3GPP/PCG#10 Meeting
Ottawa, Canada
2 May 2003

3GPP/PCG#10(03)19
25 April 2003
page 1 of 36

Source: **TSG RAN Chairman**

Title: **Consideration of OFDM modulation in 3GPP**

Agenda item: **4.3**

Document for:

Decision	
Discussion	
Information	**X**

1 Introduction

PCG has previously discussed the proposal for OFDM modulation to be included within the 3GPP work programme. TSG RAN was charged with the task to study the proposal and keep PCG informed of the results.

A summary of the findings made so far can be found attached, together with a draft of a Technical Report on the subject.

PCG will be kept informed of any future developments.

3GPP PCG meeting #10
Ottawa, Canada Ontario, May 2nd 2003

TSG-RAN meeting #19 RP-030161
Birmingham, UK, 11th – 20th March 2003

Status Report for SI to TSG

Study Item Name: Analysis of OFDM for UTRAN enhancement

SOURCE: Rapporteur (Sarah Boumendil, Nortel Networks) **TSG:** RAN **WG:** 1

E-mail address rapporteur: boumendi@nortelnetworks.com

Ref. to SI sheet: RAN_Study_Items.doc

Progress Report since the last TSG (for all involved WGs):

RAN1 #30:

- An agreement was reached on the OFDM parameter sets to be used for the performance evaluation. Two sets have been selected and added to the technical report TR25.892 "Analysis of OFDM for UTRAN enhancement".
- Another variant of OFDM termed IOTA was also presented and discussed.
- A revised text proposal for tutorial sections of the TR was presented and discussed. It was submitted afterwards on the reflector with minor changes according to the comments for inclusion in the TR after the next meeting.
- Simulation methodology was discussed again, and it was decided that it should be revised (to add traffic models and a few other details) and posted on the reflector 3 weeks before RAN1 #31.
- Other contributions discussing OFDM interleaving and the choice of a preferred advanced WCDMA receiver scheme for the study were presented and discussed.

RAN1 #31:

- The revised TR, including details on the OFDM parameter sets, was presented and agreed [1].
- The revised text proposal for the tutorial sections of the TR was presented and accepted with minor changes.
- Text proposals clarifying the time structure for one of the parameter sets and presenting basic concepts related to IOTA were presented and agreed for inclusion in the TR.
- The revised simulation methodology document was discussed. Parts of the documents pertaining to link and system level simulation assumptions, traffic models etc. were accepted for inclusion in the annexe of the TR.
- Other text proposals discussing physical layer structure, multiplexing and spectrum issues, and contributions discussing modulation diversity and WCDMA MMSE receiver modelling were also presented.
- The updated TR including all of the accepted text proposals will be posted on the reflector to review the changes prior to next meeting.

List of Completed elements (for complex work items):

- Documentation of OFDM fundamentals
- Sets of reference parameters
- Link and system level simulation assumptions

List of open issues:

- Some elements of simulation methodology (e.g. HARQ modelling)
- Release 5 channels to be carried by the OFDM carrier
- Physical Channel definition and mapping of transport channels onto physical channels
- Performance evaluation
- Compatibility and impact evaluation

Estimates of the level of completion (when possible):

30%

SI completion date review resulting from the discussion at the working group:

Currently RAN#20 (June 2003). Proposal from rapporteur is to move the completion date to RAN#22 (Dec03)

References to WG's internal documentation and/or TRs:

[1] R1-030312, TR25.892, Analysis of OFDM for UTRAN enhancement, version 0.1.0 as accepted in RAN1 #31.

3GPP TR 25.892 V0.2.0 (2003-03)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Feasibility Study for OFDM for UTRAN enhancement;
(Release 6)

OFDM for UTRAN enhancement

<keyword[, keyword]>

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

Introduction

This technical report presents the results of the 3GPP system Study Item to consider the application of OFDM techniques to 3GPP-based systems. This study includes an analysis of the feasibility and potential benefits of introducing OFDM in UTRAN and a recommendation to RAN Plenary on a potential standardisation work plan and time frame.

As the mobile radio systems evolve and become more integrated with daily activities, there is an increasing requirement for additional services requiring very high bit rates and higher system capacity. These include both services to individuals as well as multimedia broadcast and multi-cast services. OFDM (Orthogonal Frequency Division Multiplexing) is a technology that has been shown to be well suited to the mobile radio environment for high rate and multimedia services. Examples of commercial OFDM systems include the Digital Audio Broadcast (DAB), Digital Video Broadcast Terrestrial (DVB-T) and the HiperLAN and IEEE WLAN (802.11a) wireless local area network systems.

Editor’s notes : Provides a high-level outline of report, and summary of the rational, conclusions and recommendations. Important considerations are why the new technology might be needed, compatibility with previous releases of UTRAN, aspects of new service requirements, constraints of spectrum. It is a study of physical layer aspects only and does not include changes in UTRAN architectures beyond those needed to support an additional physical layer.

1 Scope

The scope of this Study Item is to consider the performance of OFDM in the mobile environment and to consider scenarios in which OFDM may be introduced in UTRAN 3GPP based systems. This activity involves the Radio Access work area of the 3GPP studies and has some effect on the Mobile Equipment and Access Network of the 3GPP systems.

The aims of this study are:

- to consider the advantages that may be gained by introducing a new modulation technique in 3GPP RAN systems,
- to estimate possible benefits and complexity and
- to recommend to 3GPP RAN if further standardisation development work should be undertaken by 3GPP.

As a starting point, OFDM will be considered in the downlink only. It should be possible to operate in a 5MHz spectrum allocation i.e. coupled with W-CDMA in the uplink for a 2*5MHz deployment scenario.

The following list provides examples of areas that are to be considered in the study:

- Support peak bit rates bit rates in the order of 10 Mbit/s and above;
- Support for MIMO and other advanced antenna array techniques;
- Support for personal, multimedia and broadcast services;
- Deployment scenarios including frequency re-use aspects within diverse spectrum allocations;

The study should consider performance aspects, aspects linked to the evolution of UMTS (high level architecture, diverse spectrum arrangements and allocations), impacts on signalling in UTRAN , aspects of capacity/cost/complexity/coverage and aspects of co-existence with the existing UMTS modes.

The purpose of the study is to describe a representative OFDM concept that can be used in the feasibility study phase but the concept does not restrict the design when moving to the specification phase. It is a study of physical layer aspects only and does not include changes in UTRAN architecture. Changes are to be restricted to the physical layer and not extend beyond those needed to support an additional modulation. Principles as provided in TS 25.302 (Services provided by the physical layer) are to be respected where possible.

This study item was approved by the TSG RAN#16 (Marco Island Fl USA 4th – 7th June 2002).

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP, "TR 25.848: Physical layer aspects of UTRA High Speed Downlink Packet Access", Version 4.0.0, March/2001.

[2] 3GPP, "TR 25.855: High Speed Downlink Packet Access: Overall UTRAN Description", Version 5.0.0, September/2001.

[3] 3GPP, "TR 25.858: High Speed Downlink Packet Access: Physical Layer Aspects", Version 5.0.0, March/2002.

[4] 3GPP, “TS 25.212: Multiplexing and channel coding (FDD)”, Version 5.0.0, March/2002.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purpose of this document, the definitions in 3GPP TR 21.905 as well as the following definitions apply.

Guard interval / Guard time: A 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. 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: The frequency separation between OFDM sub-carriers, defined as the OFDM sampling frequency divided by the FFT size.

OFDM samples: The 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). 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: The total number of samples, including guard interval samples, transmitted during one OFDM symbol interval, divided by the symbol period.

Prefix/Postfix: See **Guard interval**.

Sub-carrier: The frequency over which the low data rate information is modulated; it also often refers to the related modulated carrier.

Sub-carrier separation: See **Inter-carrier frequency**.

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

Useful OFDM symbol duration: The time duration of the useful OFDM symbol.

3.2 Symbols

F_o	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.
t	Channel total delay spread.
$g(t)$	Prototype function
$\Im(t)$	IOTA function

τ_0	OFDM/OQAM symbol period

3.3 Abbreviations

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

FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference
IOTA	Isotropic Orthogonal Transform Algorithm
MIMO	Multiple-Input Multiple-Output
OFDM	Orthogonal Frequency Division Multiplexing
OQAM	Offset Quadrature Amplitude Modulation
PAPR	Peak-to-Average Power Ratio
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation

4 OFDM Technology

4.1 OFDM Fundamentals

4.1.1 OFDM Definition

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 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.

