing patterns. There are a total of 61 410 coded data bits out of the FEC encoder, and 30 tail bits which are inputs into the puncturing algorithm.

The data puncturing patterns are cyclic and repeat every 5, 10, 15, 20, 30 or 60 coded data bits, depending on the Punct_Pat_ID. The data bit puncturing patterns can be seen in table 4.3.

Table 4.3

Punct_Pat_ID	Code Rate	Pattern Name	Puncturing Pattern (X; Y0; Y1; Y'0; Y'1; X; Y0; …)
0	1/5	Standard	1;1;1;1;1
1	2/9	Standard	1;0;1;1;1; 1;1;1;1;1; 1;1;1;0;1; 1;1;1;1;1
2	1/4	Standard	1;1;1;0;1; 1;1;0;1;1
3	2/7	Standard	1;0;1;0;1; 1;0;1;1;1; 1;0;1;0;1; 1;1;1;0;1
4	3/10	Standard	1;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0; 1;1;1;1;1
5	1/3	Standard	1;1;0;1;0
6	1/3	Complementary1	1;0;1;0;1
7	3/8	Standard	0;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0
8	3/8	Complementary1	1;0;1;0;1; 0;0;1;0;1; 1;0;1;0;1
9	2/5	Standard	1;0;0;0;0; 1;0;1;0;1; 0;0;1;0;1; 1;0;1;0;1; 1;0;1;0;1; 0;0;1;0;1; 1;0;1;0;1; 1;0;1;0;1; 0;0;1;0;1; 1;0;1;0;1; 1;0;1;0;1; 0;0;1;0;1
10	2/5	Complementary1	1;1;0;1;0; 0;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0; 0;1;0;1;0; 1;0;0;0;0; 1;1;0;1;0; 0;1;0;1;0; 1;1;0;1;0; 1;1;0;1;0; 0;1;0;1;0; 1;1;0;1;0
11	3/7	Standard	1;0;0;0;0; 1;1;0;1;0; 0;1;0;1;0; 1;1;0;1;0; 0;1;0;1;0; 1;1;0;1;0
12	3/7	Complementary1	1;0;1;0;1; 0;0;1;0;1; 1;0;1;0;1; 1;0;0;0;0; 1;0;1;0;1; 0;0;1;0;1
13	1/2	Standard	1;1;0;0;0; 1;0;0;1;0
14	1/2	Complementary1	1;0;0;1;0; 1;1;0;0;0
15	1/2	Complementary2	1;0;1;0;0; 1;0;0;0;1
16	3/5	Standard	1;0;0;0;0; 1;0;0;1;0; 1;1;0;0;0
17	3/5	Complementary1	1;0;0;1;0; 1;1;0;0;0; 1;0;0;0;0
18	3/5	Complementary2	1;1;0;0;0; 1;0;0;0;0; 1;0;0;1;0
19	2/3	Standard	1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;1;0;1
20	2/3	Complementary1	1;0;0;0;0; 1;0;1;0;1; 1;0;0;0;0; 1;0;0;0;0
21	2/3	Complementary2	1;0;0;0;0; 1;0;0;0;0; 1;0;1;0;1; 1;0;0;0;0
22	3/4	Standard	1;0;0;0;0; 1;0;0;0;0; 1;1;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;1;0
23	3/4	Complementary1	1;0;0;0;0; 1;0;0;1;0; 1;0;0;0;0; 1;0;0;0;0; 1;1;0;0;0; 1;0;0;0;0
24	3/4	Complementary2	1;1;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;1;0; 1;0;0;0;0; 1;0;0;0;0
25	6/7	Standard	1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;1;0;0; 1;0;0;0;1
26	6/7	Complementary1	1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;1;0;0; 1;0;0;0;1; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0
27	6/7	Complementary2	1;0;0;0;0; 1;0;0;0;0; 1;0;1;0;0; 1;0;0;0;1; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0; 1;0;0;0;0
28 – 63	RFU		

Since 20 and 60 are not multiples of the 61 410 coded bits, the last 10 or 30 coded bits from those Punct_Pat_IDs respectively will only use half of the full data puncturing pattern. This is useful to fully understand the puncturing of the 30 input tail bits, which are appended to the end of the punctured coded bits. Unlike the data puncturing patterns, the tail bit puncturing patterns are over all 30 input tail bits and never repeated. The number of output tail bits are calculated in table 4.4.

Table 4.4

Punct_Pat_ID	Code Rate	Pattern Name	Output Tail Bits
0	1/5	Standard	30
1	2/9	Standard	27
2	1/4	Standard	24
3	2/7	Standard	21
4	3/10	Standard	20
5	1/3	Standard	18
6	1/3	Complementary1	18
7	3/8	Standard	16
8	3/8	Complementary1	16
9	2/5	Standard	16
10	2/5	Complementary1	16
11	3/7	Standard	14
12	3/7	Complementary1	14
13	1/2	Standard	12
14	1/2	Complementary1	12
15	1/2	Complementary2	12
16	3/5	Standard	10
17	3/5	Complementary1	10
18	3/5	Complementary2	10
19	2/3	Standard	10
20	2/3	Complementary1	8
21	2/3	Complementary2	10
22	3/4	Standard	8
23	3/4	Complementary1	8
24	3/4	Complementary2	8
25	6/7	Standard	8
26	6/7	Complementary1	8
27	6/7	Complementary2	6
28 - 63	RFU		RFU

After examining table 4.4, the number of output tail bits for rate 2/3 standard, complementary 1, and complementary 2, are 10, 8, and 10, respectively. The difference in tail bits can be explained by examining the data puncturing pattern of Table X. Since rate 2/3 data puncturing pattern repeats every 20 input bits, the last 10 input bits only use ½ the puncturing pattern. Therefore, for rate 2/3 standard and complementary 2, only 2 data output bits are generated, whereas complementary 1 outputs 4 data bits. To make up for this difference and keep the transmitted data rate the same, there should be 2 extra tail bits for the standard and complementary 2 as compared to complementary 1. This same scenario is also true for the 3 rate 6/7 puncturing patterns.

4.1.8 Overview disperser

The SDR disperser contains several components that enable different methods for signal blocage mitigation. The disperser first bit interleaves the data on a codeword basis, then the data is grouped into Interleaver units of 512 bits for time dispersal. The time dispersal is what gives the system the ability to work when a signal outage for some period of time is encountered.

It is recommended to use a schedule period with an integer value `Schedule_Period_Length_Frames[i]`, but this is not mandatory. Moreover, for achieving S-TS with a Variable Bit Rate, the parameters `STS_Width_Slots[j]` can change on a schedule period-by-schedule period basis, and `Schedule_Period_Length_Frames[i]` is also allowed to change after each schedule period. However, the efficiency of Time Slicing in the combination with the dispersing can suffer and should be taken into account. For higher time slicing efficiency, it is recommended to use the parameter choice `Schedule_Period_Length_Frames[i] = Tap_Diff_Mult_Int`.

The disperser is very flexible and can be turned off for no time buffering. The disperser can be adjusted to appear as a simple time shifted signal (early/late), as a uniform interleaver, or as some combination of these options (i.e. uniform for 50 % of the data and the rest is sent as the late part). This allows the operator to configure the disperser for various performance constraints, including signal blockage depth and zapping time. The disperser along with the FEC selection provide the best possible user experience.

