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TITLE:

Evaluation Methods for High Speed Downlink Packet Access (HSDPA)

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ABSTRACT:

This document provides background information regarding the evaluation of proposals for systems to provide high-speed packet downlink packet access for 3GPP.

1 Introduction

1.1 Study Objective and Scope

The objective of this document is to propose a set of definitions, assumptions, and a general framework for simulating a high data rate wireless system. This proposal will concentrate on simulations and performance metrics for the downlink only, since it is assumed that the packet data applications (and the call models, which result) will produce a disproportionately high ratio of forward to reverse data rates.

1.2 Simulation Description Overview

Determining high rate packet data system performance requires a dynamic system simulation tool to accurately model feedback loops, signal latency, site selection, protocol execution, random packet arrival, and mobility in a multipath fading environment. The packet system simulation tool will include Rayleigh and Rician fading and evolve in time with discrete steps (e.g. time steps of 0.667ms). The time steps need to be small enough to correctly model feedback loops, latencies, scheduling activities, measurements of required system metrics (e.g. C/I similar to CPICH Ec/No), and fast cell site selection. A Ec/Ior vs. FER curve for a AWGN (static) channel will be created using a link level simulation for each data rate, modulation and coding scheme to determine successful over the air packet delivery. Sampling Eb/Nt points over each frame creates a frame metric. For a given frame the metric is used with the static curve to determine if the frame is erased. Lognormal shadowing, delay spread, and fractional recovered power (per ray) will also be modeled. Scheduling and MAC will be included in the simulation to the detail necessary to model resource allocation latencies.

The data traffic model is intended to capture the interaction between radio link algorithms/designs and end-user applications. As such, it is proposed that both best effort and real-time models be simulated to capture air-interface performance. Ideally, best effort services should be modeled by a closed-loop traffic model in the form of a full web browsing model operating over a TCP/IP stack. The close-loop traffic model provides a variable IP packet stream that reacts to the quality of the radio link and the policies of the radio network's packet scheduler. Furthermore, the close-loop traffic model should properly model the bursty nature of data traffic and limit the simulation scheduler to a causal implementation that operates on available information such as the current queue depths and bounds buffering delays to practical levels. The ideal real-time model combines specific frame-erasure rates and delay guarantees to test the capability of the air interface. These real-time models will likely consume greater resources than best effort service. The ability of the air-interface to meet these guarantees may be measured by both the probability of blocking and the residual capacity remaining for best effort services.

2 Link Level Data

2.1 *Link Level Parameters and Assumptions*

2.1.1 Frame Erasures

The system simulation will be dynamic in that fast (Rayleigh and Rician) and slow (lognormal) fading conditions are included and time is evolved in discrete steps (e.g. 0.667 ms). An Ec/Ior vs FER curve for an AWGN (static) channel will be created using link level simulation for each data rate, modulation and coding scheme. Sampling Eb/Nt points every 0.667ms over a frame creates a frame metric were it is assumed that fading is constant during that interval. Each frame metric is used with the appropriate static curve to determine if the frame is erased.

Method 1:

$$\frac{\overline{E_b}}{N_t} = \frac{\sum_{n=1}^{N} E_b(n)}{\sum_{n=1}^{N} N_t(n)} \qquad FER_1 = f\left(\frac{\overline{E_b}}{N_t}\right) \qquad FE(k) = \begin{matrix} 1 & urv < FER_1 \\ 0 & otherwise \end{matrix}$$ **Equation 1**

where the function f() represents the mapping of the Eb/Nt through the appropriate static (AWGN) curve to determine an instantaneous FER in the range from 0 to 1. A uniform random variable (*urv*) is then selected to determine if the represented frame for frame interval k is erased or not. Note that this technique is frequently referred to as the quasi-static approach to performing system simulations and is described to some degree in [3].

2.1.2 Target FERs

FERs will be targeted that maximize data throughput.

2.1.3 Radio Environments

The channel models are to be included in the system simulation are given in **Table 1** and are based on empirical data [4-7] and GSM 5.05 Recommendation Typical Urban model [8] and the ITU Pedestrian models [2].