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

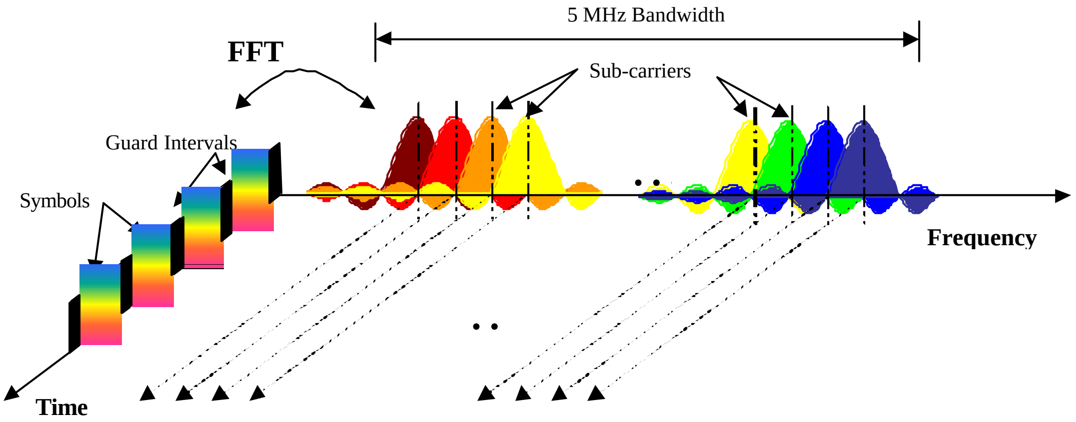


Figure 1: Frequency-Time Representation of an OFDM Signal

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 Conceptual 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 or QAM). The generation of the OFDM signal can be conceptually illustrated as in Figure 2,

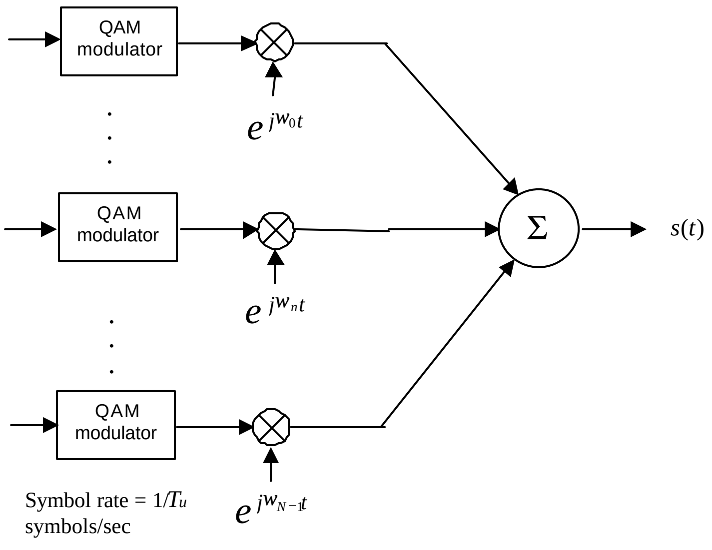


Figure 2: Conceptual Representation of OFDM Symbol Generation

where w_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:

$$\frac{|w_n - w_{n-1}|}{2p} = \Delta f, \qquad n \in [1, N-1].$$

4.1.3 Practical OFDM Signal Generation Using IFFT Processing

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 $mT_u < t \leq (m+1)T_u$.

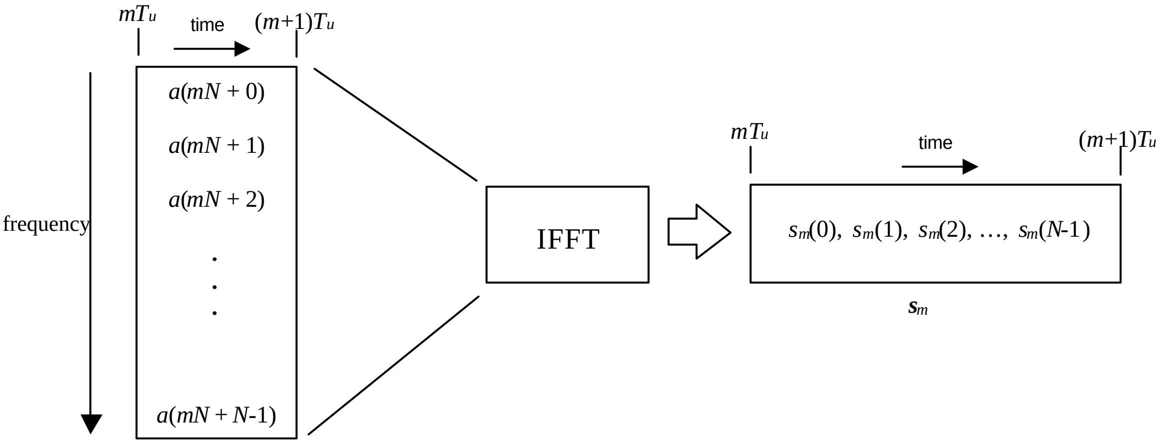


Figure 3: OFDM Useful Symbol Generation Using an IFFT

The vector $\boldsymbol{s}_m$ is defined as the useful OFDM symbol. Note that the vector $\boldsymbol{s}_m$ 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 (see Figure 1). 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.

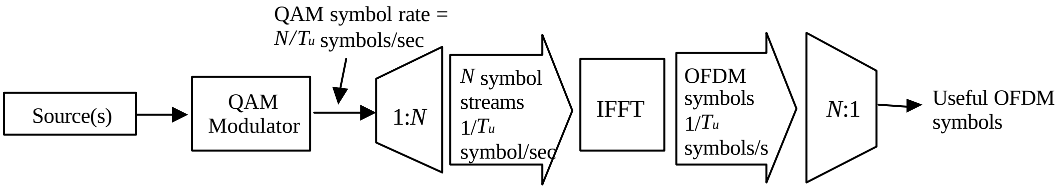


Figure 4: OFDM Signal Generation Chain

4.1.4 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) must hence 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.

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.

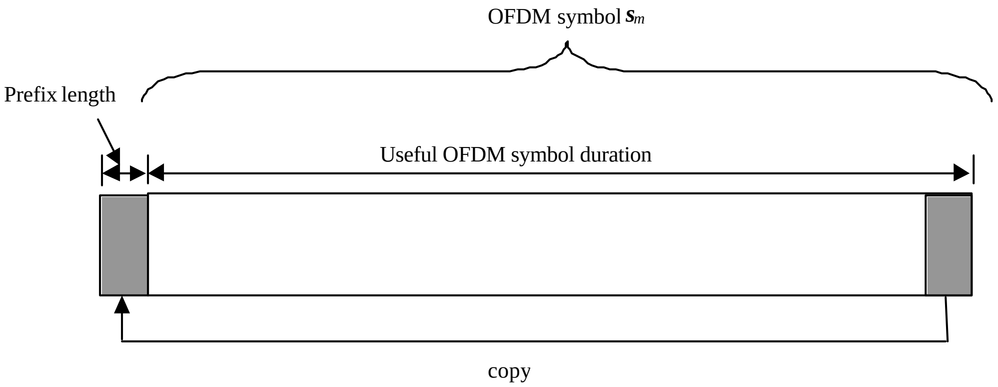


Figure 5: Cyclic Prefix Insertion

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

The OFDM sampling frequency F_o can therefore be expressed as

$$F_o = \frac{N + N_p}{T_s}.$$

Hence, the sub-carrier separation becomes:

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

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 requirement specified in TS 25.141.

4.1.5 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.

$$T_g > t\ ,$$

where t 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 section.

4.1.6 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:

$$T_s >> t \ .$$

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, specially, if the symbol period is large compared to the channel coherence time, then the channel can no longer be considered as constant through the OFDM symbol, therefore will introduce the inter-sub-carrier orthogonality loss This can affect the performance in fast fading conditions. 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 must, in general, be chosen such that:

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

4.1.7 Impact of Inter-Carrier Spacing

Because of the time-frequency duality, some of the time-domain arguments of Section 4.1.6 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 t, the sub-carrier separation is generally designed such that:

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

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. This enables a straightforward introduction of advanced MIMO schemes.

Moreover, in order to combat Doppler effects, the inter-carrier spacing should be much larger than the maximum Doppler shift f_d:

$$\Delta f >> f_d \ .$$

4.1.8 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.

