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Foreword

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

1 Scope

The present document entails a feasibility study that evaluates the use of the OFDM Radio Interface proposed the 3GPP TR 25.892 [i.1] as Satellite Radio Interface on the satellite downlink, presenting physical layer results and link budget studies. The present document contains informative elements that should serve as a starting point for the definition and finalization of advanced Satellite Radio Interfaces. The adoption of the OFDM Radio Interface results in higher link margin under key propagation conditions such as the NLOS propagation case and when CGCs are considered.

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2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] 3GPP TR 25.892 (V6.0.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement (Release 6)".

[i.2] 3GPP TR 25.858 (V5.0.0): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; High Speed Downlink Packet Access: Physical Layer Aspects (Release 5)".

[i.3] ETSI TS 125 212: "Universal Mobile Telecommunications System (UMTS); Multiplexing and channel coding (FDD) (3GPP TS 25.212 version 5.9.0 Release 5)".

[i.4] S. Chang: "Compensation of nonlinear distortion in RF power amplifiers", Wiley Encyclopedia of Telecommunications, J.J. Proakis Ed., 2002.

[i.5] S. Benedetto and E. Biglieri: "Nonlinear equalization of digital satellite channels", IEEE J. Select. Areas Comm., vol. 1, pp. 57-62, Jan. 1983.

[i.6] J.K. Cavers: "Amplifier Linearization using a digital predistorter with fast adaptation and low memory requirements", IEEE Trans. Vehic. Tech., vol. 39, pp. 31-40, Nov. 1990.

[i.7] P. Salmi, M. Neri, and G.E. Corazza: "Fractional Predistortion. Techniques with Robust Modulation Schemes for Fixed and mobile Broadcasting", 13th IST Mobile & Wireless Communications Summit (IST2004), pp. 990-995, June 2004.

[i.8] S.W. Golomb, and H. Taylor: "Construction and Properties of Costas Array", Proc. IEEE, vol. 72, pp. 1143-1163, Sep. 1984.

[i.9] S. Cioni, G.E. Corazza, M. Neri, and A. Vanelli-Coralli: "On the Use of OFDM Radio Interface for Satellite Digital Multimedia Broadcasting Systems", International Journal of Satellite Communications and Networking, February 2006, Int. J. Satell. Commun. Network. 2006; 24:153-167, published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/sat.836.

3 Definitions, symbols and abbreviations

3.1 Definitions

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

cell: geographical area under Complementary Ground Component coverage

downlink: unidirectional radio link for the transmission of signals from a satellite to a UE

forward link: unidirectional radio link for the transmission of signals from a gateway to a UE via a satellite

guard interval / guard time: number of samples inserted between useful OFDM symbols, in order to combat inter-OFDM-symbol-interference induced by channel dispersion and to assist receiver synchronization

NOTE: It may also be used to aid spectral shaping. The guard interval may be divided into a prefix (inserted at the beginning of the useful OFDM symbol) and a postfix (inserted at the end of the previous OFDM symbol).

inter-carrier frequency / sub-carrier separation: frequency separation between OFDM sub-carriers, defined as the OFDM sampling frequency divided by the FFT size

OFDM unit: group of constellation symbols to be mapped onto a sub-band, a subset of the OFDM carriers

OFDM samples: discrete-time complex values generated at the output of the IFFT, which may be complemented by the insertion of additional complex values (such as samples for pre/post fix and time windowing)

NOTE: Additional digital signal processing (such as filtering) may be applied to the resulting samples, prior to being fed to a digital-to-analog converter.