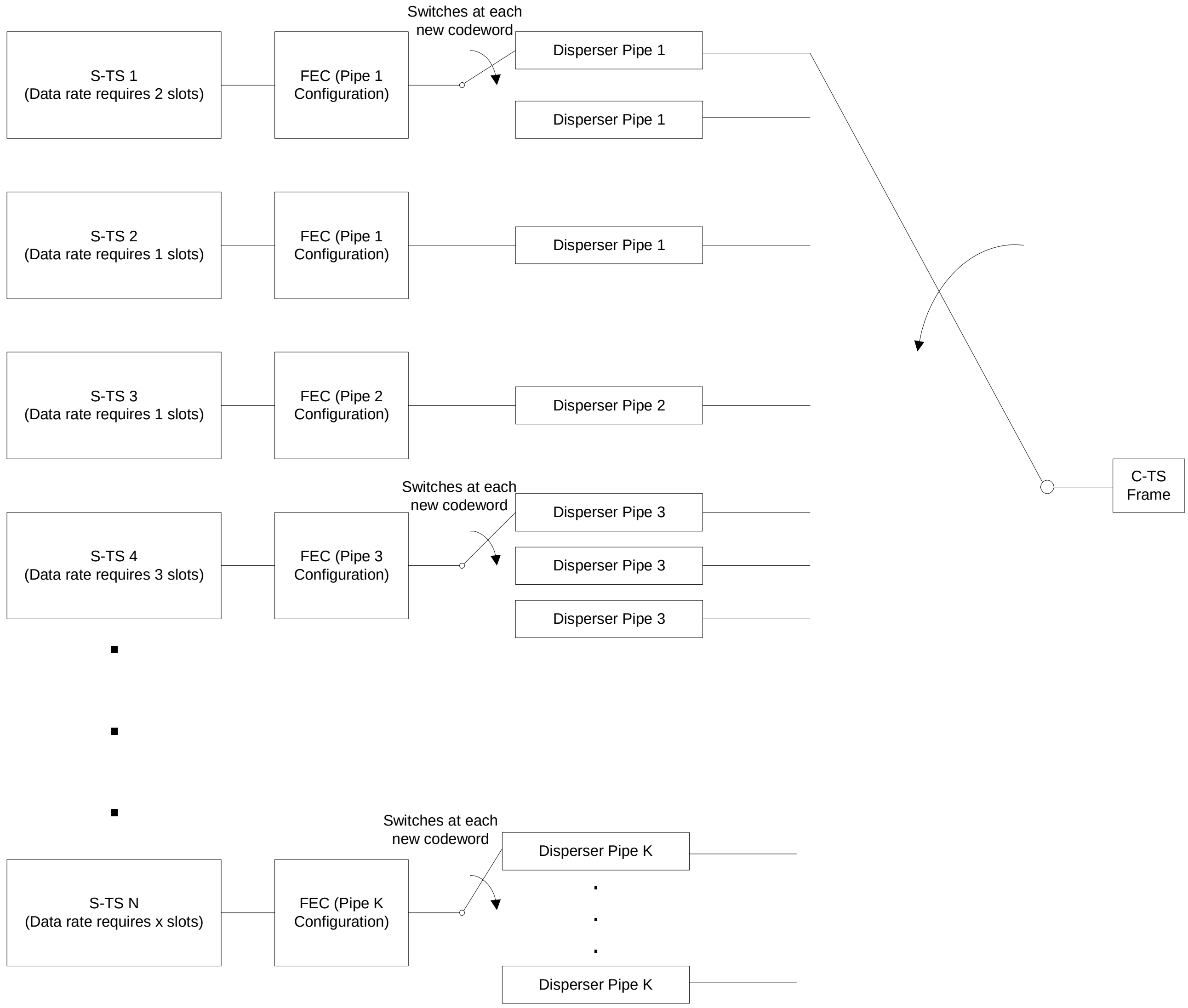

Figure 4.5: Placement and usage of disperser in formation of C-TS frame

For each S-TS in a given pipe, there is an associated disperser. Each S-TS is allocated an integer number of slots per frame, where a slot is defined as the number of bits for the output FEC codeword (i.e. for rate 1/5 the slot size is 61 440). Therefore, for each S-TS the data rate will be some multiple of 12 282/(C-TS Frame Period).

There are two profiles that are straightforward implementations, the early/late and the uniform interleaver profiles. A third profile will be defined which will encompass all non-standard implementations. This third profile will be called the combinational profile, and will include any implementation that is not included in the first two profiles.

4.1.8.1 Early/late profile

This profile should only be used with FEC rate configurations of less than ½. For any rates above ½, the early/late interleaver becomes ineffectual (both the early and late signal are needed for FEC decoding). This profile should be used to put half of the transmitted data without any delay and the other half with the desired outage protection of delay. This profile requires two disperser sections. Each early and late section is be defined using 16 taps and Tap_Diff value set to 0. In the second section, the Gap_Width will be set according to the following equation:

$$\text{Gap\_Width} = \text{ceil}(\text{Desired Blockage}/\text{C-TS Frame Period})$$

Example of early/late interleaver profile using a FEC rate of 1/3 with 8 seconds of signal blockage protection. Note, the memory requirement is for a single S-TS slot (approx. 28 kbps of channel content), the zapping time is calculated when 28 IUs are available at the FEC decoder. For a system that uses two indepentent sources (one for the early signal and one for the late), the zapping time can be up to the blockage time when the late signal is blocked. Additionally, the system is susceptible to signal loss until the buffer is filled. Buffering unused S-TS slots improves receiver performance at the expense of hardware.

NOTE: All screenshots in the present document were provided by Delphi Deutschland Electronics Europe GmbH for illustrative purposes.

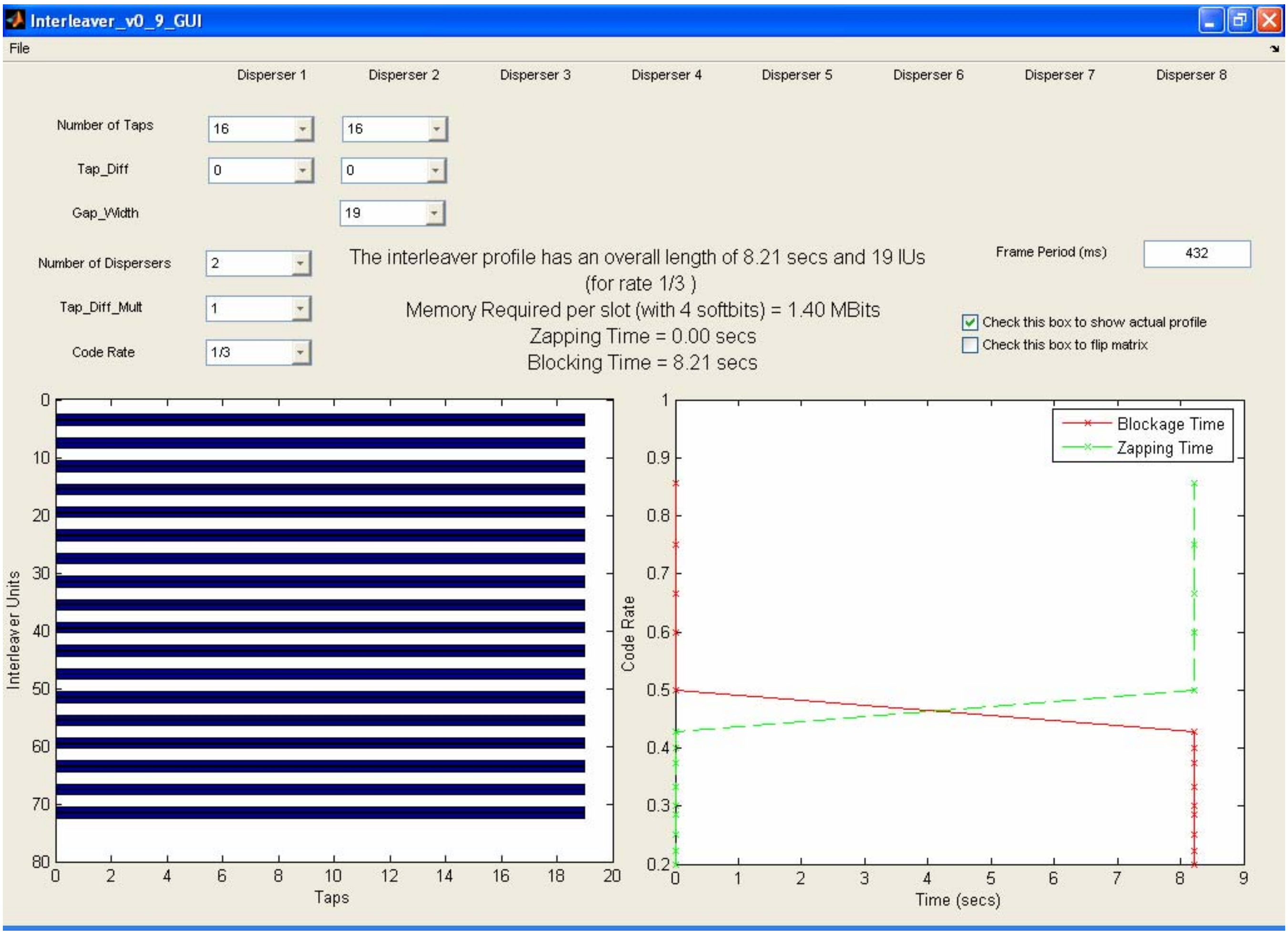

Figure 4.6: Example of early/late interleaver profile

4.1.8.2 Uniform profile

This profile can be used with all code rates, however the zapping time and blockage time will vary with different FEC configurations. For the uniform profile, only one disperser section is used. The Tap_Diff variable sets up the number of C-TS frames between each Interleaver Unit of a codeword. Therefore, the following equation can be utilized to find the amount of time the codeword will be interleaved over:

$$\text{Interleaver\_Time} = \text{Tap\_Diff} \times \text{Number Of IUs/codeword}$$

Figure 4.7 shows a uniform interleaver example using FEC rate 1/3 and 8 seconds of blockage protection. Note, the memory requirement is for a single S-TS slot (approx. 28 kbps of channel content), the zapping time is calculated when 28 IUs are available at the FEC decoder with sufficient margin to allow FEC decoding. The system is less susceptible to signal loss as the buffer fills. Buffering unused S-TS slots improves receiver performance at the expense of hardware. This is especially applicable to zapping time.