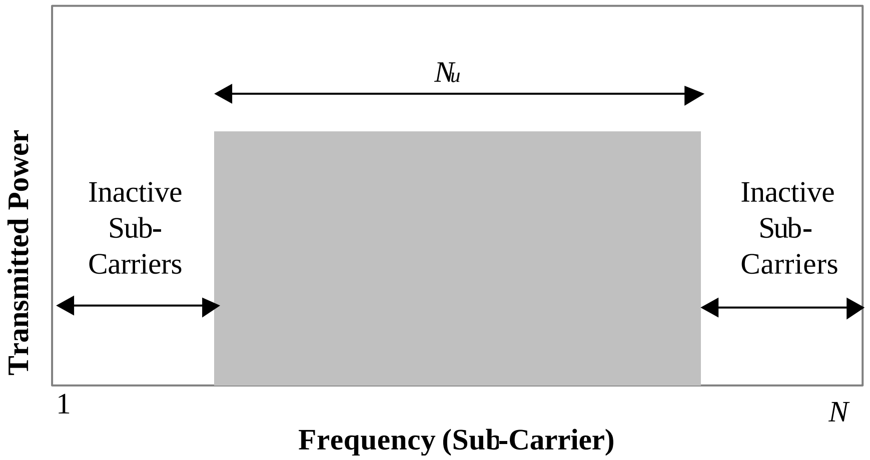
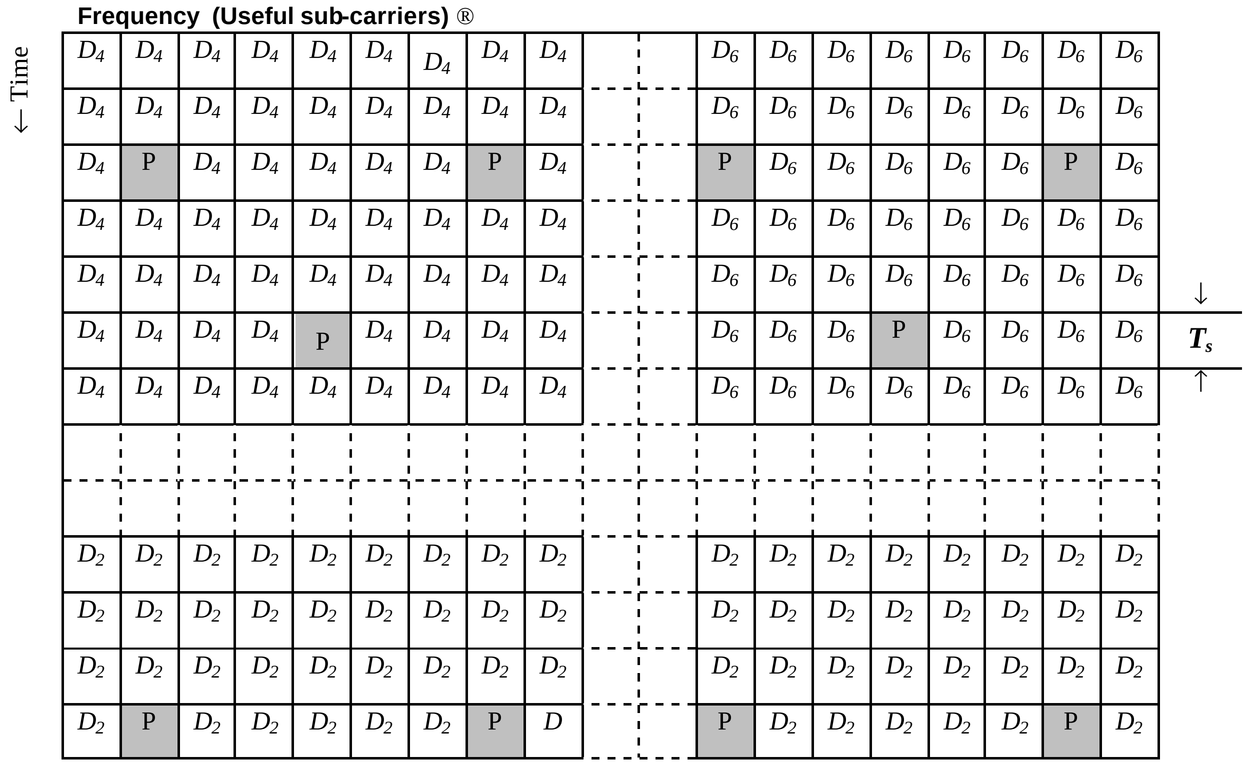


Figure 6: OFDM Spectrum with Incative Sub-carriers

The N_u mdulated sub-carriers (i.e. carrying information), are centered in the N FFT bins, with the remaining inactive sub-carriers, on either side of the modulated sub-carriers.

4.1.9 Time-Frequency Multiplexing

Multiple users can be multiplexed, both in time and in frequency, with pilot and signalling information. In the frequency dimension (i.e. the sub-carrier dimension), users data symbol can be multiplexed on different numbers of useful sub-carriers. In addition, sub-carriers or group of sub-carriers can be reserved to transmit pilot, signaling or other kind of symbols. Multiplexing can also be performed in the time dimension, as long as it occurs at the OFDM symbol rate or at a multiple of the symbol rate (i.e. from one IFFT computation to the other, every k*T_s seconds). The modulation scheme (modulation level) used for each sub-carrier can also be changed at the corresponding rate, keeping the computational simplicity of the FFT-based implementation. This allows 2-dimensional time-frequency multiplexing, of the form shown in Figure 7.



D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4		D_6	D_6	D_6	D_6	D_6	D_6	D_6	D_6
D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4		D_6	D_6	D_6	D_6	D_6	D_6	D_6	D_6
D_4	P	D_4	D_4	D_4	D_4	D_4	P	D_4		P	D_6	D_6	D_6	D_6	D_6	P	D_6
D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4		D_6	D_6	D_6	D_6	D_6	D_6	D_6	D_6
D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4		D_6	D_6	D_6	D_6	D_6	D_6	D_6	D_6
D_4	D_4	D_4	D_4	P	D_4	D_4	D_4	D_4		D_6	D_6	D_6	P	D_6	D_6	D_6	D_6
D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4	D_4		D_6	D_6	D_6	D_6	D_6	D_6	D_6	D_6
D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2		D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2
D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2		D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2
D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2		D_2	D_2	D_2	D_2	D_2	D_2	D_2	D_2
D_2	P	D_2	D_2	D_2	D_2	D_2	P	D		P	D_2	D_2	D_2	D_2	D_2	P	D_2

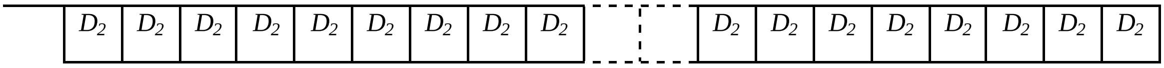


Figure 7: Example of OFDM 2-D structure; P = pilot or signaling, D = data. The subscript indicates the modulation level M=2,4 or 6 (QPSK, 16QAM or 64QAM).

4.1.10 OFDM Signal Reception Using the FFT

At the receiver, a computationally efficient Fast Fourier Transform (FFT) is used to demodulate the multi-carrier information and to recover the transmitted data.

4.2 OFDM/IOTA Fundamentals

OFDM/IOTA is an OFDM/OQAM modulation using a particular function, called IOTA, modulating each sub-carrier. First, the general principle of OFDM/OQAM is introduced, and then IOTA filter is presented

4.2.1 OFDM/OQAM Principles

OFDM/OffsetQAM modulation is an alternative to classical OFDM modulation. Contrary to it, OFDM/OQAM modulation does not require a guard interval (also called cyclic prefix).

For this purpose, the prototype function modulating each sub-carrier must be very well localized in the time domain, to limit the inter-symbol interference[1]. Moreover, it can be chosen very well localized in the frequency domain, to limit the inter-carrier interferences (Doppler effects, phase noise…). This function must also guarantee orthogonality among sub-carriers and among multi-carrier symbols. Functions having these characteristics exist, which guarantee the orthogonality only in *real* domain. Consequently, the complex QAM data stream (c_{mn}) must be separated into its two real components: real part (a_{mn}) and imaginary part ($b_{mn.}$) (see Figure 8), the imaginary part being modulated with a half-symbol-duration (**$T_u/2$**) shifted version of the modulation filter (thus the connotation Offset). The classical OFDM signal (without cyclic prefix) can be written as:

$$s(t)=\sum_{n=-\infty}^{n=+\infty}\sum_{m=0}^{m=N_u-1} c_{mn}e^{(2i\pi m\ \Delta f\ t)}g(t-nT_u),$$

where g(t) is a rectangular filter.

By separating the two parts of (c_{mn}), the corresponding OFDM/OQAM modulated signal can be written as:

$$s(t)=\sum_{n=-\infty}^{n=+\infty}\sum_{m=0}^{m=N_u-1} a_{mn}i^m e^{(2i\pi m\Delta f t)}g\left(t-nT_u\right)+ib_{mn}i^m e^{(2i\pi m\Delta f t)}g\left(t+{T_u}/{2}-nT_u\right)$$

where g(t) is the prototype function (noted $\Im(t)$ in the case of IOTA). In a more concise writing, this gives:

$$s(t)=\sum_{n}\sum_{m=0}^{N_u-1} d_{m,n}i^{m+n}e^{2i\pi m\Delta f t}\Im(t-nt_0), \qquad d_{m,n}=a_{m,n}\ or\ b_{m,n}$$

Note that data is multiplied by i^{m+n} prior to modulation in order to have orthogonality in real domain.

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[1] For comparison, in classical OFDM with guard interval, the prototype function modulating the sub-carriers is the rectangular function.

Notation: in OFDM/OQAM, the symbol period is usually noted t_0 and $t_0 = T_u/2$

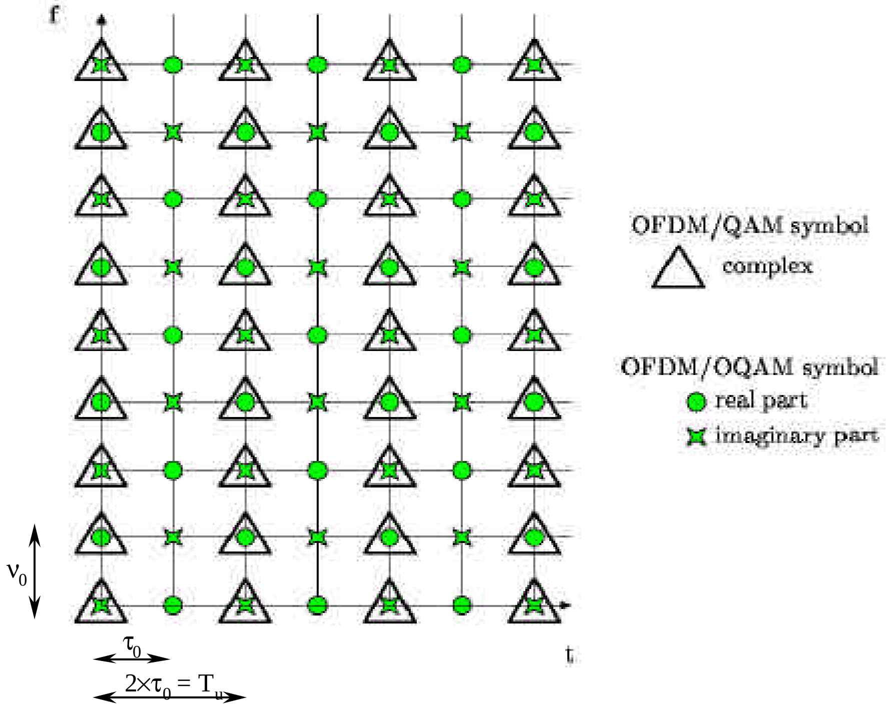

Figure 8: OFDM/OQAM time and frequency lattices (compared to OFDM w/o guard interval)

Figure 9 represents the OFDM/OQAM transmitter.