OFDM sampling frequency: total number of samples, including guard interval samples, transmitted during one OFDM symbol interval, divided by the symbol period

repeater: device (e.g. CGC) that receives, amplifies and transmits the radiated or conducted RF carrier both in the down-link direction (from the satellite to the mobile area) and in the up-link direction (from the mobile to the satellite)

return link: unidirectional radio link for the transmission of signals from a UE to a gateway via a satellite

rice factor: power ratio between LOS component and diffuse component

spot: geographical are under beam coverage

uplink: unidirectional radio link for the transmission of signals from a UE to a satellite

useful OFDM symbol: time domain signal corresponding to the IFFT/FFT window, excluding the guard time

useful OFDM symbol duration: time duration of the useful OFDM symbol

3.2 Symbols

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

F_0	OFDM sampling frequency
F_d	Maximum Doppler shift.
N	Total number of IFFT/FFT bins (sub-carriers)
N_p	Number of prefix samples
N_u	Number of modulated sub-carriers (i.e. sub-carriers carrying information)
T_s	OFDM symbol period
T_g	OFDM prefix duration
T_u	OFDM useful symbol duration
Δf	Sub-carrier separation

3.3 Abbreviations

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

ACI	Adjacent Channel Interference
APSK	Amplitude and Phase Shift Keying
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
C/N	Carrier to Noise power ratio
CGC	Complementary Ground Component
CRC	Cyclic Redundancy Check
CPICH	Common Pilot Channel
DC-RF	Direct Current to Radio Frequency
DL	Down Link
EIRP	Effective Isotropic Radiated Power
FDM	Frequency Division Multiplexing
FFS	For Further Study
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
GEO	Geostationary Earth Orbit
GW	GateWay
HARQ	Hybrid Automatic Repeat reQuest
HPA	High Power Amplifiers
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed - Downlink Shared CHannel
IBO	Input Back-Off
IFFT	Inverse Fast Fourier Transform
IMR	Intermediate Module Repeater
ISI	Inter Symbol Interference
LOS	Line-Of-Sight
LTWTA	Linearized Travelling Wave Tube Amplifier
LUT	Look-Up Table
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
NL	Non Linear
NLOS	No Line-Of-Sight
OBO	Output Back Off

OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-to-Average Power Ratio
PDSCH	Physical Downlink Shared CHannel
PER	Packet Error Rate
PhCh	Physical ChannelPSK Phase Shift Keying
QAM	Quadrature Amplitude Modulation
SCCH	Shared Control CHannel
S-DMB	Satellite-Digital Mobile Broadcasting
SFN	Single Frequency Network
SNR	Signal-to-Noise Ratio
T-F	Time-Frequency
TPCCH	Transmit Power Control CHannel
TTI	Transmission Time Interval
TWTA	Travelling Wave Tube Amplifier
UE	User Equipment
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

4 OFDM technology and background

4.1 OFDM Fundamentals

4.1.1 OFDM Definitions

The technique of Orthogonal Frequency Division Multiplexing (OFDM) is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels.

The OFDM technique differs from traditional FDM in the following interrelated ways:

1) multiple carrier multiple carriers (called sub-carriers) carry the information stream;

2) the sub-carriers are orthogonal to each other; and

3) a guard time may be added to each symbol to combat the channel delay spread and inter-symbol interference induced by linear distortion.

These concepts are illustrated in the time-frequency representation of OFDM presented in figure 1.