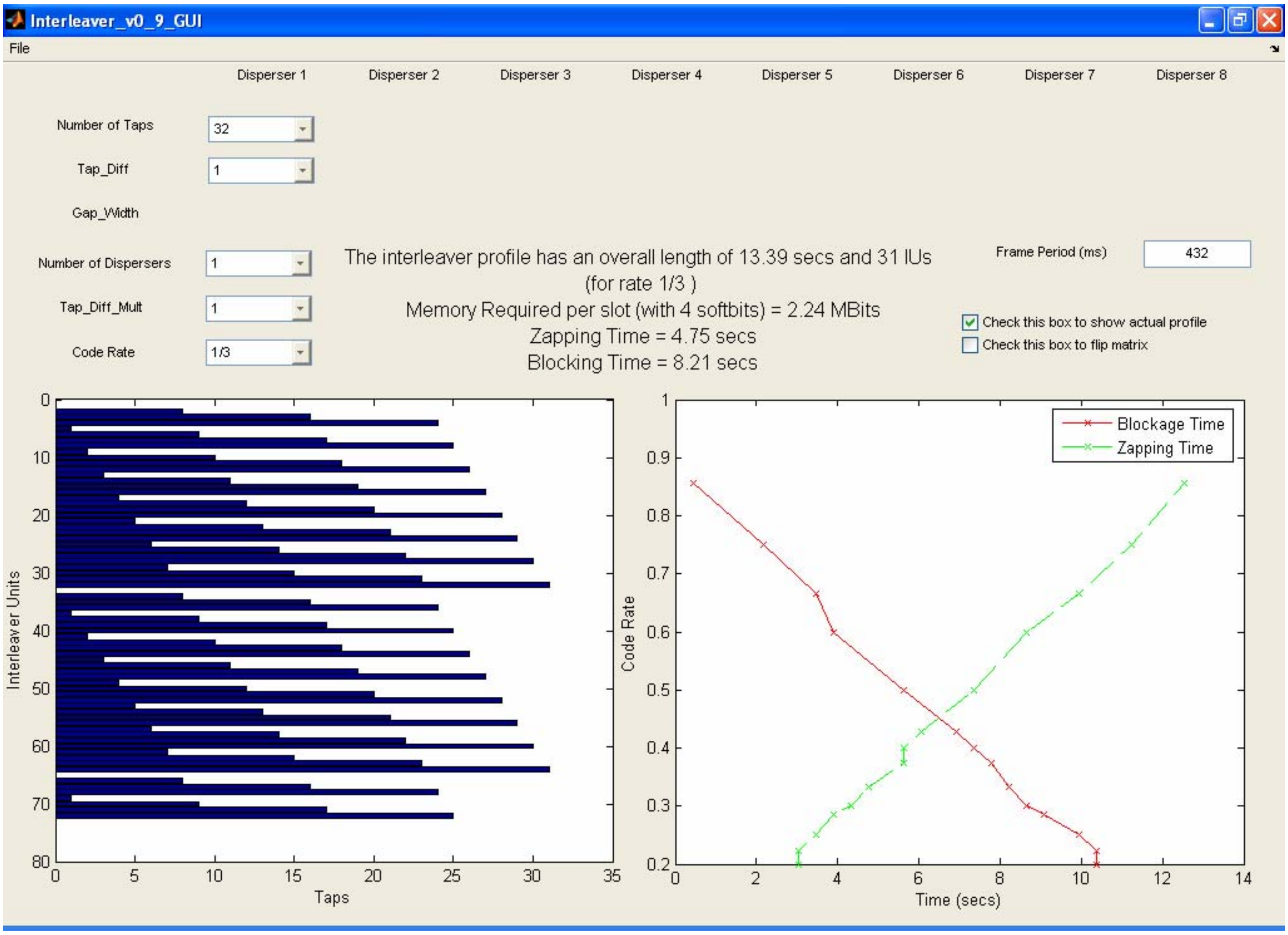

Figure 4.7: Example of uniform interleaver profile

4.1.8.3 Combinational profile

This profile can be used with all code rates, however the zapping time and blockage time will vary with different FEC configurations. Also, it should be noted that the performance of the time interleaver will vary for different FECs and interleaver profiles. It is permissible to have up to 8 disperser sections, however, the more disperser sections that are used, the fewer taps that are in each disperser, and the overall profile will not signifigantly fluctuate. Also, the more disperser sections that are used will reduce the number of pipes that can be used.

Figure 4.8 shows a combinational interleaver example using FEC rate 1/3 and 8 seconds of blockage protection. Note, the memory requirement is for a single S-TS slot (approx. 28 kbps of channel content), the zapping time is calculated when 28 IUs are available at the FEC decoder. The system is less susceptible to signal loss as the buffer fills. Buffering unused S-TS slots improves receiver performance at the expense of hardware.

