

ESG

Engineering Services Group

UMTS/HSDPA Backhaul Bandwidth Dimensioning

80-W1193-1

Revision A

May 18, 2007



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Executive Summary

This paper presents a simulation-aided approach for the dimensioning of the ATM-based Iub interface in UMTS/HSDPA networks. Besides considering different user applications, as well as the peculiarities of the radio protocols above and within the backhaul transport infrastructure to estimate Iub utilization, this paper also provides insights in to the HSDPA air interface capacity given different data traffic and voice traffic scenarios for different UE categories (e.g. UE Cat 12, 6, 8).

Since R99 PS (Packet Switched) services are less spectral efficient and there is a clear trend to replace such services with HS (High Speed) services in most WCDMA networks, this study focus on the analysis of HSDPA PS data services and only considers R99 radio bearers for AMR voice calls.

The paper has three key objectives:

1. Provide an approach and an algorithm to estimate the backhaul bandwidth
2. Use simulation data to provide actual estimates of the backhaul bandwidth requirements to support AMR and HSDPA traffic in different network configurations
3. Discuss the technical trade-offs of dimensioning the backhaul based on different traffic types and deployment constraints.

The initial three sections of the paper deal with the modeling of all related backhaul overheads and the Iub dimensioning algorithm proposal. The last three sections of the document describe the system level simulation assumptions, and present the simulation results of the air interface capacity and backhaul bandwidth requirements for all the proposed combinations of UE categories and air interface traffic modeling.

In general, it has been found that the Iub dimensioning problem requires minimizing backhaul bandwidths (reducing costs) while maximizing air interface capacity utilization (increasing profit). There is no brick wall rule for that process and the proper dimensioning depends on how the network operator faces the technical advantages/disadvantages of a specific Iub bandwidth decision. This decision must consider the economical impacts in terms of cost savings (due to backhaul capacity reduction) and profits (coming from effective air interface capacity utilization). This study focuses on the technical challenges of determining a proper backhaul bandwidth as a function of different air interface capacity utilization levels without considering the associated economical tradeoffs which depend on individual network operator business model.

To aid further with specific backhaul dimensioning needs, there is an associated tool available on request [12].

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1 Introduction

Fast paced deployment of HSDPA networks and the eagerness to increase Average Revenue per User (ARPU) have caused WCDMA cellular network operators to offer different mobile data intensive applications. The bandwidth requested by devices operating on these networks has also increased given application like high bit-rate video/music downloads large email attachments and graphic enabled web-pages viewable on large-screens. As a result, it is expected an increased usage of the air-interface capacity. But associated with increased utilization of over the air capacity, there is an associated increase of operational costs in maintaining the terrestrial interfaces between network nodes at the required capacity so as not to affect the quality of services of the advertised over the air data services.

This paper deals with the efficient dimensioning of the most critical terrestrial interface of the UTRAN: The link that connects each base station (or Node B) to the Radio Network Controller (RNC) called backhaul (or lub interface) [1]. In terms of UTRAN Operating Expenditures (OPEX), the efficient dimensioning of the lub interface is of key importance, especially since there could be thousands of Node Bs in the network and their connection expenses represent a significant part of the total monthly operational costs.

From physical layer perspective, these backhaul connections may use a variety of TDM interfaces, for example channelized E1/T1 interfaces for data and voice traffic carried over leased lines, Microwave (WIMAX inclusive), and/or Optical interfaces. According to 3GPP standards, lub interface can be transported over IP or ATM protocols [1]. Our study focuses on the ATM-based lub interface that is currently the most widely implemented by UTRAN vendors taking into account different user applications, as well as the peculiarities of the radio protocols above the transport infrastructure.

Further, since R99 PS (Packet Switched) services are less spectral efficient and there is a clear trend to replace such services with HS (High Speed) services in most WCDMA networks, we focus our analysis on HSDPA PS (Packet Switched) data services and only consider R99 radio bearers for AMR voice calls. Differently than [9] and [10], the study presented here is a simulation-aided backhaul dimensioning approach which considers:

- Various HSDPA UE categories and receiver types: UE categories 12, 6 and 8 designed to support up to 1.8, 3.6 and 7.2 Mbps respectively and either Rake or Equalizer receivers
- Code Division Multiplexing (Multi-user per-TTI)
- Different levels of inter-cell interference
- Full Buffer (FB) and HTTP traffic models

The rest of the paper is organized as follows: Section 2 presents the system model and the backhaul overheads calculations for AMR voice, HSDPA traffic and other control plane protocols. Section 3 includes a description of the simulation-aided lub bandwidth dimensioning algorithm. This algorithm has also been implemented within a backhaul dimensioning tool [12] that can be requested and used by an operator to estimate bandwidth requirements based on field deployment considerations. Section 4 describes the AMR and HSDPA Air Interface Capacity Simulation Model including Network Layout, Channel Modeling, HSDPA Configurations and UE receiver categories. Section 5, present air interface capacity simulation results, a complete lub dimensioning example and the backhaul bandwidth estimates. The paper is closed in Section **Error! Reference source not found.** with the final considerations and conclusions.