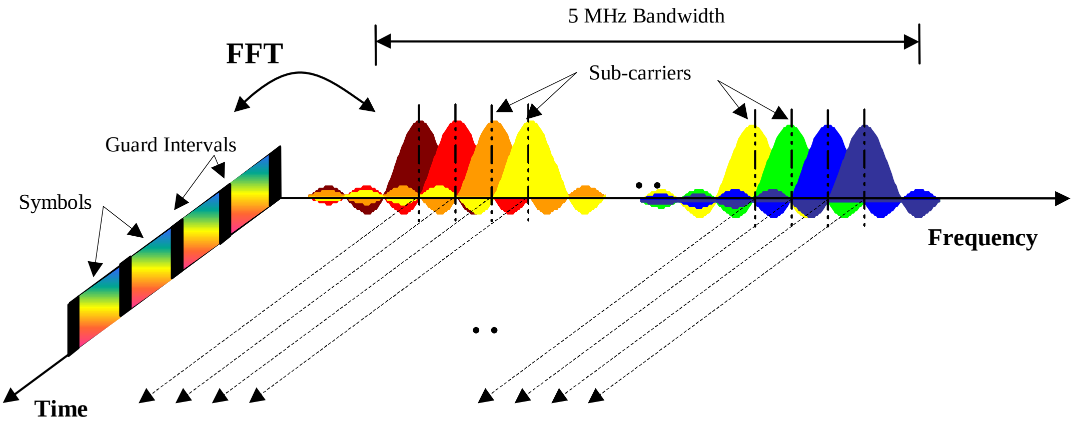

Figure 1: Frequency-Time representation of an OFDM Signal

Since the orthogonality is guaranteed between overlapping sub-carriers and between consecutive OFDM symbols in the presence of time/frequency dispersive channels the data symbol density in the time-frequency plane can be maximized.

4.1.2 OFDM Signal Generation

Data symbols are synchronously and independently transmitted over a high number of closely spaced orthogonal sub-carriers using linear modulation (either PSK, APSK or QAM). The generation of the QAM/OFDM signal can be conceptually illustrated as in figure 2, where ω_n is the n^{th} sub-carrier frequency (in rad/s) and $1/T_u$ is the QAM symbol rate. Note that the sub-carriers frequencies are equally spaced and hence the sub-carrier separation is constant. That is:

$$\frac{|\omega_n - \omega_{n-1}|}{2\pi} = \Delta f, \qquad n \in [1, N-1].$$

In practice, the OFDM signal can be generated using IFFT digital signal processing. The baseband representation of the OFDM signal generation using an N-point IFFT is illustrated in figure 3, where $a(mN+n)$ refers to the n^{th} sub-channel modulated data symbol, during the time period $mT_u < t \le (m+1)T_u$.