Table 1. Fraction of power recovered (FRP) per tap for delay spread model

	Delay Spread Model	1st ray	2nd ray	3rd ray	Assignment Probability
	Pedestrian A (1-ray)	0.98			0.33
	2-ray	0.80	0.12		0.34
	3TU (Similar to Pedestrian B)	0.50	0.22	0.10	0.33

The delay spread models are uniformly (randomly) assigned to various users at the beginning of each drop and are not changed for the duration (e.g. 20 minutes) of that drop.

2.2 Required Link Level Simulation Data

Include Ec/Ior vs FER curves/tables generated from downlink level simulations in Appendix A. Include other link level data needed to support system models, conditions, parameters, thresholds, etc.

3 System Level Data

3.1 Traffic Definitions

A pedestrian and low mobility environment will be modeled using the speed distribution given in **Figure 1** below and the delay spread models given in the Radio Environment section 2.1.3. Data only users will be considered in the phase 1 simulation effort. A speed is assigned to each user at the beginning of the drop and will not change for the duration (e.g. 20 minutes) of the drop. All signal paths are independently Rayleigh faded based on their assigned speed for all speeds except for stationary UEs (speed = 0). Stationary UEs signal paths will be Rician faded with K factor of 12dB and have a 2Hz Doppler frequency.

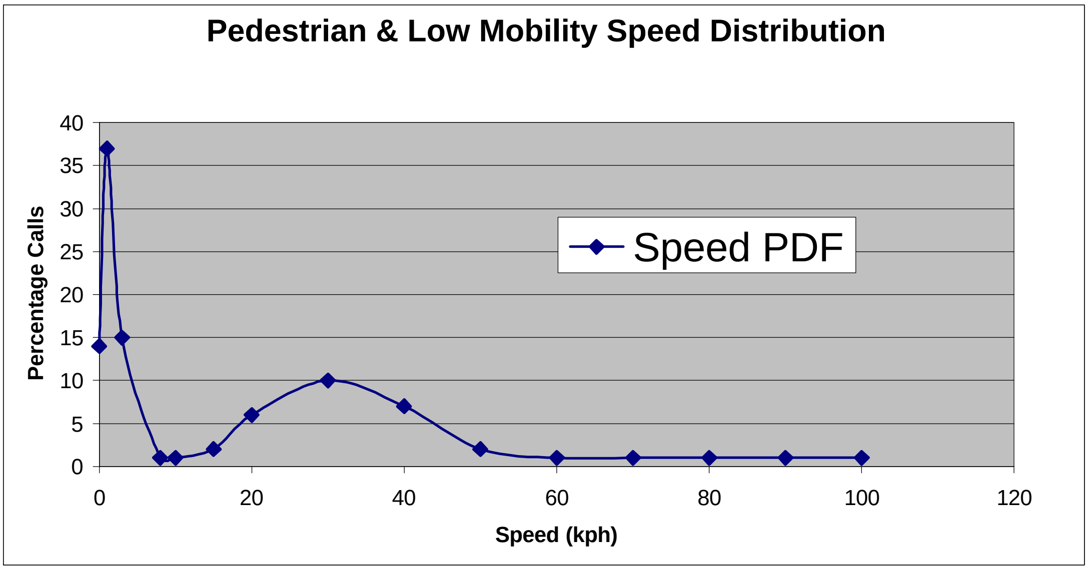


Figure 1. Pedestrian and Low Mobility Speed Distribution

Table 2. Speed Density Function

Speed (kph)	0	1	3	8	10	15	20	30	40	50	60	70	80	90	100
Probability	14	37	15	1	1	2	6	10	7	2	1	1	1	1	1

3.2 Antenna Pattern

The antenna pattern to be used for each sector, reverse link and Downlink, is shown in Figure 2 and is specified by the following equation:

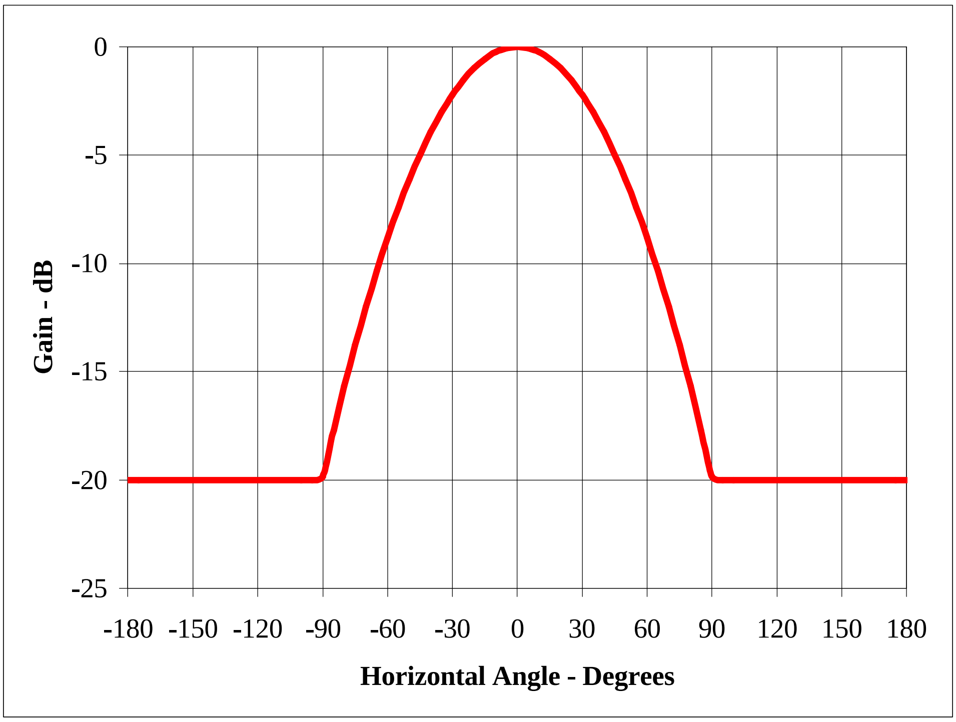


Figure 2. Antenna Pattern for 3 Sector Cells

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

and q_{3dB} is the 3dB beamwidth and $A_m = 20dB$ is the maximum attenuation.

3.3 System Level Assumptions

The downlink system level parameter assumptions are listed in Table 3. The values shall be used for each parameter listed in Table 3. Where values are not shown, the values and assumptions used shall be specified.

Table 3 System Level Simulation Parameters

Parameter	Value	Comments
Number of Cells (3 sectored)	19	
Antenna Horizontal Pattern	70 deg (-3 dB) with 20 dB front-to-back ratio	see Section 3.2
Antenna Orientation	0 degree horizontal azimuth is East (main lobe)	No loss is assumed on the vertical azimuth. (See Appendix C)
Propagation Model (BTS Ant Ht=32m, MS=1.5m)	28.6+ 35log10(d) dB, d in meters	Modified Hata Urban Prop. Model @1.9GHz (COST 231)
Log-Normal Shadowing	8.9 dB	See Appendix B
Base Station Correlation	0.5	
Overhead Channel Downlink Power Usage		CPICH, P-CCPCH, S-CCPCH, SCH, etc. (e.g. 20%)
Base Noise Figure	5.0 dB	
UE Noise Figure	10.0 dB	
Carrier Frequency	2000 MHz	
BS Antenna Gain w Cable Loss	14 dB	
MS Antenna Gain	0 dBi	
Vehicle Penetration	8 dB	
Body Loss	2 dB	
Maximum MS EIRP	21 dBm	
Speed	Pedestrian & Low mobility model	See Section 3.1
Fast Fading Model	Based on Speed	See Section 3.1
Active Set Parameters		e.g., secondary pilot within x dB of strongest pilot and above minimum SIR threshold.
Delay Spread Model	Equi-probable 1,2,3 ray model	Specified in Section 2.1.3
Fast Cell Site Selection	Switch on frame interval	
Downlink Power Control: (if used on dedicated channel)	Power Ctl. loop delay: ½ slot (measured from the time that the SIR is sampled to the time that the UE changes TX power level.)	Update Rate: Up to 1600Hz PC BER: 4% or can be based on matched filter bound
BS PA Size	25 Watts	
Cell Radius	1 km	

3.4 Data Traffic Model

The packet model described simulates bursty web traffic for each 30-second simulation run. The parameters of the model based on [1] but have been tailored to reduce simulation complexity by minimizing the number of UEs required to achieve peak system loading. In addition, TCP/IP rate adaptation mechanisms have been included to pace the packet arrival process of packets within a packet call.