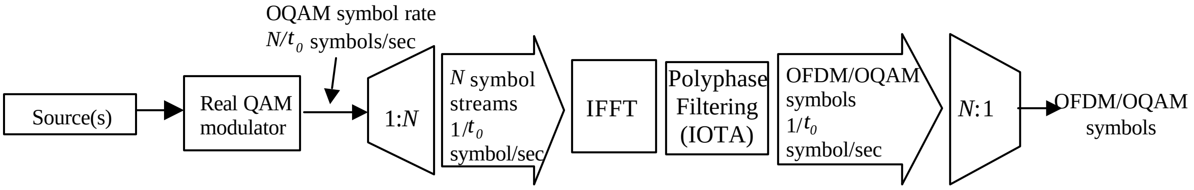

Figure 9: OFDM/OQAM Signal Generation Chain

The “real OQAM modulator” is simply a Pulse Amplitude Modulator. Thanks to the Inverse Fourier Transform, the time filtering is implemented in its polyphase form, in order to reduce the complexity of the filtering.

4.2.2 IOTA filter

IOTA filter guarantees a quasi-optimal localisation in time/frequency domain; it is obtained by applying the Isotropic Orthogonal Transform Algorithm to the Gaussian function aiming at orthogonalizing this function.

Thus, the IOTA function has the following properties:

- it is identical to its Fourier Transform, so, the OFDM/IOTA signal is affected similarly by the time and frequency spreading due to propagation conditions (if parameters are adapted to the channel),

- the time-frequency localization is quasi optimal as the IOTA function does not differ a lot from the Gaussian function (optimally localized).

Figure 10 and Figure 11 show various representations of the IOTA function. On Figure 11, the frequency response of the IOTA function is represented, as well as the rectangular function (used in classical OFDM).

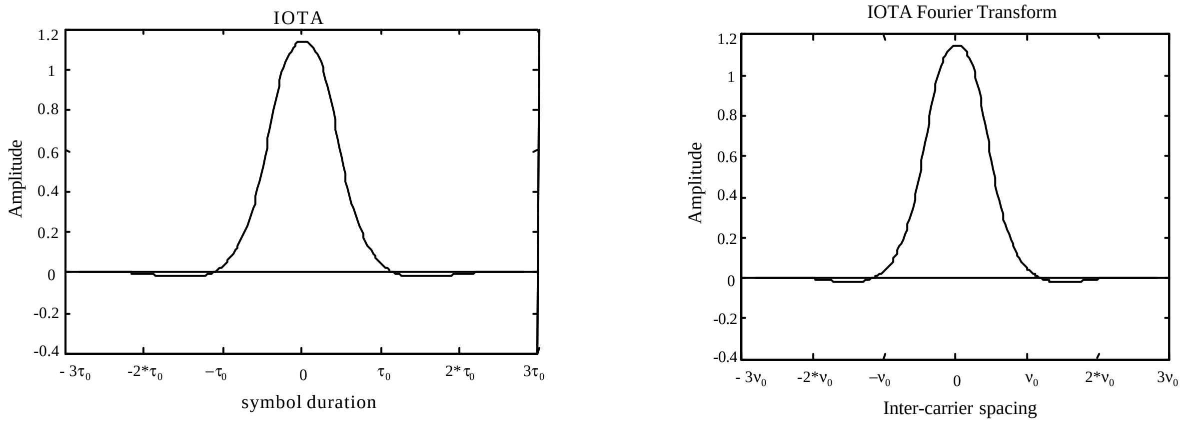

Figure 10: IOTA function and its Fourier transform

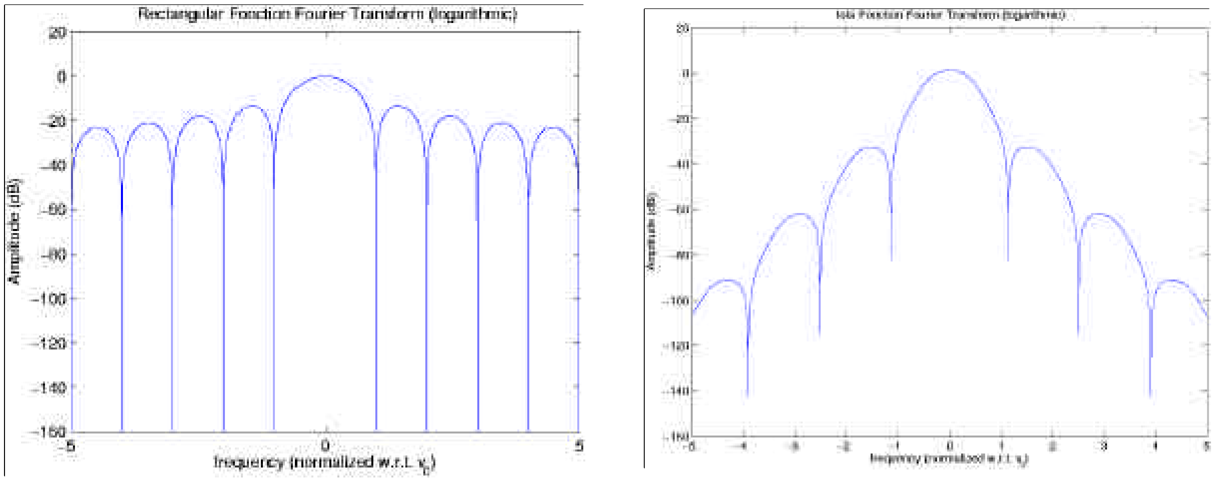

Figure 11: IOTA and Rectangular Function Fourier transforms

Orthogonality of IOTA function is expressed as:

$$\mathrm{Re}\left(\int_{\Re} \Im_{m,n}(t).\Im^{*}_{m',n'}(t)dt \right) = d_{m,m'} d_{n,n'}$$

with $\Im_{m,n}(t) = i^{m+n} e^{2ip\Delta ft} \Im(t - nt_0)$.

OFDM/OQAM using the IOTA filter is noted OFDM/IOTA.

4.2.3 OFDM/ IOTA parameters

As for classical OFDM, the OFDM/IOTA parameters have to be designed according to the channel constraints. Conditions from sections 4.1.6 and 4.1.7 are still relevant in the IOTA case:

We need to have $t_0 >> t$ and $t_0 << \frac{1}{f_d}$ in time domain, or $\Delta f << \frac{1}{t}$ and $\Delta f >> f_d$ in frequency domain.

According to the channel environment (Doppler frequency f_d, delay-spread t), the value of $\Delta f = {}^{1}\!/_{2t_0}$ is chosen in such a way that the FFT size is a power of two.

With the IOTA filter flexibility, as there is no guard interval, the design of the parameter set leads to an integer number of symbols per TTI (2 ms) with a frequency sampling of 7.68 MHz. The configuration can be done by soft means. For examples, a 512 points FFT leads to 60 symbols in a TTI and a 1024 points FFT leads to 30 symbols per TTI.

4.3 OFDM for Mobile Systems

OFDM has intrinsic features that are generally acknowledged to be well suited to the mobile radio environment. The following channel, signal or receiver characteristics are worth noting:

- **Time dispersion**

  The use of several parallel sub-carriers in OFDM enables longer symbol duration, which makes the signal inherently robust to time dispersion. Furthermore, a guard time may be added to combat further the ISI.

- **Spectral Efficiency**

  OFDM is constructed with fully orthogonal carriers, hence allowing tight frequency separation and high spectral efficiency. The resulting spectrum also has good roll-off properties, given that cross-symbol discontinuities can be handled through time windowing alone, filtering alone, or through a combination of the two techniques.

- **Reception**

  Even in relatively large time dispersion scenarios, the reception of an OFDM signal requires only an FFT implementation in the UE. No intra-cell interference cancellation scheme is required. Furthermore, because of prefix insertion, OFDM is relatively insensitive to timing acquisition errors. On the other hand, OFDM requires to perform frequency offset correction.

- **Extension to MIMO**

  Since the OFDM sub-carriers are constructed as parallel narrow band channels, the fading process experienced by each sub-carrier is close to frequency flat, and therefore, can be modelled as a constant complex gain. This may simplify the implementation of a MIMO scheme if this is applied on a sub-carrier or subset of carrier basis.