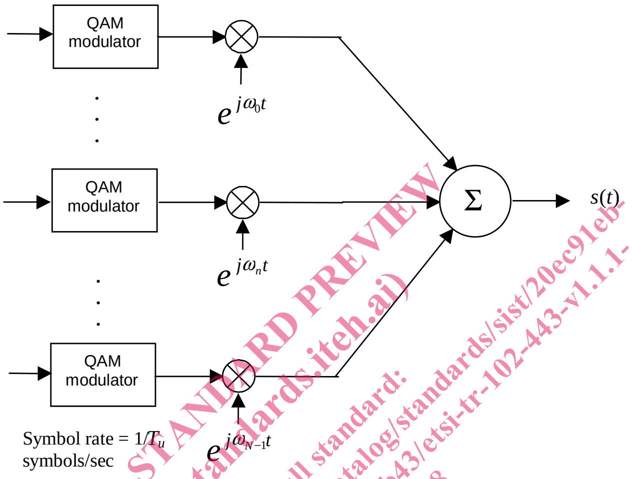

Figure 2: Conceptual representation of OFDM symbol generation

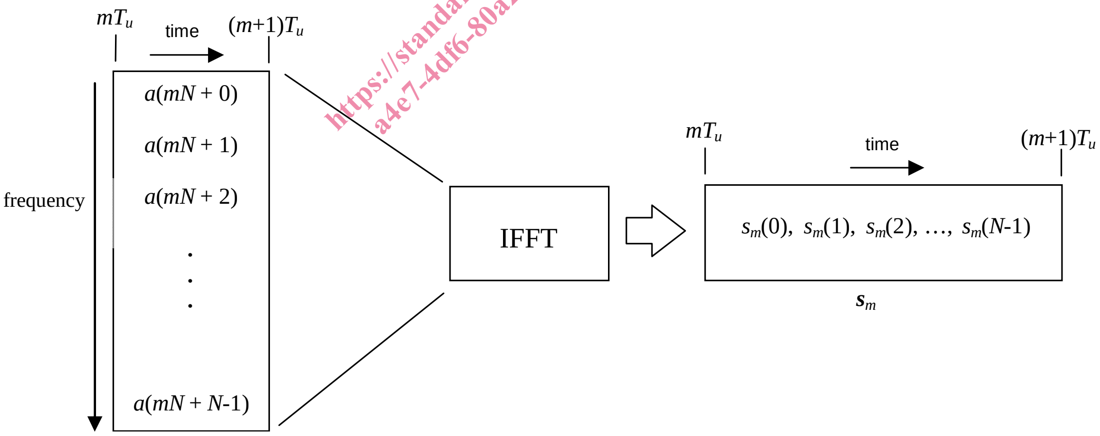

Figure 3: OFDM useful symbol generation using an IFFT

The vector $\mathbf{s}_m$ is defined as the useful OFDM symbol. Note that the vector $\mathbf{s}_m$ is in fact the time superposition of the N narrowband modulated sub-carriers.

It is therefore easy to realize that, from a parallel stream of *N* sources of data, each one modulated with QAM useful symbol period T_u, a waveform composed of *N* orthogonal sub-carriers is obtained, with each narrowband sub-carrier having the shape of a frequency *sinc* function. Figure 4 illustrates the mapping from a serial stream of QAM symbols to *N* parallel streams, used as frequency domain bins for the IFFT. The *N*-point time domain blocks obtained from the IFFT are then serialized to create a time domain signal.

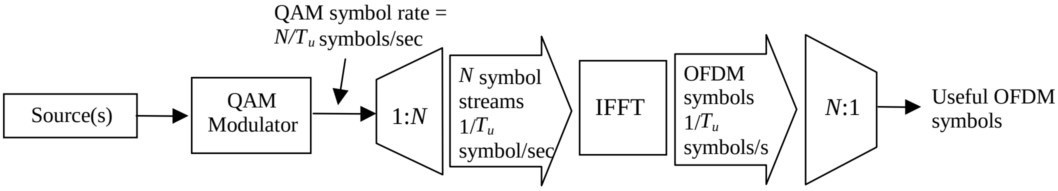

Figure 4: OFDM signal generation chain

4.1.3 Guard Interval

A guard interval may be added prior to each useful OFDM symbol. This guard time is introduced to minimize the inter-OFDM-symbol-interference power caused by time-dispersive channels. The guard interval duration T_g (which corresponds to N_p prefix samples) needs to be sufficient to cover the most of the delay-spread energy of a radio channel impulse response. In addition, such a guard time interval can be used to allow soft-handover.

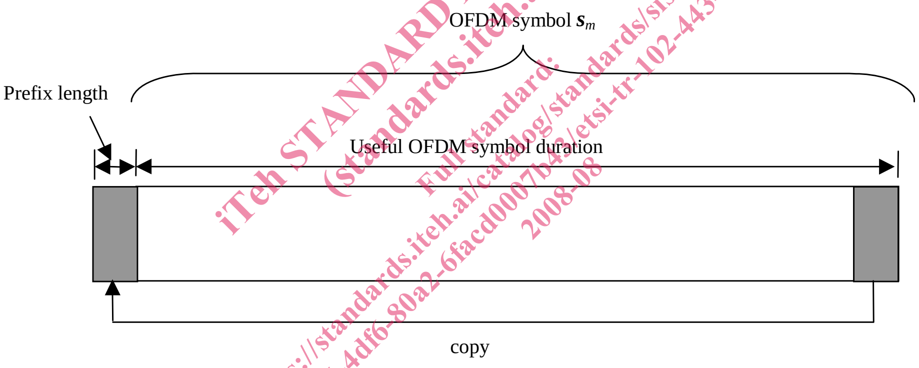

Figure 5: Cyclic prefix insertion

A prefix is generated using the last block of N_p samples from the useful OFDM symbol. The prefix insertion operation is illustrated in figure 5. Note that since the prefix is a cyclic extension to the OFDM symbol, it is often termed cyclic prefix. Similarly, a cyclic postfix could be appended to the OFDM symbol.