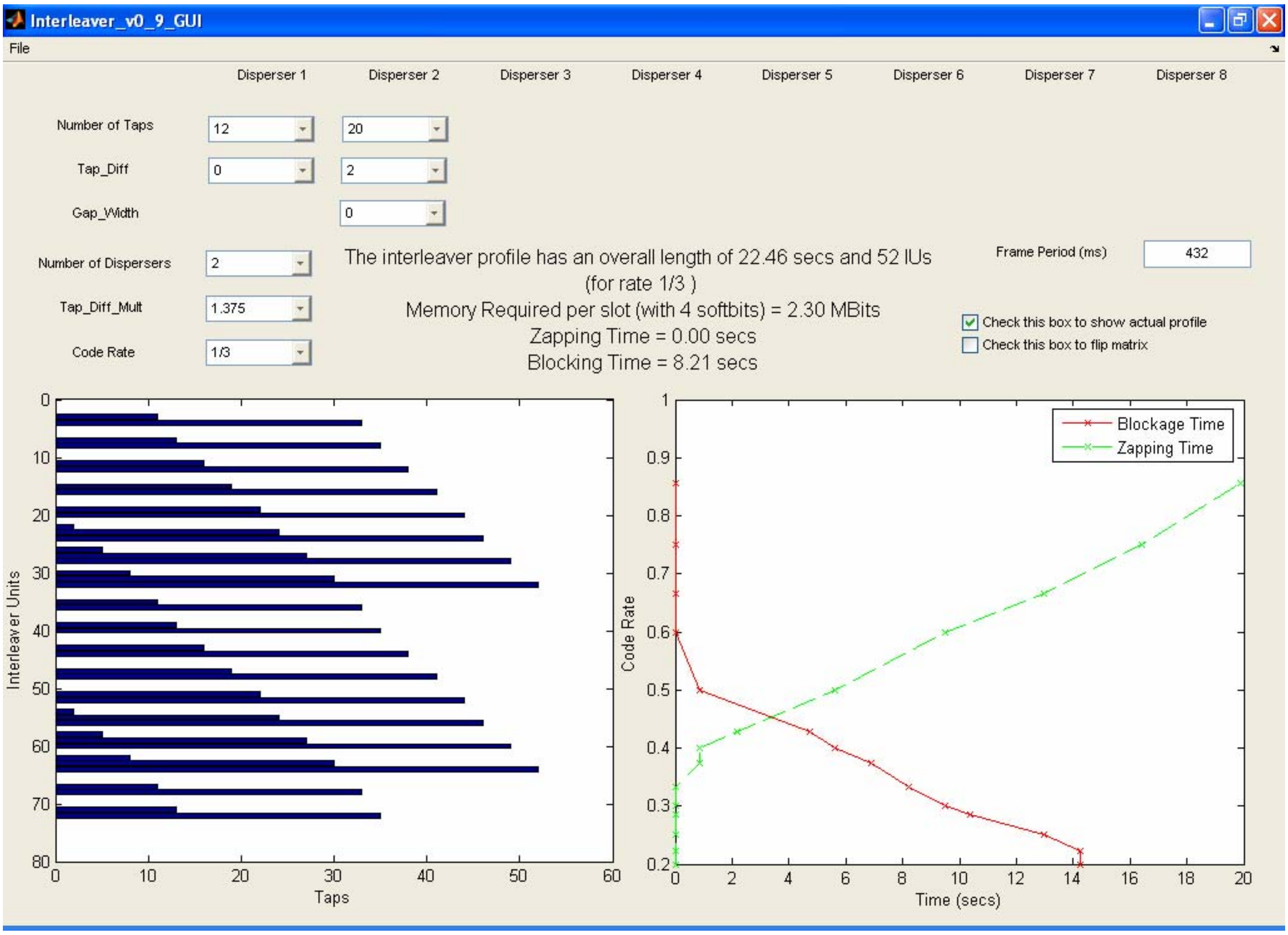

Figure 4.8: Example of combinatorial interleaver profile

4.1.9 Overview signaling pipe

The flexibility of the SDR system is found in the signalling pipe. This pipe contains the location of each S-TS inside the physical data stream. It also contains the FEC and Disperser characteristics for the S-TS. This signal is well protected with the lowest FEC rate available (1/5) and is not dispersed in time. The signalling pipe should not be changed rapidly, but coordinated changes should occur when the least users are expected to be using the system. This will minimize the potential for users to experience system drop outs. Since the signalling pipe changes slowly (if at all), the receiver should use the last known "good" signalling pipe configuration if an error is detected in the current signalling pipe.

A pipe can have a CU width of 0 when no data is available to transmit. This preserves the signalling pipe configuration for all other pipes and allows flexibility for control of data. This feature along with the tail pipe configuration allows the service provider to control the FEC rates for various data services.

The number of pipes inside the data stream always contain the tail pipe. This extra pipe has no time interleaving capability, but can contain any FEC rate. The tail pipe is used as a mechanism to optimize data transfer when the main payload pipes do not completely fill all available CUs. The tail pipe CUs are buffered by the receiver until the last CU of the tail pipe codeword is received. This codeword is then passed to the turbo decoder for processing. The tail pipe is useful for non time critical information such as stock tickers, weather, traffic data, etc.

If the payload pipes (including the tail pipe) do not fill the available CUs in the frame, the remaining CUs are padded to 0 to complete the frame. The tail pipe can contain upto 512 CUs.

4.2 Overview inner physical layer single carrier

The single carrier modulation is expected to be used for most satellite signals. The QPSK and 8-PSK modulation modes can be considered constant modulus and therefore transmitted near or at saturation for satellite transponders.

4.3 Overview inner physical layer multiple carrier

The OFDM modulation has higher peak to average power and can be used for satellite and terrestrial hybrid systems when single frequency networks are desired. All terrestrial transmitters are expected to use the OFDM modulation even when hybrid systems use single carrier modulation on the satellites.

4.4 Layers above the physical layer

The set of physical layer standards enables transmitting certain types of bit streams, which carry digital audio and video content. The digital coding of audio and video, as well as the required formatting, takes place on layers above the physical layer. ETSI has not defined SDR specific technology for the layers above. The usage of existing standards and specifications on these layers is discussed in the following.

A stream carried by a pipe the SDR physical layer is called Service Transport Stream (S-TS). The Outer Physical Layer standard defines the following types of S-TS: Transparent, MPEG Transport Stream, IP Stream. In addition, dummy packets and type identifiers for future use are defined. The Transparent mode allows to extend functionality by additional specifications without changes to the Outer Physical Layer standard. Certain audio and video coding technologies are typically used in existing applications of MPEG Transport Stream and IP Stream.

The S-TS stream type MPEG Transport Stream allows to apply the multiplexing, video coding and audio coding defined by the MPEG-2 standards ISO/IEC 13818-1 [9], 2 [10] and 3 [11]. The DVB Project has complemented MPEG-2 by several standards. TR 101 154 [5] specifies the minimum requirements for the interoperability of broadcast receivers. It is required because MPEG-2 is a "toolbox standard" that contains a wide range of profiles. EN 300 468 [6] defines the service information that complements the Program Specific Information (PSI) of MPEG-2 by informing a broadcast receiver about the transmitted services. A TV or radio "channel" is called a service in DVB terminology. DVB specifies a common scrambling algorithm for conditional access, which is addressed in ETR 289 [7]. Advanced video coding according ISO/IEC 14496-10 [12], which has been introduced in conjunction with high-definition television, is also carried over an MPEG-2 Transport Stream. MPEG-2 together with the complementing DVB specifications are widely used for satellite, cable or terrestrial broadcast above the corresponding transmission (physical layer) standards.

MPEG-2 and the complementing DVB standards can in principle be applied in SDR networks on the layers above the SDR physical layer. Transmission of an MPEG-2 Transport Stream need to have a constant end-to-end delay. Therefore, the receiver revokes the delay jitter caused by SDR physical layer processing.

The S-TS stream type IP Stream is a sequence of Internet Protocol (IP) datagrams. IP multicast has to be applied due to the one-way broadcast characteristic of an SDR network. Technologies for transporting coded video and audio are available and have been standardised.

TS 102 005 [8] defines the audio and video coding for DVB services delivered over IP networks without an MPEG-2 Transport Stream involved. It assumes that RTP according to RFC 3550 [13] is applied above IP and UDP. A choice of state-of-the-art audio and video coding standards including the applicable modes of operation is defined. For each coding standard the adaptation to RTP is defined. File formats for download are specified as well.

In summary, the S-TS stream types MPEG Transport Stream and IP Stream both allow making use of existing standards and specifications for the layers above the physical layer. In particular, DVB standards can be applied.

5 SDR design guidelines satellite

A satellite only SDR system can be implemented, but there will be coverage gaps inside urban environments.

5.1 HEO based satellite system

A Highly Elliptical Orbit (HEO) satellite system can provide very high elevation angles to earth located receivers. A HEO system includes at least 2 satellites. The system has ascending and descending satellites that are co-ordinated for optimal performance. This requires the system to handover the satellite signal from a descending satellite to the ascending satellite for continuous reception. During this handover, there will be a short period of time when no signal is present at the receivers, however, this short loss can be compensated by using some form of time redundancy along with FEC. The handover appears as a short blockage to FEC decoder/time un-disperser. Additionally, the carrier tracking mechanism is capable of handling the doppler frequency change at handover.

5.1.1 HEO system using single satellite source

In a HEO system with a single satellite source, time redundancy is provided in a time division multiplex manor. This is done by using a low code rate along with the time disperser to provide protection to signal blockage. This code rate should be approximately ½ the rate of a multiple satellite system using two sources. The higher the minimum elevation angle, the less probable a signal is blocked. For a three satellite HEO system, the minimum eleavation in Europe is greater than 65 degrees (see figure 5.1). The single source HEO signal provides maximum mobile performance for a HEO based satellite design.