4.4 Reference system scenario

4.4.1 OFDM Downlink

In the Section, an initial reference system configuration is proposed to evaluate an OFDM downlink. The reference architecture is generic, and is compatible with the current 3GPP Rel 5 configuration. In the proposed configuration, new data services are provided through the use of a separate 5 MHz downlink carrier, supporting the OFDM HS-DSCH transmission. The reference architecture is shown in Figure 12.

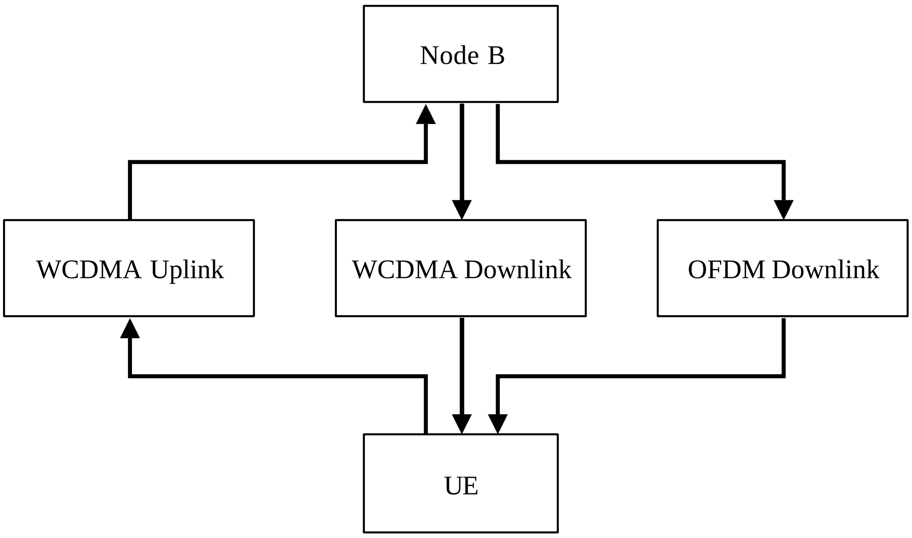

Figure 12: Network deployment for the OFDM HS-DSCH transmission

The separate OFDM DL carrier is operated using HSDPA features, such as link adaptation and HARQ. At this stage, it is assumed that network access is performed through the WCDMA architecture, and handover to the OFDM carrier occurs, when needed, for interactive background and streaming data services. In this case, a UE with OFDM HS-DSCH receiving capabilities would also have WCDMA receiving capabilities. In the first stage, the WCDMA link would be used to achieve the initial network access. However, when there is a requirement for high bit rate traffic, the HS-DSCH mode may be initiated, using either the WCDMA DL carrier (Rel 5 HSDPA) or the separate OFDM DL carrier.

Based on this initial reference scenario, a UE with OFDM HS-DSCH receiving capabilities is not required to receive the WCDMA and OFDM carriers simultaneously. This implies that, if there is a need for real time services, such as voice communications supported only on the WCDMA carrier, the UE would use the WCDMA mode. Note however that if OFDM proves to be useful in the HS-DSCH scenario, other services could also be mapped to the OFDM downlink in future work. In the proposed configuration, the current UMTS uplink carrier is reused and is considered to have sufficient capacity to support either a Rel 5 WCDMA DL carrier, or the separate OFDM DL carrier. There is no special assumption about the separate carrier frequency.

4.4.2 Equivalent WCDMA Scenario

[Editor’s note: This section should define a DL scenario equivalent to the one used for OFDM to provide a fair comparison basis.]

5 OFDM performance analysis

Editor’s note : Provides the high-level overview of the performance of OFDM when compared with W-CDMA radio systems.

5.1 Requirements

Editor’s note : Discusses the requirements and constraints for the introduction of a new modulation system. Should set some targets for bit rates and system capacity as well as define the Rel5 and REL6 configurations that are the basis for comparison.

5.2 Reference OFDM configuration for the evaluation

Two sets of reference OFDM configuration parameters are listed in Table 1.

Parameters	**Set 1**	**Set 2**
TTI duration (msec)	2	2
FFT size (points)	512	1024
OFDM sampling rate (Msamples/sec)	7.68	6.528
Ratio of OFDM sampling rate to UMTS chip rate	2	17/10
Guard time interval (cyclic prefix) (samples/µsec)	56 / 7.29 57 / 7.42[2]	64/9.803
Subcarrier separation (kHz)	15	6.375
# of OFDM symbols per TTI	27	12
OFDM symbol duration (µsec)	73.96/74.09[3]	166.67
# of useful subcarriers per OFDM symbol	299	705
OFDM bandwidth (MHz)	4.485	4.495

Table 1: Reference OFDM configuration parameter sets

The parameter set 1 consists of nine OFDM symbols that fit into a 0.667 us timeslot. The useful symbol duration is equal to 512 samples. The guard interval is equal to 56 samples for the 0th symbol, and 57 samples for symbols 1..8 of every timeslot, as illustrated in figure 13. The actual position of the 56-sample GI symbol is believed to be inconsequential as long as it is known by both the transmitter and receiver. Therefore, it may be revisited in future, should a different location be deemed more favourable.

It should be noted that spectral shaping of the OFDM signal is required for out-of-band emission compliance. The implications of spectral shaping on delay spread robustness are discussed in a separate section of this report.

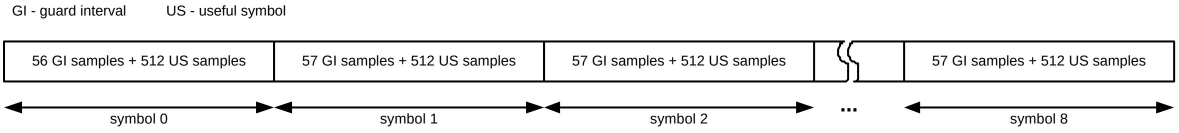

Figure 13: Temporal structure of the OFDM signal (one timeslot), parameter set 1.

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[2] Requires one extra prefix sample for 8 out of 9 OFDM symbols.

[3] Depending on guard interval duration

5.3 Data rates

Editor's note : Discusses and shows the performance of OFDM when compared with W-CDMA for the user data rate. This includes comparison with both Rel5 and Rel6 UTRAN systems.

5.4 System Capacity

Editor's note : Discusses and shows the performance advantage of OFDM when compared with W-CDMA for the system traffic capacity. This includes comparison with both Rel5 and Rel6 UTRAN systems.

6 OFDM feasibility

Editor's note : This chapter discusses a number of specific technical and operational issues related to the application of OFDM within the framework of 3GPP systems. These are not in any particular order of presentation.

6.1 Spectrum compatibility

Editor's note : Discussion of compatibility of OFDM modulation when operating within the channels for UTRAN spectrum allocations. This includes in-band and adjacent channel emissions and sensitivity to interference both from other UTRAN radios and nearby radio systems (nearby in terms of spectrum).

6.2 Multiplexing user traffic

Editor's note : Discussion of the multiplexing of user traffic on the OFDM transmissions. This includes time-division multiplexing and sub-carrier grouping. This may also include the mapping of the UTRAN logical traffic and user data channels onto the OFDM signal.

6.3 Impacts on UL

Editor's note : this section will study whether any change in the UL dedicated channels is needed in order to support OFDM in the DL.

6.4 Handover

Editor's note : Discussion of the handover of services between the OFDM and the WCDMA radio access technology. This will also include discussion of soft-handover between cells.

6.5 Synchronisation

Editor's note : Discussion of any necessary synchronisation at the physical or protocol layers of OFDM transmissions between cells.

6.6 Frequency re-use

Editor's note : Discussion of the re-use of the spectrum assignments for OFDM systems. This includes discussion of the "re-use of one" scenario.

6.7 Consideration for Advanced Antenna Systems

Editor’s note : Discussion of the use of the OFDM in relation to advanced antenna systems. This includes, for example, discussion of “multiple input multiple output” (MIMO) scenarios

6.8 Analysis of User Equipment Complexity

Editor’s note : Discussion of the consequences for the User Equipment (UE) as a result of the introduction of the OFDM technique. This includes discussion of the additional requirements for OFDM capable UE that must operate in an environment in which both OFDM and W-CDMA are in operation and also in environments in which only W-CDMA technology is available. The section should in particular address RF considerations and complexity issues.

6.9 Analysis of Node B impacts

Editor’s note : Discussion of the consequences for the OFDM capable Node B as a result of the introduction of the OFDM technique. The section should in particular address RF considerations and complexity issues.

6.10 Backward compatibility

6.11 Application to 3GPP system and services

Editor’s note : Discussion of the applicability of OFDM to the various existing and new 3GPP system capabilities including speech, real time, multi-media, packet, broadcast and multi-cast services.

7 Conclusion

Editor’s note : Concludes on the feasibility of OFDM for application to 3GPP radio access systems and, if appropriate, provides a possible work plan for further standardisation development.

Annex A:
Simulation Assumptions and Results

A.1 Link Simulation Assumptions

Some specific link-level assumptions are listed in this section. In terms of physical layer operations that are not covered specifically here, the specifications described in **[2]** and **[3]** are followed. Information on channel power levels is also included in **Table 5**.