The model assumes that all UEs dropped are in an active packet session. These packet sessions consist of multiple packet calls representing Web downloads or other similar activities. Each packet call size is modeled by a truncated Pareto random variable producing a mean packet call size of 25 Kbytes. Each packet call is separated by a reading time. The reading time is modeled by a Geometric random variable with a mean of 5 seconds. The reading time begins when the UE has received the entire packet call.

Each packet call is segmented into individual packets. The time interval between two consecutive packets will be modeled in two ways, first as an open loop process and then as a closed loop process. The open loop model will model the timer interval as a geometrically distributed random variable. Specifically, the mean packet inter-arrival time will be set to the quotient of the maximum packet size divided by the peak link speed. The closed loop model will incorporate the TCP/IP rate control mechanism “slow-start” for pacing packet traffic. Slow-start will be implemented as described in <u>TCP/IP Illustrated, Volume 2 : The Implementation</u> [5]. A round trip network delay of 100 ms will be assumed for TCP ACK feedback.

The fundamentals of the web-browsing model are captured in Table 4.

Table 4 Web Browsing model parameters

Process	**Random Variable**	**Parameters**
Packet Calls Size	Pareto with cutoff	=1.1, k=4.5 Kbytes, m=2 Mbytes, = 25 Kbytes
Time Between Packet Calls	Geometric	= 5 seconds
Packet Size	Segmented based on MTU size	(e.g. 1500 octets)
Packets per Packet Call	Deterministic	Based on Packet Call Size and Packet MTU
Packet Inter-arrival Time (open- loop)	Geometric	= MTU size /peak link speed (e.g. [1500 octets * 8] /2 Mbps = 6 ms)
Packet Inter-arrival Time (closed-loop)	Deterministic	TCP/IP Slow Start (Fixed Network Delay of 100 ms)

As stated the model has been selected to reduce simulation complexity by minimizing the number of UEs required to achieve peak loading. The expected throughput contribution of a individual UE can be estimated by the following formula:

$$\frac{Ave \quad Throughput}{UE} \cong \frac{Packet \quad Call \quad Size}{\mathrm{Re}\,ading \quad Time} = \frac{8 \times 25 kbytes}{5 \sec} = 40 kbps$$

An increase in the packet call size or a decrease in the reading time will increase the contribution of each individual UE thus reducing the number of UEs required per drop and the overall simulation complexity. With this in mind, a larger packet call of 25 Kbytes has selected with a smaller reading time of 5 seconds. In Section 4, the number of UEs per drop has been select to provide a offered sector load of 1.5, 2.25, 3 and 6 Mbps.

Real-time traffic models are FFS.

3.5 Packet Scheduler

Two simple scheduling algorithms are used to bound system performance. The first method (C/I) provides maximum system capacity at the expense of fairness, because all frames can be devoted to a single user with good channel conditions. The second method (RR) provides fair sharing of resources (frames) at the expense of slightly less system capacity. In addition to these two, data for an alternative scheduler may also be presented.

Specifying two standard schedulers for evaluation will allow vendors to validate system performance without the need to disclose proprietary scheduling algorithms.

Both Scheduling methods obey the following rules.

- An ideal scheduling interval is assumed and scheduling is performed on a frame by frame basis.
- The frame is defined by the air-interface (e.g. 0.67ms, 3.33ms, or 10 ms)
- A queue is 'non-empty' if it contains at least 1 octet of information.
- Packets received in error are explicitly rescheduled after the ARQ feedback delay consistent with the air-interface definition. -
- Packets to be retried are only placed in the high-priority queue after a specified time interval (e.g. 5 sec). If the packet in the high-priority queue is not rescheduled after a second time interval (e.g. 10sec) it is dropped.
- Packets from the low priority queue may only be transmitted after the high-priority queue is empty.
- Retransmissions reduce the data rate for the packet (see Section 4.3).
- Transmission during a frame cannot be aborted or pre-empted for any reason

C/I scheduler

The C/I scheduler obeys the following additional rules:

- At the scheduling instant, all non-empty source queues are rank ordered by C/I for transmission during a frame.
- The scheduler may continue to transfer data to the UE with the highest C/I until all thate UE’s packets have been transfered, data arrives for another UE with higher C/I, or a retransmission is scheduled taking higher priority.
- Both high and low priority queues are ranked by C/I.