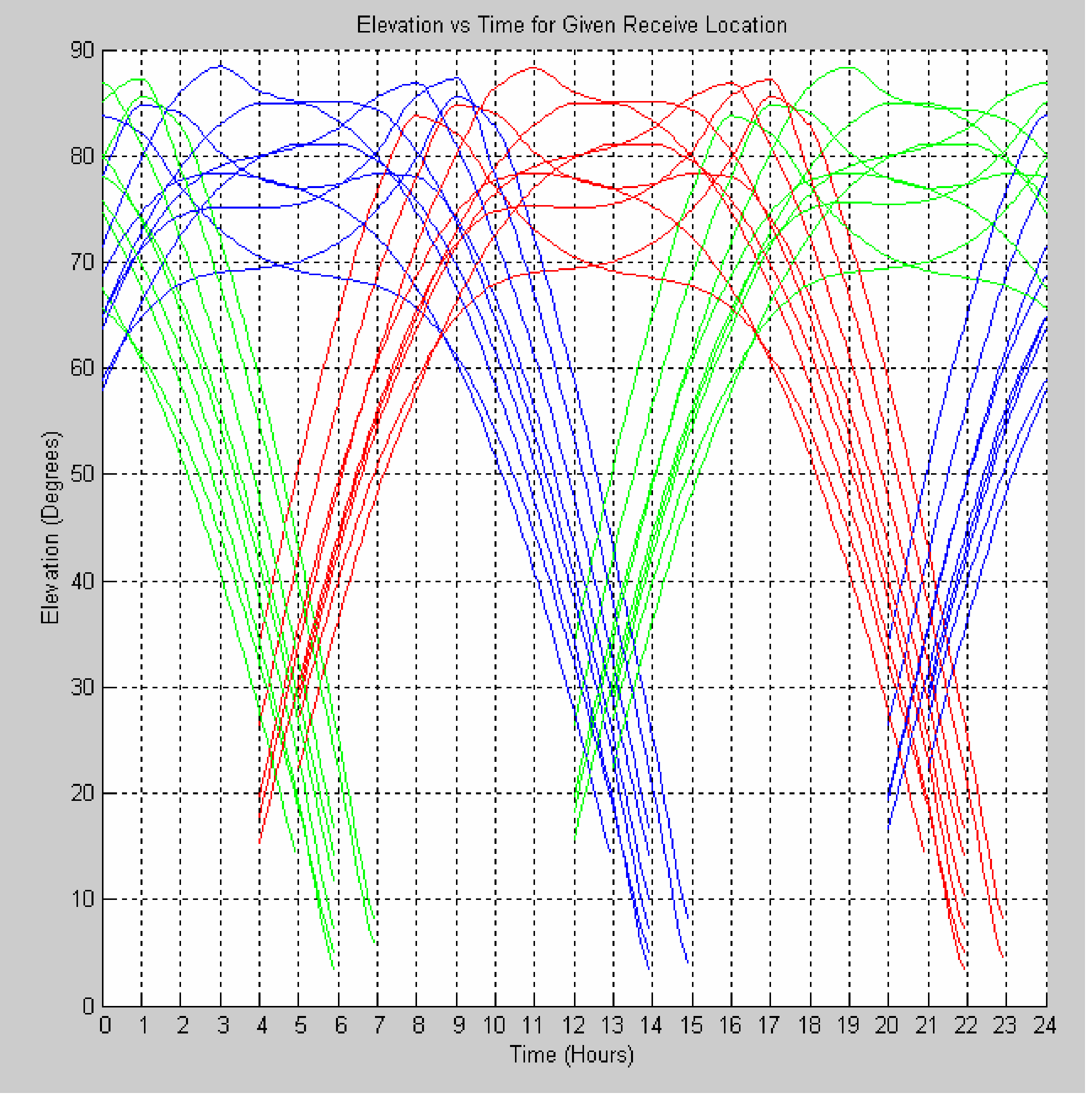

Figure 5.1: Elevation angle for HEO constellation at several locations in Europe (red = Sat1, blue = Sat2, green = Sat3)

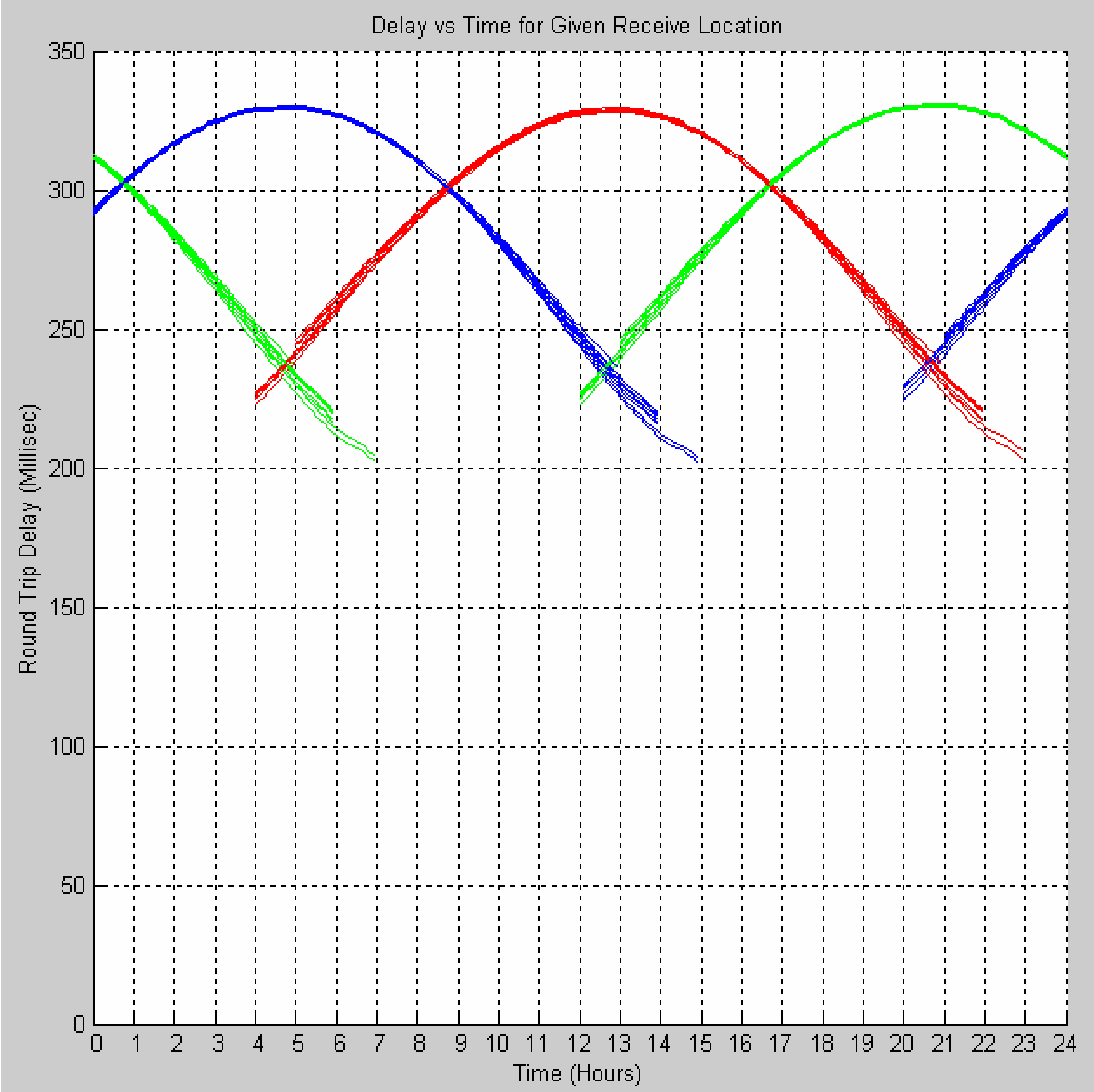

Figure 5.2: Round trip delay time for HEO signal at several locations in Europe (red = Sat1, blue = Sat2, green = Sat3)