A.1.1 Link Level Simulation Assumptions for OFDM

Table 2 provides a list of the link-level simulation assumptions that are relevant to the OFDM evaluation case. Here, it has been necessary to define an OFDM structure that is compatible with the HSDPA physical layer design.

Parameter	**Explanation/Assumption**	**Comments**
Carrier frequency	2 GHz	
Residual Frequency Offset Correction Error	TBD	
Fast fading model	Jakes model	
HSDPA slot length (TTI)	2 msec	
Channel estimation	Ideal Real	Ideal channel information is assumed to be available at the receiver. Perfect timing and frequency estimation is also assumed. Real channel estimation from pilot subcarriers.
MIMO configuration *NT:NR*	1:1	
Channel width	5 MHz	
Number of subcarriers	See Table 1	
OFDM sampling frequency	See Table 1	
FFT size	See Table 1	
Subcarrier MCS levels	All data subcarriers carry equal-weight data with the same modulation and code rate.	Assume one user per TTI
Bit interleaving	Uses 2nd interleaving defined in **[4]**.	

Rate matching	Performed to make the number of coding blocks compatible with the radio frame size.	Refer to Section 5.5.2 of **[3]**

Table 2: Down link OFDM link-level simulation assumptions

A.1.2 Link Level Simulation Assumptions for WCDMA

Table 3 provides a list of the link-level simulation assumptions that are relevant to the WCDMA evaluation case. These are consistent with the HSDPA design presented in **[3]**. Other aspects of the WCDMA HSDPA link level simulator are directly taken from **[3]** and **[4]**.

Parameter	**Explanation/Assumption**	**Comments**
Carrier frequency	2 GHz	
Fast fading model	Jakes model	
HSDPA slot length (TTI)	2 msec	
Channel estimation	Ideal Real	Ideal channel information is assumed to be available at the receiver. Perfect timing and frequency estimation is also assumed. Real channel estimation from pilot subcarriers
MIMO configuration *NT:NR*	1:1 used	
Chip-rate	3.84 Mcps	
Spreading factor	16	
Channel width	5 MHz	

Table 3: Down link WCDMA link-level simulation assumptions

A.1.3 Link Level Simulation Scenarios

Table 4 provides a list of the specific simulation cases that will need to be evaluated. For each of the channel models, a fading rate (corresponding to the UE velocity in km/h) is also given. The channel models are described in more detail earlier in **Table 10**.

Parameter	**Cases**	**Comments**
Channel model and fade rate	Ch-100, 30 km/h	Single path
	Ch-100, 120 km/h	Single path

	Ch-104, 30 km/h Ch-104, 120 km/h Ch-102, 3 km/h Ch-103 3 km/h	ITU Vehicular A ITU Vehicular A ITU Pedestrian A ITU Pedestrian B
Modulation	QPSK, 16QAM, 64QAM	
Code rate	1/3, 1/2, 2/3	Additional code rates can be generated with puncturing
Coding block size	TBD. Should be identical in WCDMA and OFDM [4]	Additional coding block can be simulated. 5114 bits is the maximum code block size for turbo coding **[3]**

Table 4: Down link link-level simulation scenarios

A.2 Link Simulation Results

A.3 System Simulation Assumptions

A.3.1 Antenna Pattern

The antenna pattern used for each sector, is specified as :

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3\,dB}}\right)^2, A_m\right], \quad \text{where} \quad -180 \le \theta \le 180\ ,$$

where min[ ] is the minimum function, θ_{3dB} is the 3dB beamwidth (corresponding to θ_{3dB} = 70 degrees) , and A_m= 20 dB is the maximum attenuation.

A.3.2 Antenna Orientation

The antenna bearing is defined as the angle between the main antenna lobe center and a line directed due east given in degrees. The bearing angle increases in a clockwise direction. Figure 14 shows an example of the 3-sector 120-degree center cell site, with Sector 1 bearing angle of 330 degrees. Figure 15 shows the orientation of the center cell (target cell) hexagon and its three sectors corresponding to the antenna bearing orientation proposed for the simulations. The main antenna lobe center directions each point to the sides of the hexagon. The main antenna lobe center directions of the 18 surrounding cells shall be parallel to those of the center cell. Figure 15 also shows the orientation of the cells and sectors in the two tiers of cells surrounding the central cell.

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[4] A coding block size of 5114 bits is appropriate for traffic models such as FTP and HTTP, where each IP packet contains 12000 bits. However, it should be noted that the block size may depend on the traffic type being considered. Some traffic types will have much smaller IP packets and would therefore benefit from smaller coding blocks

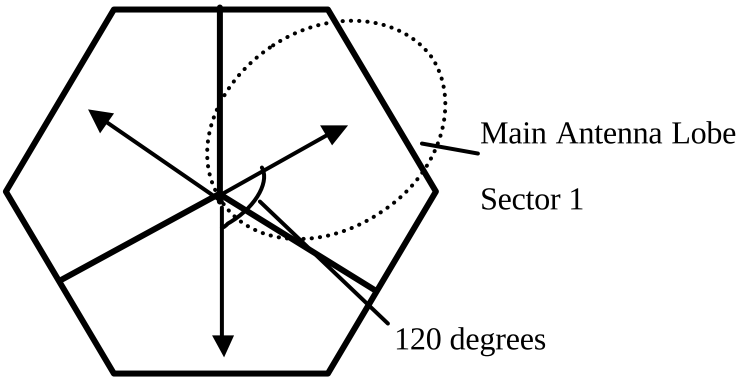

Figure 14: Centre cell antenna bearing orientation diagram

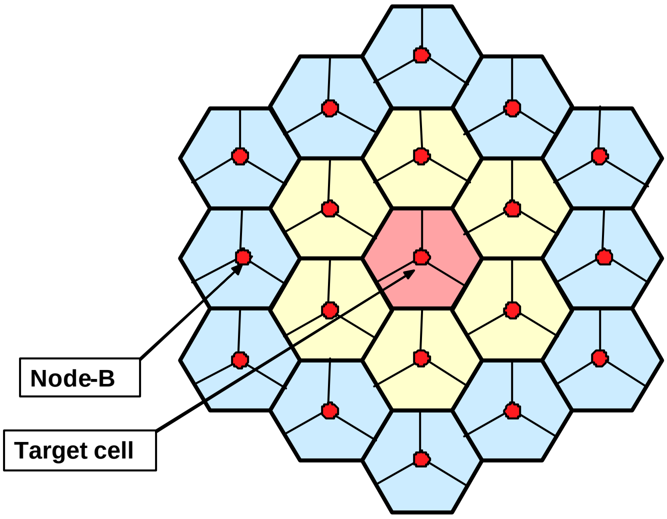

Figure 15: Configuration of adjacent tiers of neighbouring cells, sectors, and Node-Bs

A.3.3 Common System Level Simulation Assumptions

The assumptions used in the system-level simulations are listed in Table 5 and are primarily taken from **[1]**.

Parameter	**Explanation/Assumption**	**Comments**
Cellular layout	Hexagonal grid, 3-sector sites	See Figure 15
Antenna horizontal pattern	70 deg (-3 dB) with 20 dB front-to-back ratio	
Site to site distance	2800 m	Or 1000 m
Propagation model	$L = 128.1 + 37.6\, Log_{10}(R)$	R in kilometers

CPICH power	-10 dB	
Other common channels	-10 dB	
Power allocated to HSDPA transmission, including associated signalling	Max. 80 % of total cell power	
Slow fading	As modelled in UMTS 30.03, B 1.4.1.4	
Standard deviation of slow fading	8 dB	
Correlation between sectors	1.0	
Correlation between sites	0.5	
Correlation distance of slow fading	50 m	
Carrier frequency	2000 MHz	
BS antenna gain	14 dB	
UE antenna gain	0 dBi	
UE noise figure	9 dB	
Thermal noise density	-174 dBm/Hz	
Max. # of retransmissions	3	Retransmissions by fast HARQ. Does not include the initial transmission. Programmable
Fast HARQ scheme	Chase combining or incremental redundancy	
Scheduling algorithm	TBD	
BS total Tx power	Up to 44 dBm	
Specific fast fading model	Jakes spectrum	
HSDPA slot length	2 msec	
MCS feedback delay	2 TTIs	
UE spatial distribution	Uniform random spatial distribution over elementary single cell hexagonal central Node-B	
MIMO configuration *NT:NR*	1:1	
Channel width	5 MHz	
Frequency Re-use	1	

Table 5 Down-link system-level simulation assumptions

A.3.4 Traffic Sources

Three different traffic types are suggested for evaluation purposes.

A.3.4.1 HTTP Traffic Model Characteristics

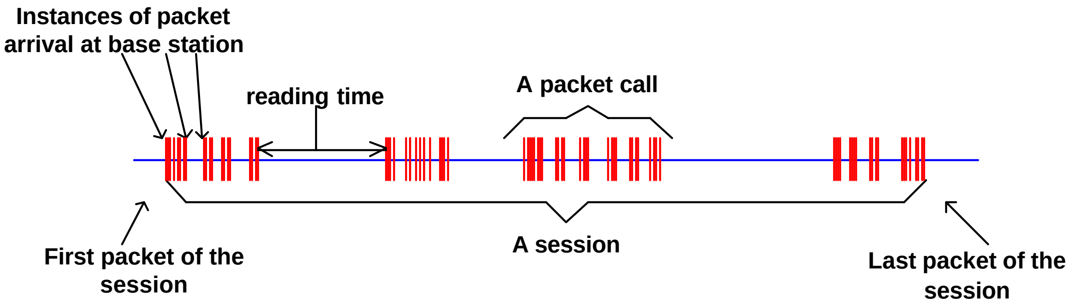

Figure 16: Packet Trace of a Typical Web Browsing Session

Figure 16 shows the packet trace of a typical web browsing session. The session is divided into ON/OFF periods representing web-page downloads and the intermediate reading times, where the web-page downloads are referred to as packet calls. These ON and OFF periods are a result of human interaction where the packet call represents a user's request for information and the reading time identifies the time required to digest the web-page.