The round robin scheduler obeys the following rules:

- At the scheduling instant, non-empty source queues are serviced in a round-robin fashion.
- All non-empty source queues must be serviced before re-servicing a user.
- Therefore, the next frame cannot service the same user as the current frame unless there is only one non-empty source queue.
- The scheduler is allowed to group packets from the selected source queue within the frame.

3.6 Adaptive Modulation and Coding / Fast Link Adaptation

Two schemes must be simulated.

Idealized

It is required that the data rate selection process be explicitly modeled. The model will include the following steps:

1. Measurement by the UE of the C/I (CPICH RX Ec/No) at frame/slot N in the simulation.
2. The measurement feedback delay will be modeled as M frames/slots with a minimum of one frame/slot transmission delay (i.e. M=1).
3. The MCS level is chosen based on the reported C/I and shall be applied to frame/slot N+M+1.
4. Alternatively, power control feedback information can be used to determine the MCS level. Power control feedback error is zero.

Practical

The same steps as in the *idealized* scheme with the addition of:

1. The C/I measured will have a standard deviation of   dB. Averaging should be simulated if it is used to reduce the C/I variance.
2. The C/I reporting process will have 1% decoding erasure .
3. Power control feedback error is 4% or based on matched filter bound equations (see Table 3).

4 Simulation Requirements

4.1 Simulation Flow

The phase one simulation will make the following assumptions:

1. UEs are first dropped uniformly throughout the system. The number of UEs dropped shall be as given in Table 5 in Section 4.2. Each UE corresponds to an active user session. The sessions run for the duration of the drop. UEs are randomly assigned speeds, fast fading models and delay spread models for the drop based on the distribution given in sections 3.1 and 2.1.3, respectively.
2. The total simulation time per drop will be 5 minutes excluding any time required for initialization. The total number of drops per run as given in section 4.2 in Table 5 will be 12 for a total simulation time of 1 hour per condition.
3. Packet calls arrive as per the modified ETSI model of section 3.4. Packets are not blocked when they arrive into the system (i.e. queue depths are infinite).
4. Packets are scheduled with one of up to three schedulers. Two required schedulers are described in section 3.5.
5. The ARQ process is modeled by explicitly rescheduling a packet as part of the current packet call after a specified ARQ feedback delay period.
6. Adaptive Modulation and Coding / Fast Link Adaptation is performed as described in section 3.6.

4.2 Required Runs

The following 16 cases are required for comparison.

Table 5 Required Simulation Cases

Run Number	Number of UEs per Drop				Scheduler Implementation		Link Adaptation	
	2100	3200	4275	8500	C/I	RR	Idealized	Practical
1	X				X		X	
2		X			X		X	
3			X		X		X	
4				X	X		X	
5	X				X			X
6		X			X			X
7			X		X			X
8				X	X			X
9	X					X	X	
10		X				X	X	
11			X			X	X	
12				X		X	X	
13	X					X		X
14		X				X		X
15			X			X		X
16				X		X		X

Note that additional runs with diversity can be performed at the discretion of the participant.