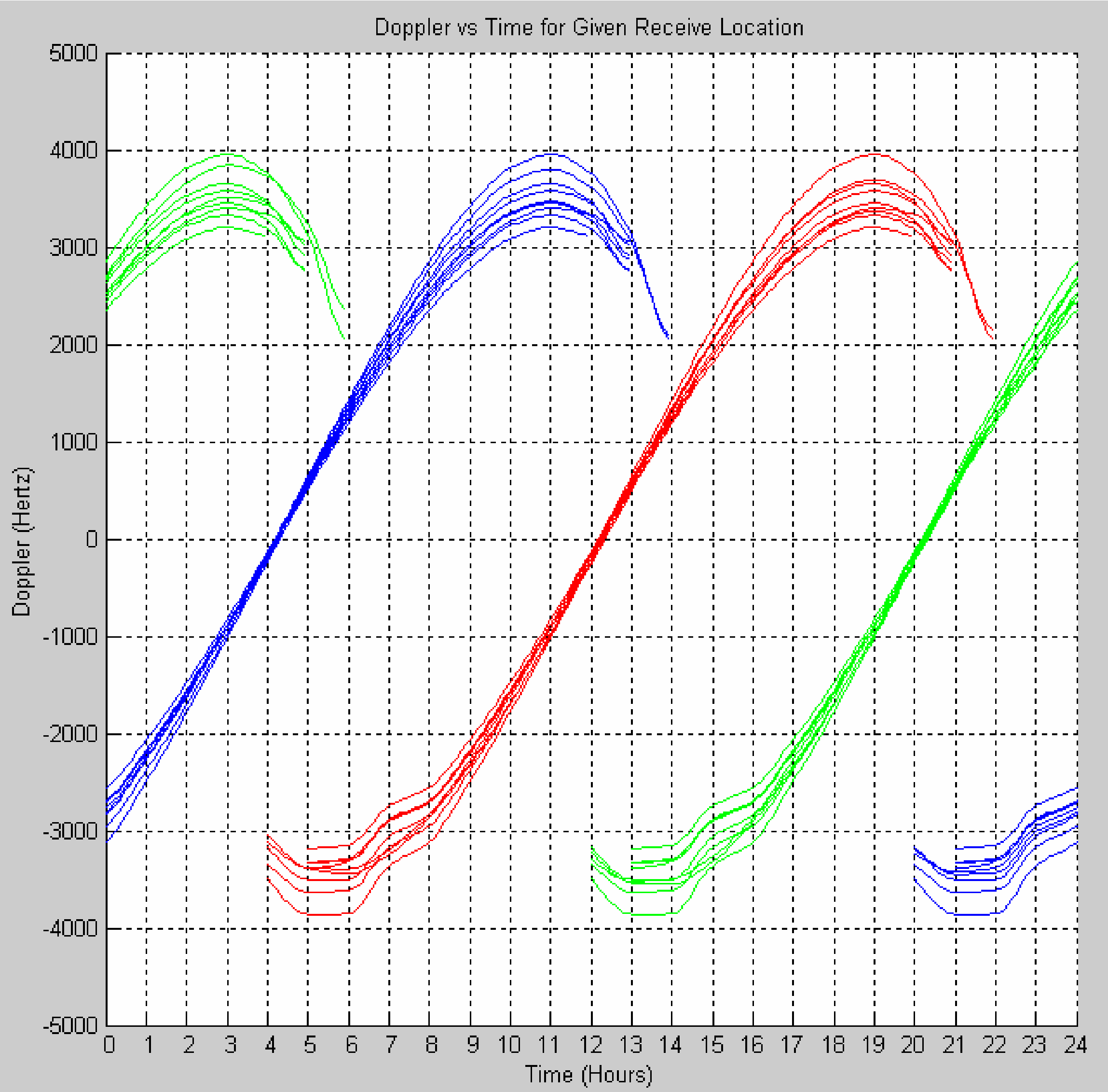

Figure 5.3: Doppler shift at several locations in Europe over time (red = Sat1, blue = Sat2, green = Sat3)

5.1.2 HEO system using multiple satellite source

In a HEO system with multiple satellite sources, time redundancy is provided in a a frequency multiplex manor. This is done by using two complementary codes along with a source split time disperser. This provides an overall protection to signal blockage using time, space and frequency. For a three satellite HEO system, the minimum elevation for one source is greater than 65 degrees, the minimum elevation of the second source is dependent on time and orbital parameters. The multiple source HEO signal provides maximum stationary performance for a HEO based system.

5.2 GEO based satellite system

A Geostationary Orbit (GEO) satellite system can provide fixed elevation angles to earth located receivers. A GEO system includes at least 1 satellite. The system has satellite in a fixed position over the equator. There is no requirements for handover from one satellite to another in the GEO system. This type of system is ideal for fixed reception where a receive antenna can be pointed towards the satellite.

5.2.1 GEO system using single satellite source

In GEO system with a single satellite source, time redundancy is provided in a time division multiplex manor. This is done by using a low code rate along with the time disperser to provide protection to signal blockage. This code rate should be approximately ½ the rate of a multiple satellite system using two sources. The elevation angle is determined by the geographical location of the receiver. The best performing mobile receivers are located closer to the equator, where the elevation angle is greatest.

5.2.2 GEO system using multiple satellite source

In GEO system with multiple satellite sources, time redundancy is provided in a a frequency multiplex manor. This is done by using complementary codes along with a source split time disperser. This provides an overall protection to signal blockage using time, space and frequency. For a two satellite GEO system, the satellites should have the highest space diversity possible. The multiple source GEO signal provides maximum mobile and stationary performance for a GEO based system.

5.3 Other satellite systems

It is possible to implement a HEO and GEO combination. This would enable good home and mobile reception.

6 SDR design guidelines terrestrial

The terrestrial signal for the SDR system is a coherent OFDM based modulation. The signal is designed for a single frequency network enabling a large number of terrestrial repeaters in a service area. These repeaters may be stand alone similar to DAB/DMB or as a supplemental gap filler for a hybrid system. The SDR has significant advantages over the older DAB/DMB systems in performance and capacity.

6.1 Terrestrial network topology

The terrestrial network may be configured as a single frequency network or as a single transmitter. Both large and small transmitter networks are possible.

6.1.1 Low power transmitter topology

In a small transmitter single frequency network, transmitters are closer together and the guard interval is less critical for system performance. Smaller transmitter power reduces the interference to adjacent systems for overload and intermodulation distortion. However, more transmitters are required to cover a given area compared to higher power transmitters.

6.1.2 High power transmitter topology

Care should be taken in a high power transmitter single frequency network to minimize guard interval violations. Fewer transmitters are required to cover a given area. Receivers should be designed to handle the larger input signal without causing self interference.

6.2 Terrestrial network feed

The Terrestrial network can be fed by many sources. These include the systems satellite broadcast channel, external satellites, fiber optics and other land line methods.

6.2.1 Internal signal feed

One method to feed the terrestrial signal is to use the hybrid system satellite. This is very effective for GEO systems where a high gain antenna can be pointed at the stationary satellite. The high gain antenna can be used to reject the terrestrial energy from blocking the satellite feed from terrestrial receiver saturation.

A HEO system would require satellite tracking for high gain antenna use.

In general, the terrestrial signal is a re-multiplex of the single carrier satellite signal for hybrid systems. The re-multiplex is required because the OFDM and single carrier bit rates are not identical. It is possible to include two satellite single carrier streams in one terrestrial multiplex by using 16-QAM.

6.2.2 External signal feed

This method can be used by stand alone terrestrial systems or HEO based hybrid systems. Typically this will involve a Ku band or equivalent satellite signal to feed the terrestrial network.

Another method is using land line technology to feed the network. This may be useful for local content insertion.

6.3 SFN synchronization

Multiple carrier modulation using OFDM enable single frequency networks for terrestrial and hybrid systems.

6.3.1 Terrestrial only SFN

This SFN can be used for stand alone terrestrial systems or hybrid systems using single carrier modulation for the satellite. Time synchronization should be used to align each transmitter in time to minimize guard interval violations for the covered area. GPS, hybrid satellite or other known time references can be used to synchronize each transmitter.

6.3.2 Hybrid SFN

This system is more critical for time alignment. The satellite is part of the SFN and cannot be adjusted indepently for a given area. Each terrestrial repeater is adjusted to align with the satellite signal. Care should be given to ensure that the terrestrial signals do not interfere with each other.

6.4 Non-hierarchical

The OFDM signal can use either QPSK or 16-QAM modulation on the data sub-carriers. The QPSK modulation will tolerate more guard interval violations than the 16-QAM at the same FEC rate. Two QPSK single carrier data streams can be re-multiplexed into one terrestrial 16-QAM data stream. This reduces the number of terrestrial frequencies required for a hybrid system.

6.4.1 Local content insertion

Because the multicarrier data stream is not identical to the single carrier data stream, additional content may be inserted into the terrestrial network. This allows the service provider to locally send content.

6.5 Hierarchical

The OFDM High Priority signal (HP) is the QPSK signal where the low priority signal (LP) is a super-imposed QPSK signal. The parameter alpha is used to set the LP/HP ratio. This mode is useful for transmitting local content in the vicinity of a repeater or SFN.

In a single frequeny network, some guard interval violations may occur. The HP signal will have good SFN performance relative to the LP signal. This allows each repeater in a SFN to have a unique LP signal for local content.

6.5.1 SFN local content with satellite multicarrier

In the case of a hybrid system using OFDM on the satellite, local content can be inserted into the terrestrial network using hierarchical modulation. The HP signal is common between the satellite and terrestrial. The LP signal is unique to the terrestrial SFN, the satellite has no LP signal.

When a receiver sees both a satellite and terrestrial signal, the effective alpha varies directly with the strength of the satellite signal.

6.5.2 SFN local content with satellite single carrier

In the case of a single carrier hybrid system, local content can be inserted into the terrestrial network using hierarchical modulation. The HP signal contains the re-multiplexed satellite data and the LP signal contains the local content. The terrestrial SFN hierarchical signal is the same for all transmitters in the given area.

6.5.3 Individual transmitter local content

Each repeater can contain unique local content using hierarchical modulation. It should be noted that the LP signals will interfere with each other and will have very localized reception. The HP signal is common for all repeaters.

7 SDR design guidelines hybrid system

The hybrid systems use at least one satellite and one terrestrial repeater to provide seamless coverage.

hybrid uses 1 or more satellites to provide line of sight reception for satellite reception. The terrestrial repeater system provides for a redundant signal in urban areas where the satellite may be blocked.