As is well known, web-browsing traffic is self-similar. In other words, the traffic exhibits similar statistics on different timescales. Therefore, a packet call, like a packet session, is divided into ON/OFF periods as in Figure 16. Unlike a packet session, the ON/OFF periods within a packet call are attributed to machine interaction rather than human interaction. A web-browser will begin serving a user's request by fetching the initial HTML page using an HTTP GET request. The retrieval of the initial page and each of the constituent *objects* is represented by ON period within the packet call while the parsing time and protocol overhead are represented by the OFF periods within a packet call. For simplicity, the term "page" will be used in this paper to refer to each packet call ON period.

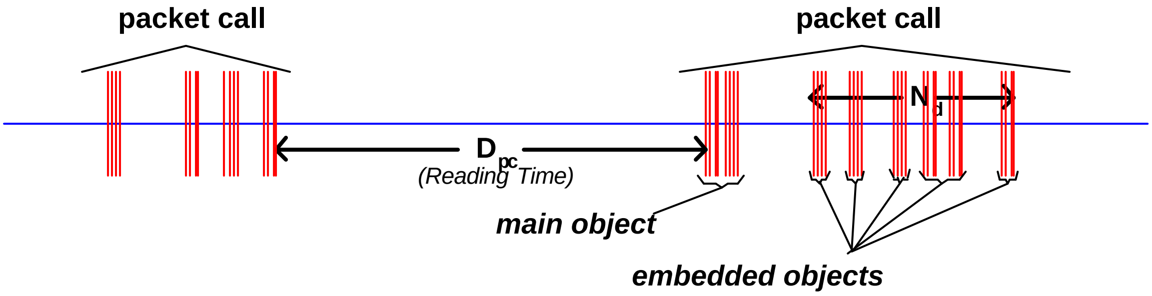

Figure 17: Contents in a Packet Call

The parameters for the web browsing traffic are as follows:

- S_M: Size of the main object in a page
- S_E: Size of an embedded object in a page
- N_d: Number of embedded objects in a page
- D_{pc}: Reading time
- T_p: Parsing time for the main page

HTTP/1.1 persistent mode transfer is used to download the objects, which are located at the same server and the objects are transferred serially over a single TCP connection. The distributions of the parameters for the web browsing traffic model are described in Table 6.

Component	**Distribution**	**Parameters**	**PDF**
Main object size (S_M)	Truncated Lognormal	Mean = 10710 bytes Std. dev. = 25032 bytes Minimum = 100 bytes Maximum = 2 Mbytes	$f_x = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left[\frac{-(\ln x-\mu)^2}{2\sigma^2}\right], x \ge 0$ $\sigma = 1.37, \mu = 8.35$
Embedded object size (S_E)	Truncated Lognormal	Mean = 7758 bytes Std. dev. = 126168 bytes Minimum = 50 bytes Maximum = 2 Mbytes	$f_x = \frac{1}{\sqrt{2\pi}\sigma x}\exp\left[\frac{-(\ln x-\mu)^2}{2\sigma^2}\right], x \ge 0$ $\sigma = 2.36, \mu = 6.17$
Number of embedded objects per page (N_d)	Truncated Pareto	Mean = 5.64 Max. = 53	$f_x = \frac{\alpha k^\alpha}{x^{\alpha+1}}, k \le x < m$ $f_x = \left(\frac{k}{m}\right)^\alpha, x = m$ $\alpha = 1.1, k = 2, m = 55$ Note: Subtract k from the generated random value to obtain N_d
Reading time (D_{pc})	Exponential	Mean = 30 sec	$f_x = \lambda e^{-\lambda x}, x \ge 0$ $\lambda = 0.033$
Parsing time (T_p)	Exponential	Mean = 0.13 sec	$f_x = \lambda e^{-\lambda x}, x \ge 0$ $\lambda = 7.69$

Table 6: HTTP Traffic Model Parameters

A.3.4.2 FTP Traffic Model Characteristics

In FTP applications, a session consists of a sequence of file transfers, separated by *reading times*. The two main parameters of an FTP session are:

1. S : the size of a file to be transferred
2. D_{pc}: reading time, i.e., the time interval between end of download of the previous file and the user request for the next file.

The underlying transport protocol for FTP is TCP. The model of TCP connection described in Section 0 will be used to model the FTP traffic. The packet trace of an FTP session is shown in Figure 18.

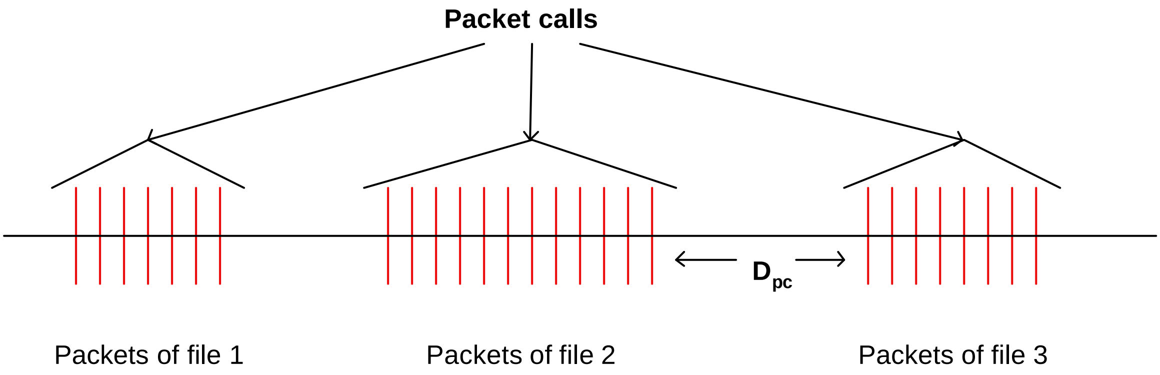

Figure 18: Packet Trace in a Typical FTP Session

The parameters for the FTP application sessions are described in Table 7.

Component	**Distribution**	**Parameters**	**PDF**
File size (S)	Truncated Lognormal	Mean = 2Mbytes Std. Dev. = 0.722 Mbytes Maximum = 5 Mbytes	$f_x = \frac{1}{\sqrt{2\pi\sigma x}} \exp\left[\frac{-(\ln x - \mu)^2}{2\sigma^2}\right], x \ge 0$ $\sigma = 0.35, \mu = 14.45$
Reading time (D_{pc})	Exponential	Mean = 180 sec.	$f_x = \lambda e^{-\lambda x}, x \ge 0$ $\lambda = 0.006$

Table 7: FTP Traffic Model Parameters

Based on the results on packet size distribution, 76% of the files are transferred using and MTU of 1500 bytes and 24% of the files are transferred using an MTU of 576 bytes. For each file transfer a new TCP connection is used whose initial congestion window size is 1 segment (i.e. MTU).

A.3.4.3 NRTV (Near Real Time Video) Traffic Model Characteristics

This section describes a model for streaming video traffic on the forward link. Figure 19 describes the steady state of video streaming traffic from the network, as seen by the base station. Latency at call startup is not considered in this steady-state model.

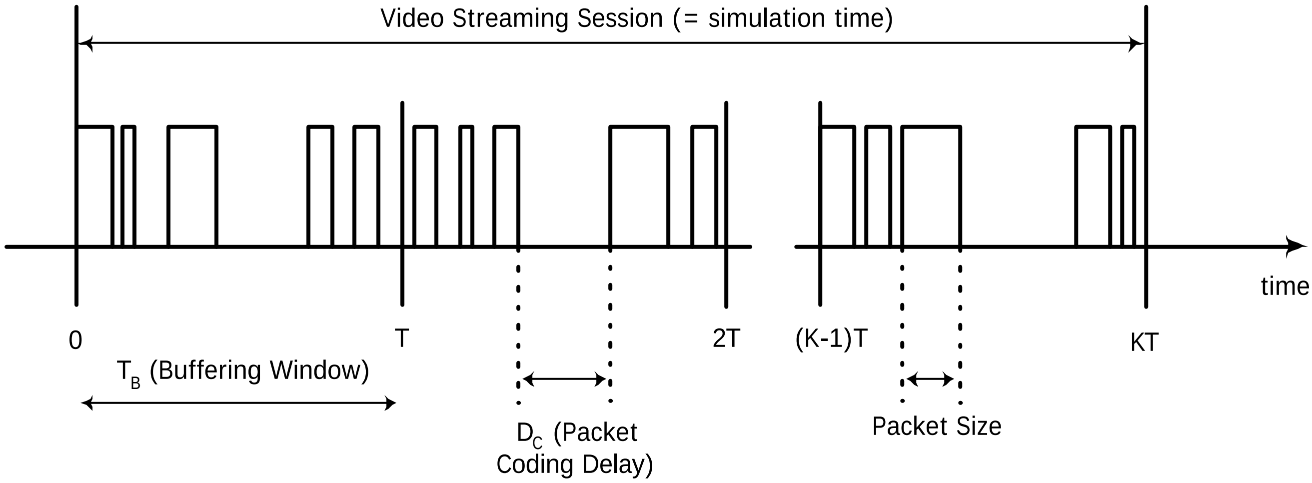

Figure 19: Video Streaming Traffic Model

A video streaming session is defined as the entire video streaming call time, which is equal to the simulation time for this model. Each frame of video data arrives at a regular interval T determined by the number of frames per second (fps). Each frame is decomposed into a fixed number of slices, each transmitted as a single packet. The size of these packets/slices is distributed as a truncated Pareto distribution. Encoding delay, Dc, at the video encoder introduces delay intervals between the packets of a frame. These intervals are modelled by a truncated Pareto distribution.