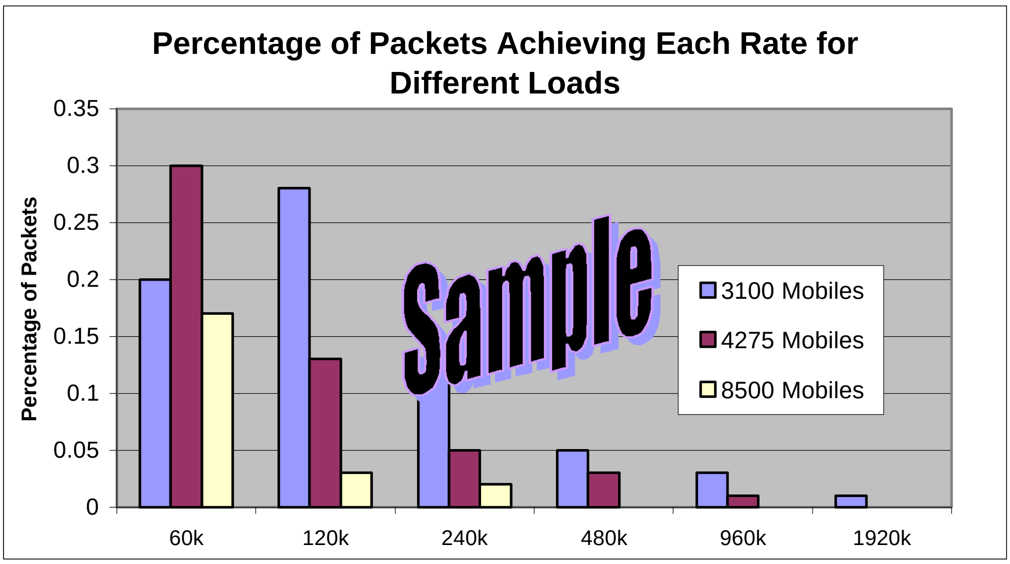
4.3 Outputs & Performance Metrics

Provide the following performance metrics for both the entire system and the center cell taken over each simulation run as shown in section 4.2. In all cases, a packet is as defined by the traffic model (section 3.4), not the particular air interface.

1) Percentage of users as a function of throughput for the different loading levels. Throughput is measured on a per packet basis and is equal to the number of information bits divided by the total transmission time. In other words, retransmission are accounted for and reduced the peak data rate statistic. The total transmission time is defined to include the time to transmit the initial attempt and each subsequent retry.

For example, consider a packet "*m*":

- Packet *m* contains Im information bits.
- Packet requires three attempts to transmit.
- Packet m takes $T_{m,j}$ seconds to transmit for attempt j



$$R(m) = \frac{I_m}{\sum_{j=1}^{3} T_{m,j}}$$ **Equation 2**

Figure 3 Percentage of Packets as function of throughput for the different loading levels.

2) Mean distance from serving cell for each throughput level, measured per packet. The rate of each packet is calculated as in the previous section.

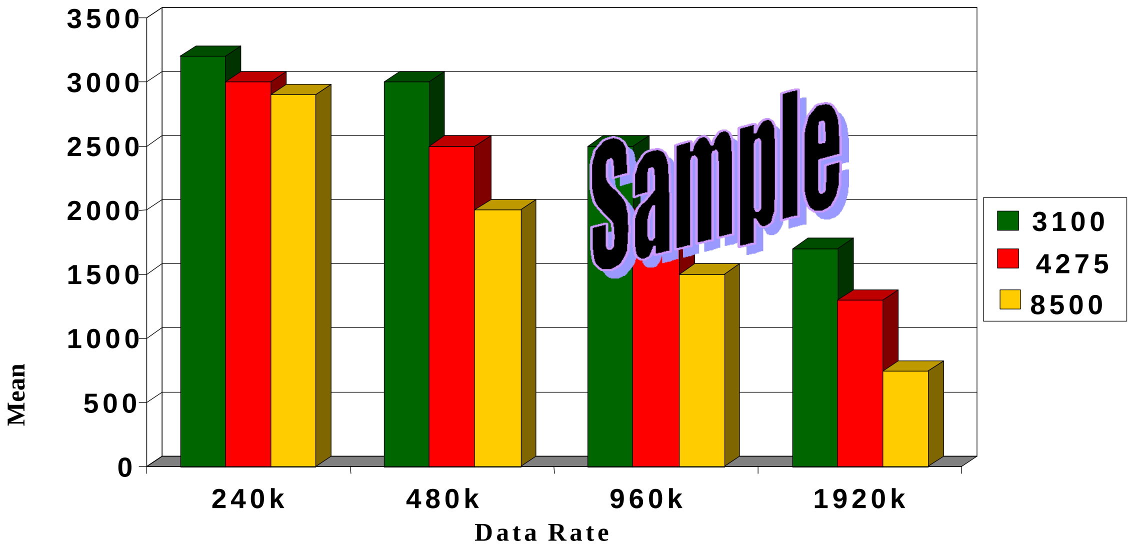


Figure 4. Mean Distance from serving cell for each throughput level.