7.1 Receiver architecture

The following receiver architecture to support both single and multi-carrier modulation and antenna diversity exist.

7.1.1 High performance receiver

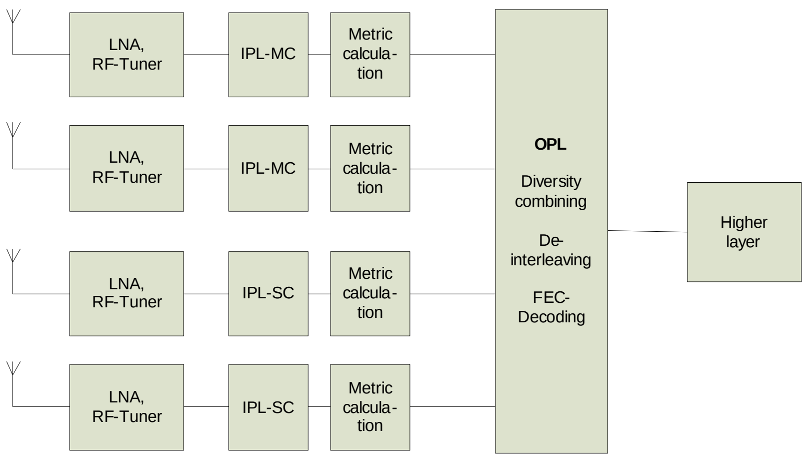

Figure 7.1: High performance receiver architecture

The high performance receiver (see figure 7.1) uses four distinct antennas (two for satellite, two for terrestrial) where both pairs provide antenna diversity on their respective transmission environment.

7.1.2 Low cost receiver

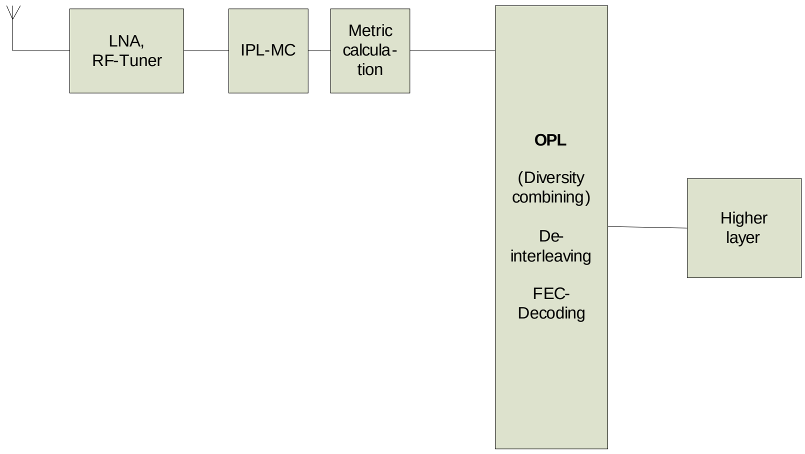

Figure 7.2: Low cost receiver architecture

The low cost receiver (see figure 7.2) uses one common antenna for both satellite and terrestrial reception. The same waveform is used here.

7.1.3 Multi-carrier only with antenna diversity ("selective combining")

This receiver type (see figure 7.3) supports antenna diversity (one dedicated antenna for satellite, another one for terrestrial). There is only one demodulator, and the combining is made based on measurements on the signal level directly after the RF input stages. This configuration is called "selective combining". The combining control is switching between the two antennas and needs to be informed about the estimated signal level or demodulator performance.

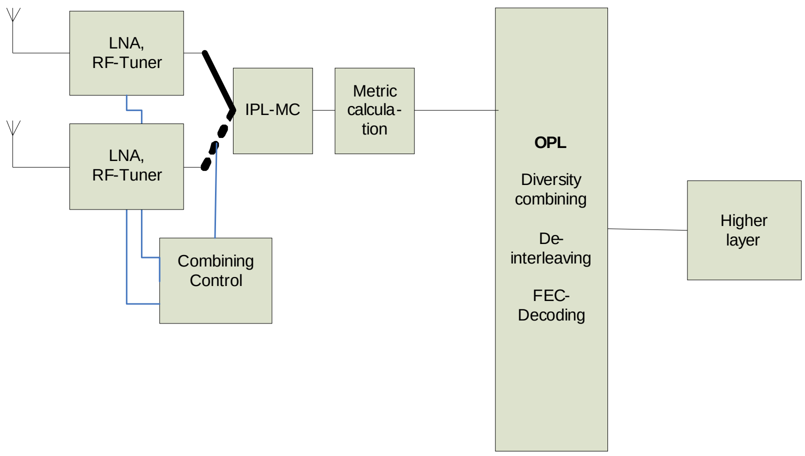

Figure 7.3: Multi-carrier only receiver with two distinct antennas, selective combining

7.1.4 Multi-carrier only with antenna diversity ("maximum ratio combining")

This receiver (see figure 7.4) includes two demodulators and combines the signal from the two antennas before the FEC decoder. The "combining control" as in the architecture before can now be omitted; therefore the FEC decoder is now the instance to optimally combine the demapped LLRs.

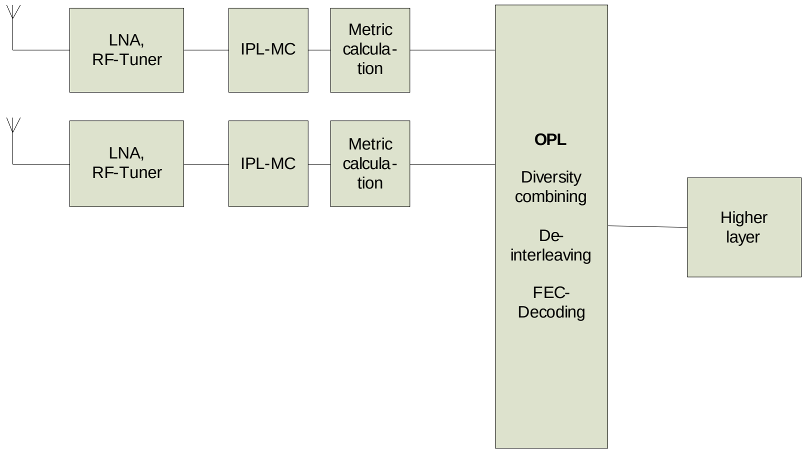

Figure 7.4: Multi-carrier only receiver with two distinct antennas, maximum ratio combining

7.1.5 Hybrid receiver with different antennas for satellite and terrestrial

This type of receiver (see figure 7.5) uses dedicated antennas for satellite and terrestrial. Different modulation is used in this configuration, so two different demodulators are used. Combining is again performed at the input of the FEC decoder, but now different code rates may be used on both transmission paths. This permits the use of CCC (complementary code combining).

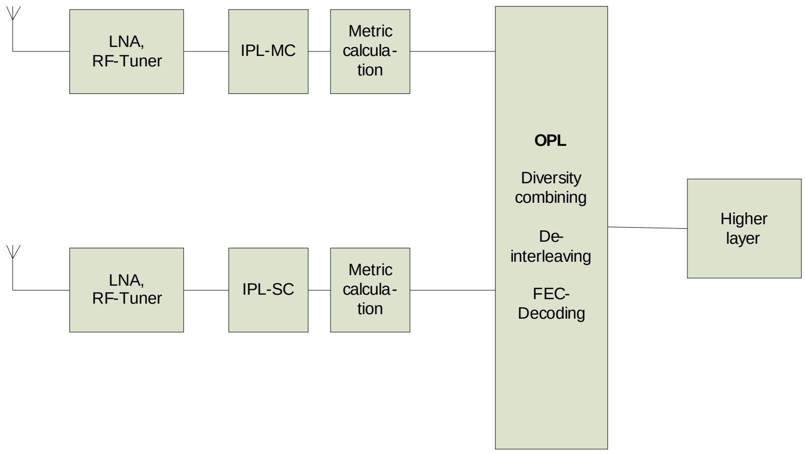

Figure 7.5: Hybrid receiver (single and multi-carrier) with two distinct antennas

7.1.6 Hybrid receiver a common antenna for satellite and terrestrial

This type of receiver (see figure 7.6) uses one single antenna for satellite and terrestrial. Different modulation is used in this configuration, so two different demodulators are used. Combining is performed at the input of the FEC decoder, but different code rates may be used on both transmission paths. This permits the use of Complementary Code Combining (CCC). Only one RF tuner is needed in this configuration as both signals are split after the frequency down-conversion.