The parameter T_B is the length (in seconds) of de-jitter buffer window in the mobile station, and is used to guarantee a continuous display of video streaming data. This parameter is not relevant for generating the traffic distribution, but it is useful for identifying periods when the real-time constraint of this service is not met. At the beginning of the simulation, it is assumed that the mobile station de-jitter buffer is full with (T_B x source video data rate) bits of data. Over the simulation time, data is "leaked" out of this buffer at the source video data rate and "filled" as forward link traffic reaches the mobile station. As a performance criterion, the mobile station can record the length of time, if any, during which the de-jitter buffer runs dry. The de-jitter buffer window for the video streaming service is 5 seconds.

Using a source video rate of 64 kbps, the video traffic model parameters are defined in Table 8.

Information types	Inter-arrival time between the beginning of each frame	Number of packets (slices) in a frame	Packet (slice) size	Inter-arrival time between packets (slices) in a frame
Distribution	Deterministic (Based on 10fps)	Deterministic	Truncated Pareto (Mean= 50bytes, Max= 250bytes)	Truncated Pareto (Mean= 6ms, Max= 12.5ms)
Distribution Parameters	100ms	8	K = 40 bytes $\alpha = 1.2$	K = 2.5ms $\alpha = 1.2$

Table 8: Video Streaming Traffic Model Parameters.

Only system-level simulations with homogenous traffic mixes are to be conducted. That is, for a particular simulation, all users will either have all FTP traffic, all HTTP traffic, or all NRTV traffic. There is no mixing of different traffic types within a single simulation.

A.3.5 Performance Metrics

This section describes the performance statistics that are generated as an output from the system-level simulations. In each case, a performance curve given as a function of the number of users per sector is generated.

A.3.5.1 Output Metrics for Data Services

The following statistics related to data traffics should be generated and included in the evaluation report for each scheme. A frame as used below is also referred to as a transport block and consists of information bits, CRC, and tail bits.

1. **Average cell throughput [kbps/cell]** is used to study the network throughput performance, and is measured as

$$R = \frac{b}{k \cdot T}$$

   where b is the total number of correctly received data bits in all data UEs in the simulated system over the whole simulated time, k is the number of cells in the simulation and T is the simulated time. In the case of only evaluating the center cell site, k is the number of sectors.

2. **Average packet call throughput [kbps]** for user i is defined as

$$R_{pktcall}(i) = \frac{1}{K}\sum_{k=1}^{K}\frac{\text{good bits in packet call k}}{(t_{end\_k} - t_{arrival\_k})}$$

   where $k =$ denotes the k^{th} packet call from a group of K packet calls where the K packet calls can be for a given user i , $t_{arrival\_k}$ = first packet of packet call k arrives in queue, and t_{end_k} = last packet of packet k is received by the UE. Note for uncompleted packet calls, t_{end_k} is set to simulation end time. The mean, standard deviation, and distribution of this statistic are to be provided.

3. **The packet service session FER** is calculated for all the packet service sessions. A packet service session FER is defined as the ratio

$$FER_{session} = \frac{n_{erroneous\_frames}}{n_{frames}},$$

   where $n_{erroneous\_frames}$ is the total number of erroneous frames in the packet service session and n_{frames} is the total number of frames in the packet service session. These individual packet service session FERs from all packet service sessions form the distribution for this statistic. The mean, standard deviation, and the distribution of this statistic are to be provided.

   A Definition of a Packet Service Session: A Packet Service Session contains one or several packet calls depending on the application. Packet service session starts when the transmission of the first packet of the first packet call of a given service begins and ends when the last packet of the last packet call of that service has been transmitted. (One packet call contains one or several packets.) Note, that FER statistics are only collected from those frames during which UE is receiving data.

4. **The residual FER** is calculated for each user for each packet service session. A packet service session residual FER is defined by the ratio

$$FER_{residual} = \frac{n_{dropped\_frames}}{n_{frames}},$$

where $n_{dropped\_frames}$ is the total number of dropped frames in the packet service session and n_{frames} is the total number of frames in the packet service session. A dropped frame is one in which the maximum ARQ or HARQ re-transmissions have been exhausted without the frame being successfully decoded. It does not include the RLC initiated re-transmissions. The mean, standard deviation, and distribution of this statistic over all the packet service sessions in the simulation are to be provided.

5. **The averaged packet delay per sector** is defined as the ratio of the accumulated delay for all packets for all UEs received by the sector and the total number of packets. The delay for an individual packet is defined as the time between when the packet enters the queue at transmitter and the time when the packet is received successively by the UE. If a packet is not successfully delivered by the end of a run, its ending time is the end of the run.
6. **System Outage**

   A user is in outage if more than a given percentage of packets (blocks) experience a delay of greater than a certain time. The system is considered to be in outage if any individual users are in outage.

A.3.6 Channel Models and Interference

A.3.6.1 Channel Models

In this context, a channel model corresponds to a specific number of paths, a power profile giving the relative powers of these multiple paths (ITU multi-path models), and Doppler frequencies to specify the fade rate.

The channel models (from 1 to 6) are randomly assigned to the various users according to the probability distribution listed in Table 9. The channel model assigned to a specific user remains fixed over the duration of a simulation drop.

Channel Model	Multi-path Model	# of Paths	Speed (km/h)	Fading	Assignment Probability
Model 1	Ch-100	1	30	Jakes	0.1
Model 2	Ch-100	1	120	Jakes	0.1
Model 3	Ch-104	6	30	Jakes	0.1
Model 4	Ch-104	6	120	Jakes	0.1
Model 5	Ch-102	4	3	Jakes	0.3
Model 6	Ch-103	6	3	Jakes	0.3

Table 9: Channel Models and associated assignment probability distribution

The channel models, UE speeds (for fading rates), and assignment probabilities listed in Table 9 are adapted from [1]. Note that a separate link-level simulation must be performed for each specific channel model and UE velocity combination. Hence, there is a desire to minimize the number of different possible channel model combinations, while ensuring that an accurate modelling of reality is also made. The assignment probabilities in Table 9 were selected to agree with the corresponding probabilities in [1], while reducing the number of different distinct fading velocities in order to reduce the number of link level simulations that must be performed.

The normalized power profiles for the different channel models such as flat fading: Ch-100, ITU vehicular-A: Ch-104, ITU pedestrian-A: Ch-102, and ITU pedestrian-B: Ch-103 are given in Table 10. For the channel models that correspond to the standard ITU channel models, the relative ratios of the path powers are the same, but the absolute power values have been normalized so that they sum to 0 dB (unit energy) for each given channel model.

Channel Model	Path 1 (dB)	Path 2 (dB)	Path 3 (dB)	Path 4 (dB)	Path 5 (dB)	Path 6 (dB)	Rake Fingers
Flat Fading Ch-100	0	–	–	–	–	–	1
ITU Vec. A Ch-104	-3.14	-4.14	-12.14	-13.14	-18.14	-23.14	1,2,3,4,5,6
ITU Ped. A Ch-102	-0.51	-10.21	-19.71	-23.31	–	–	1,2,3,4
ITU Ped. B Ch-103	-3.92	-4.82	-8.82	-11.92	-11.72	-27.82	1,2,3,4,5,6

Table 10: Normalized power profiles for multi-path channel models

The Rake finger column in the above table indicates the paths to which WCDMA Rake fingers will be assigned. It is assumed that Rake fingers will be assigned to each multipath component within a given channel model [1].

A.4 System Simulation Results

Annex B: Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
05.07.02	RAN1#27	R1-020931			Initial draft presented for discussion		V0.0.1
23.10.02	RAN1#29	R1-021257			Update of the outline after discussions in RAN1#28bis	V0.0.1	V0.0.2
07.02.03	RAN1#31	R1-030227			Inclusion of approved text from R1-030135	V0.02	V0.0.3
19.02.03	RAN1#31	R1-030312			Removed revision marks.	V0.0.3	V0.1.0
20.02.03	RAN1#31	R1-030378			Inclusion of approved text from R1-030149, R1-030166, R1-030169 and R1-030328	V0.1.0	V0.1.1
28.03.03	RAN1#31	R1-030383			Modification to the OFDM sampling frequency definition	V0.1.1	V0.1.2
31.03.03	RAN1#31	R1-030384			Removal of revision marks	V0.1.2	V0.2.0