3) Provide the following as a function of offered load:

3.1) Throughput per sector - Total number of bits successfully transferred divided by the total number of sectors and simulation duration.

3.2) Average and Variance of Packet Call Completion Time – measured from when the first packet of a packet call arrives at the base station's queue to when the final packet of the packet call is received by the UE station.

3.3) Average and Variance Packet Call Transfer Rate - defined as the payload size of a packet call divided by the transfer time where transfer time is measured from when the first packet of a packet call is transmitted by the base station to when the final packet of the packet call is received by the UE station

3.4) Service Rate – the number of completed packet calls per second.

4) Percentage of UEs with active set containing 1, 2, or 3 pilots.

5) 98 percentile and average base station PA power level for each sector of center cell (only).

6) Provide the following key system and link parameters defined in **Table 6**. Please be sure to specify the following parameters:

Table 6 System Information

Parameter	Value / Method
Frame Size	e.g., 0.67, 3.33 or 10 ms
Discrete Time Step Size	e.g., 0.67 ms
MTU	e.g., 576 octets,1500 octets
ACK Feedback Delay	e.g., 0.67, 3.33, or 10 ms

Overhead Channel Downlink Power Usage	e.g., CPICH,P-CCPCH, S-CCPCH,SCH=20%
Link Adaptation / Data Rate Selection Method	Measurement mechanisms delay M. Explain and rate switching restrictions or averaging provisions.
Targeted FER/Outage FER	
Active Set Method & Parameters	e.g., secondary pilot must be within X dB of strongest pilot and above minimum Ec/No threshold
Minimum Downlink Channel Power (Ec/Ior)	No minimum or specify and give reasons for limit.
Rx Combining Methods	HARQ, Tx Diversity, multipath
Equalization	Explain how account for in Eb/Nt calculation
Diversity Schemes (Forward & Reverse)	STTD, etc. Explain how account for in Eb/Nt calculation and FE metric
Ec/Ior vs. FER curves for each MCS on the Downlink	Place in Appendix A

5 References

[1] ETSI TR 101 112, Universal UE Telecommunications System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS (UMTS 30.03 v3.2.0)

[2] ITU-RM.1225, Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000.

[3] Sanjiv Nanda & Kiran Rege, "Frame Error Rates for Convolutional Codes on Fading Channels and the Concept of Effective Eb/No", IEEE Transactions on Vehicular Technology, Vol 47, No. 4, November 1998, pp 1245-1250.

[4] Ken Stewart et al, "Wideband Channel Estimates for IS95 CDMA", 1995 Vehicular Technology Conference,.

[5] TCP/IP Illustrated, Volume 2: The Implementation; Gary R. Wright, Richard Stevens, Addison-Wesley Professional Computing

Appendix A: Downlink Level Data

Appendix B: Lognormal description

The attenuation between a UE and the i^{th} cell site is modeled by

$$L_i = k_o D_i^{-m} 10^{X_i/10} R_i^2 \tag{B1}$$

where D_i is the distance between the UE and the cell site, m is the path loss exponent and X_i represents the shadow fading which is modeled as a Gaussian distributed random variable with zero mean and standard deviation s . X_i may be expressed as the weighted sum of a component Z common to all cell sites and a component Z_i which is independent from one cell site to the next. Both components are assumed to be Gaussian distributed random variables with zero mean and standard deviation s independent from each other, so that

$$X_i = aZ + bZ_i \text{ such that } a^2 + b^2 = 1 \tag{B2}$$

Typical parameters are $s = 8$ and $a^2 = b^2 = 1/2$ for 50% correlation.

Appendix C: Antenna Orientation

Antenna Bearing is the angle between the main antenna lobe center and a line directed due east given in degrees. The Bearing Angle increases in a counter-clockwise direction. Figure C1 below shows a 3 sector 120 degree cell site with a sector 1 bearing angle of zero degrees.