After the insertion of the guard interval the OFDM symbol duration becomes $T_s = T_g + T_u$.

The OFDM sampling frequency F_0 can therefore be expressed as:

$$F_0 = \frac{N + N_p}{T_s}$$

hence, the sub-carrier separation becomes:

$$\Delta f = \frac{F_0}{N}.$$

It is also worth noting that time-windowing and/or filtering is necessary to reduce the transmitted out-of-band power produced by the ramp-down and ramp-up at the OFDM symbol boundaries in order to meet the spectral mask requirements.

4.1.4 Impact of Guard Interval

The cyclic prefix should absorb most of the signal energy dispersed by the multi-path channel. The entire the inter-OFDM-symbol-interference energy is contained within the prefix if the prefix length is greater than that of the channel total delay spread, i.e.:

$$T_g > \tau$$

where τ is the channel total delay spread. In general, it is sufficient to have most of the energy spread absorbed by the guard interval, given the inherent robustness of large OFDM symbols to time dispersion, as detailed in the next clause.

4.1.5 Impact of Symbol Duration

The mapping of the modulated data symbol onto multiple sub-carriers also allows an increase in the symbol duration. Since the throughput on each sub-carrier is greatly reduced, the symbol duration obtained through an OFDM scheme is much larger than that of a single carrier modulation technique with a similar overall transmission bandwidth. In general, when the channel delay spread exceeds the guard time, the energy contained in the ISI will be much smaller with respect to the useful OFDM symbol energy, as long as the symbol duration is much larger than the channel delay spread, that is:

$$T_s >> \tau .$$

Although large OFDM symbol duration is desirable to combat time-dispersion caused ISI, however, the large OFDM symbol duration can reduce the ability to combat the fast temporal fading, especially if the symbol period is large compared to the channel coherence time. Thus, if the channel can no longer be considered as constant through the OFDM symbol, the inter-sub-carrier orthogonality loss is introduced and the performance in fast fading conditions are degraded. Hence, the symbol duration should be kept smaller than the minimum channel coherence time. Since the channel coherence time is inversely proportional to the maximum Doppler shift f_d, the symbol duration T_s needs to be, in general, chosen such that:

$$T_s << \frac{1}{f_d} .$$

4.1.6 Impact of Inter-Carrier Spacing

Because of the time-frequency duality, some of the time-domain arguments of clause 4.1.5 Impact of Symbol Duration can be translated to the frequency domain in a straightforward manner. The large number of OFDM sub-carriers makes the bandwidth of the individual sub-carriers small relative to the overall signal bandwidth. With an adequate number of sub-carriers, the inter-carrier spacing is much narrower than the channel coherence bandwidth. Since the channel coherence bandwidth is inversely proportional to the channel delay spread τ, the sub-carrier separation is generally designed such that:

$$\Delta f << \frac{1}{\tau} .$$

In this case, the fading on each sub-carrier is frequency flat and can be modelled as a constant complex channel gain. The individual reception of the QAM symbols transmitted on each sub-carrier is therefore simplified to the case of a flat-fading channel. Moreover, in order to combat Doppler effects, the inter-carrier spacing should be much larger than the maximum Doppler shift f_d:

$$\Delta f >> f_d .$$

4.1.7 OFDM Inactive Sub-Carriers

Since the OFDM sampling frequency is larger than the actual signal bandwidth, only a sub-set of sub-carriers is used to carry QAM symbols. The remaining sub-carriers are left inactive prior to the IFFT, as illustrated in figure 6. The split between the active and the inactive sub-carriers is determined based on the spectral constraints, such as the bandwidth allocation and the spectral mask.