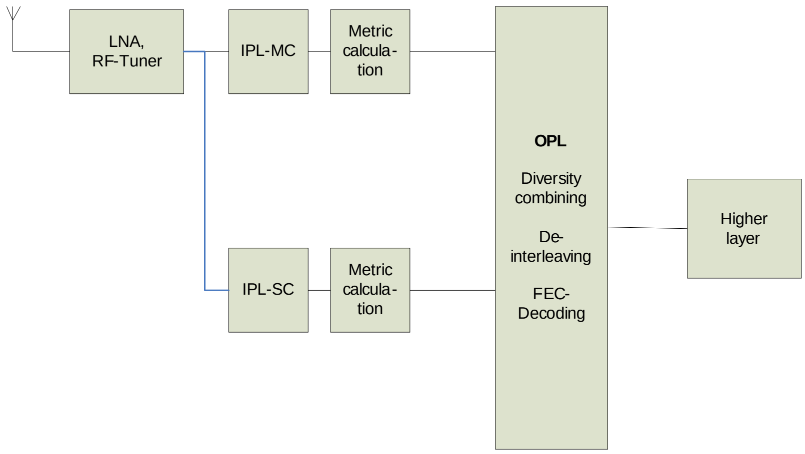

Figure 7.6: Hybrid receiver (single and multi-carrier) with only one antenna

7.1.7 Hybrid receiver with antenna diversity

As an extension to the receiver type as stated before, two antennas are now introduced which allow full exploitation of the diversity and the use of different modulation schemes on both satellite and terrestrial distribution. This receiver (see figure 7.7) supports antennas with the same characteristics (e.g. two linear polarized antennas) as well as antennas with different characteristics (e.g. one linear and one circular polarized antenna).

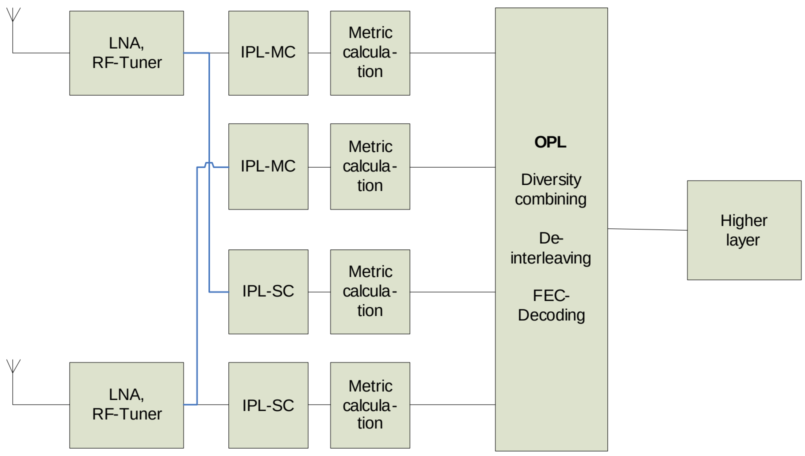

Figure 7.7: Hybrid receiver (single and multi-carrier) with antenna diversity

7.1.8 Conclusion on receiver architectures

The choice of the antenna has a major impact on the choice of the receiver architecture. Table 7.1 gives an estimated price ranking (and also complexity) for the receivers as mentioned before.

Table 7.1: Comparison of different receiver architectures with respect to cost and complexity

Type	Chapter	Price
One antenna, one RF tuner, one IPL	7.1.2	low
One antenna, one RF tuner, several IPL, same OPL	7.1.6	low
Two antennas, two RF tuners, one IPL, SC	7.1.3	medium
Two antennas, two RF tuners, same IPL, MRC	7.1.4	medium
Two antennas, two RF tuners, different IPL, CCC	7.1.5	medium
Two antennas, two RF tuners, different IPL, CCC	7.1.7	medium
Four antennas, four RF tuners, full diversity	7.1.1	high

8 Example profiles for hybrid systems

The following profiles have been proposed as examples for a GEO and a HEO hybrid system respectively. These profiles are examples only and should not be considered final.

8.1 W Profile for hybrid systems (GEO)

Infrastructure

The W profile hybrid infrastructure is based on the use of a geostationary satellite, broadcasting a set of Single Carrier (SC) signals complemented by aterrestrial repeater network broadcasting a single Multi-Carrier (MC) signal. For coverage or capacity extension purposes, an additional GEO satellite could be added to the system. The terrestrial network locally repeats 1 to 2 SC signals.

Satellite signal

Inner Physical Layer (IPL)

The satellite signal is a set of carriers compliant with IPL-SC as defined in the ETSI SDR standard.

The modulations used for IPL-SC will be QPSK or 8-PSK, depending on link budget conditions. The symbol rates and roll off factor that will be used are:

- 1,485 MSym/s.
- 15 %.

For legacy reasons and according to the possibilities offered by the standard, a second set of values will also be used:

- 1,84 MSym/s.
- 40 %.

Outer Physical Layer (OPL)

The OPL implementation of the W profile system will comply with the ETSI SDR standard.

To ensure a minimum margin to offer an adequate quality of service, the following code rates will be used:

- for live audio streaming services:
  - 1/5;
  - 1/4;
  - 1/3;
  - 2/5;
  - 1/2.
- for data services (streaming and file push):
  - 1/3;
  - 2/5;
  - 1/2;
  - 2/3.

For live audio services, long interleavers (10, 20 or 30 frames) will be selected to overcome temporary blockage situations. In conjunction with the Turbo coding gain, this will offer a good quality of service even outside repeater coverage.

End-to-end delay is not critical in the audio streaming applications. Zapping time and error correction performance will be the primary parameters of interest when defining the interleaver profile. A total optimization of the zapping time would remove the gain of interleaving the data. The profile should therefore be selected according to the code rate employed, the available link margin and the channel characteristics.

Regarding data services, the interleavers will be short (2, 4 or 10 frames) if the end-user application is not requiring a high quality of service (e.g. realtime traffic where repetition of data is foreseen). For other applications such as file delivery, depending on the average size of the files, longer interleavers such as the ones used for audio streaming services could be used.

Terrestrial signal

Inner Physical Layer (IPL)

The terrestrial signal is compliant with IPL-MC as defined in the ETSI SDR standard. The baseline modulation used for IPL-MC will be 16-QAM and the FFT will be 512. However, the W profile also foresees QPSK and FFT 1 024. It is not anticipated to use hierarchical modulation.

Outer physical layer (OPL)

The targeted code rates are:

- 1/3;
- 2/5;
- 1/2;
- 2/3;
- 3/4.

A short interleaver (2 or 4-frame) will be used irrespective of the type of service. Longer interleavers are not required for the terrestrial signal in that particular configuration.

8.2 O Profile for Hybrid Systems (HEO)

Infrastructure

The O profile hybrid infrastructure is based on the use of a Highly Eliptical Orbit (HEO) Satellite constellation. The Single Carrier (SC) satellite signals are complemented by a terrestrial repeater network broadcasting a Multi-Carrier (MC) signals. The terrestrial network is expected to repeat 2 SC signals.

Satellite Signal

Inner Physical Layer (IPL)

The satellite signal consists of multiplexes that are compliant with the IPL-SC as defined in the ETSI SDR standard.

The selected modulation schemes will be either QPSK or 8-PSK. The symbol rate and roll off factor is:

- 1,485 MSym/s.
- 15 %.

Outer Physical Layer (OPL)

The OPL implementation of the O profile system will comply with the ETSI SDR standard. To ensure an adequate quality of service and capacity, the following code rates may be used:

- for live streaming services:
    - 1/5;

  - 2/9;
  - 1/4;
  - 2/7;
  - 3/10 (preferred);
  - 1/3;
  - 3/8;
  - 2/5;
  - 3/7;
  - 1/2.
- for data services:
  - 1/2;
  - 3/5;
  - 2/3;
  - 3/4;
  - 6/7.

For live services, long interleavers of approximately 20 frames will be used to overcome temporary blockage situations. In conjunction with the FEC, this will enable good service availability for satellite reception.

Terrestrial Signal

Inner Physical Layer (IPL)

The terrestrial signal is compliant with IPL-MC as defined in the ETSI SDR standard. The baseline modulation used for IPL-MC will be 16-QAM and the FFT will be 512.

Outer physical layer (OPL)

The targeted code rates are:

- 3/10;
- 1/3;
- 3/8;
- 3/7;
- 1/2;
- 3/5;
- 2/3.

A short interleaver is expected for all services.

History

Document history		
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