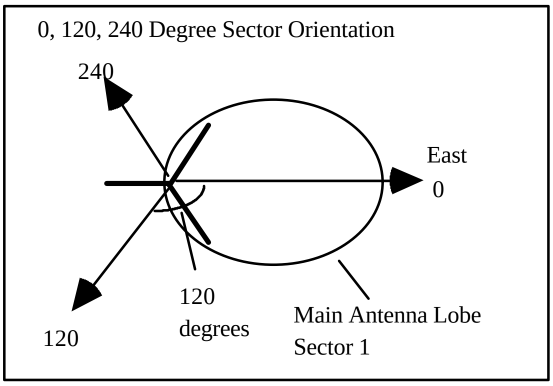


Figure C1. Antenna Bearing orientation diagram example.

Antenna downtilt is the angle between the main antenna lobe center and a line directed perpendicular from the antenna face. As the downtilt angle increases (positively) the antenna main lobe points increasingly toward the ground.

The Antenna gain that results for a given bearing and downtilt angle for a given cell/sector 'i' with respect to a UE 'k' is characterized by the equations given below (C1,2). A geometric representation is given in Figure C2 below.

$$\theta(i,k) = \gamma(i,k) - \xi(i) \tag{C1}$$

$$\phi(i,k) = \omega(i,k) - \zeta(i,k) \tag{C2}$$

where

$\theta(i,k)$ = angle between antenna main lobe center and line connecting cell 'i' and UE 'k' in radians in horizontal plane.

$\phi(i,k)$ = angle between antenna main lobe center and line connecting cell 'i' and UE 'k' in radians in vertical plane.

$\xi(i)$ = antenna bearing for cell 'i' in radians.

h(i) = antenna height for cell 'i' in meters.

$\delta(i)$ = antenna downtilt in radians .

$\zeta(i,k)$ = corrected downtilt angle for given horizontal offset angle ($\theta(i,k)$) in radians.
= ATAN(COS(θ(i,k))TAN(δ(i)))

$\omega(i,k)$ = antenna-UE line of site angle in radians
= ATAN(h(i)/d(i,k)) .

d(i,k) = (UE(k)_ypos - cell[i]_ypos)^2 + (UE(k)_xpos - cell[i]_xpos)^2 = distance

$\gamma(i,k)$ = UE bearing is the angle between the line drawn between the cell and UE and a line directed due east from the cell.
= ATAN2((UE(k)_ypos - cell[i]_ypos, (UE(k)_xpos - cell[i]_xpos))

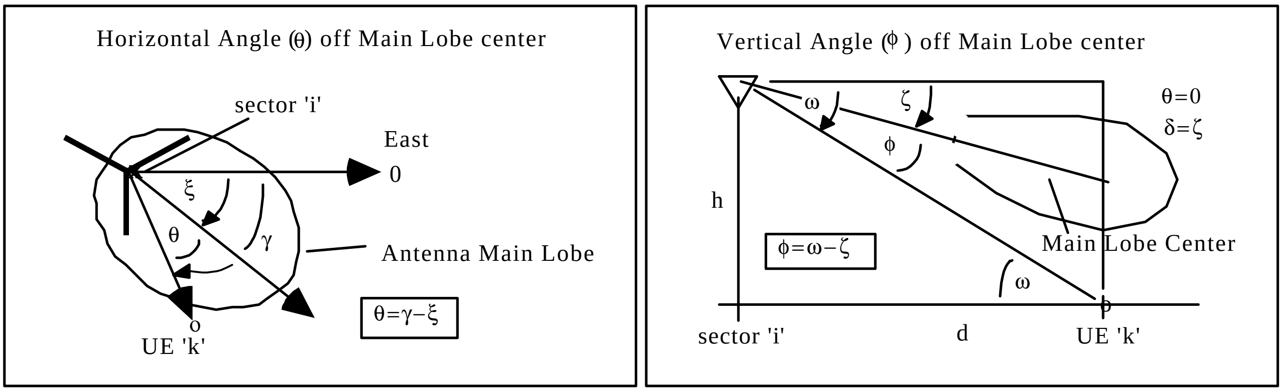


Figure C2. UE Bearing orientation diagram example.