2 System Model and Protocol Overheads

2.1 System Model

As shown in Figure 2-1, the Iub interface protocol architecture consists of two functional layers [1]:

1. Radio Network Layer: defines procedures related to the operation of Node B and consists of a radio network control plane and a radio network user plane.
2. Transport Layer: defines procedures for establishing physical connections between Node B and the RNC.

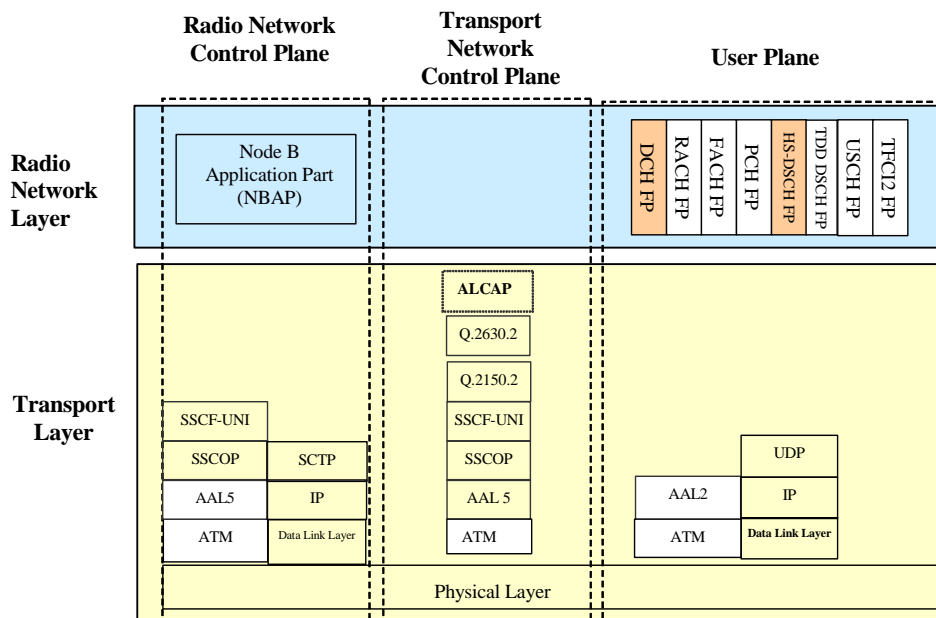


Figure 2-1: Iub Protocol Stack [1]

In the transport layer, 3GPP specifies that each user flow is carried over an ATM Adaptation Layer 2 (AAL2) connection or IP based transport between RNC and Node B. Each AAL2 connection corresponds to a dedicated channel Radio Access Bearer (RAB) setup per user or a common channel RAB. Several AAL2 connections belonging to users of the same Node B can further be multiplexed over an ATM Virtual Channel Connection (VCC) that terminates in the corresponding Node B. In this way, variable-length AAL2 packets carrying information of different users are concatenated and sent within the fixed-length ATM cells of the VCC. 3GPP also specifies the use of AAL5 for the transport network control plane and the radio network control planes.

When an ATM cell is partially filled and there are no more pending AAL2 packets, the sender times out, completes the ATM cell with padding octets, and sends it immediately in order to avoid long delays¹. It is possible, but not the intention of this paper, to establish guidelines for the optimum settings of this AAL2 multiplexing cumulative timer (Timer_CU) as a function of loading and link utilization efficiency. The interested reader is referred to [2]

¹ In a second step, AAL2 may allow for traffic flows of a group of Node Bs to further be statistically multiplexed. In terms of data units, this means that AAL2 packets belonging to *different users in different Node Bs* (not only to different users in the *same Node B*) are concatenated by the RNC (downlink direction) and the AAL2 switch (uplink direction) inside the ATM cells of a single VCC between both nodes. This reduces the number of partially filled cells and increases the efficiency.

2.2 User Traffic streams and its impacts in backhaul load

As shown in Figure 2-1, all user traffic (mainly DCH, RACH, FACH and HS-DSCH) related to the radio bearers over Iub will be carried over the Frame Protocol (FP). To consider the traffic flow over Iub, it is necessary to consider the various protocol overheads over the Iub interface.

2.2.1 Iub overheads for AMR Voice Calls

For voice traffic, the transport of radio bearers over the radio interface takes place over the Uplink and Downlink Dedicated Physical Channels (DCH) [3]. In this case the Node B receives FP frames every 20ms. At FP layer, traffic voice consists of a succession of ON and OFF periods.

A. Backhaul data rates during AMR ON periods:

At the output of the Frame Protocol there are: 31 bytes of payload + 5 bytes of overhead. To estimate the ATM transport overhead per AMR active frame, we assume that the Node B voice load and ATM collection timer – Timer Common Usage (Timer_CU) – allow the multiplexing of one entire FP frame and part of another in every ATM cell addressed to a Node B [9]. In this case, there would be a backhaul ATM related overhead of 5 bytes for the ATM Header+2*3 bytes CPS multiplexing for every ATM cell. This results, in average, around $11/2 = 6$ bytes of additional ATM overhead per AMR frame.

Hence, the resulting required data rate during AMR ON periods would require sending 31 bytes of FP payload + 5 bytes of FP overhead + 6 Bytes of ATM/AAL2 overhead every 20 ms which is equivalent to 16.8 Kbps.

R_{ON} Summary:

- i. AMR Encoder Rate = 12.2 kbps
- ii. ATM & FP overheads (38%) result in R_{ON} = 16.8 kbps

B. Backhaul data rates during AMR OFF periods:

In this case, at the output of the Frame Protocol, there is close to zero bytes of payload + 5 Bytes of overhead transmitted every 20 ms $5*8*1000/20$ (2 kbps). To estimate the ATM transport overheads per AMR null traffic, we assume the Node B load and ATM collection timer allows the multiplexing of up to five null frames. In this case, there would be a backhaul ATM related overhead of: 5 bytes ATM Header+5*3 bytes CPS multiplexing for every ATM cell. This results in around $20/5 = 4$ bytes of ATM overhead per null AMR frame.

Hence, the resulting required data rate during AMR OFF periods would require sending 5 bytes of FP overhead + 4 Bytes of ATM/AAL2 overhead every 20 ms which is equivalent to 3.6 Kbps.

R_{OFF} summary:

- i. AMR rate = 0
- ii ATM & FP overheads result in R_{OFF} = 3.6 kbps

C. Average backhaul data rates for Voice AMR calls

Observe that SID first and SID update frames were not directly considered as their percentage is very low if compared to Full and Null frames and its influence in terms of backhaul utilization can directly be captured by the settings of the Voice Activity Factor. Also additional overheads due to in-band signaling and soft handover reduction factor need to be considered in order to have the average required backhaul capacity per-AMR call:

$$R_{AMRVoice} = [R_{ON} VAF + R_{OFF} (1 - VAF)] SHO + Iub_{InBandSignaling} \quad (1)$$

Observe here that the air interface SHO reduction factor², translates into a backhaul overhead factor, since backhaul resources need to be reserved for the establishment of additional SHO radio links. For a VAF of 60%, a SHO reduction factor of 1.2 and lub in-band signaling of 1.36 kbps (40% the maximum possible signaling rate of 3.4 kbps as defined in [3]) Equation 1, results in around 15 kbps average data rate per AMR call in the backhaul.

Finally, the total expected average backhaul traffic per cell due to voice traffic can be calculated as:

$$R_{AMRVoice_cell} = N_{VoiceUsers} \cdot R_{AMRVoice} \quad (2)$$

Observe that, in this paper, the number of simultaneous voice users per cell is based on operator input (operating point) and on air interface capacity simulations that relate additional cell power available (with HTTP traffic) as described in Section 3. Further, the total expected average backhaul voice traffic per Node B, assuming same loading characteristics for each of its cells, is given by:

$$R_{AMRVoice_NodeB} = N_{CellsPerSite} \cdot R_{AMRVoice_cell} \quad (3)$$

2.2.2 lub overheads for HSDPA

For HS traffic, the transport of data takes place over HS-DSCH [5]. In this case, the Node B receives HS user traffic from the RNC over the HS-DSCH Frame Protocol (FP).

The expected HS air interface throughput, R_{HS} , and its associated requirement in terms of backhaul bandwidth depends on the particulars of power availability for the HSDPA channels (HS-DSCH and HS-SCCH), UE Category and data traffic type distribution among the HS users in a cell.

Specific cell throughput values for UE categories 6, 8 and 12, HSDPA available power ranging from 30%-80% of the total power and considering Full-Buffer and HTTP traffic models are obtained through system level simulations as described in Section 4.

As shown in Figure 2-1, HS-DSCH FP frames are still transported over AAL2 ATM Cells. Each ATM cell, in this case, carries 5 bytes of ATM header+1 ATM start byte+ Number of FP overhead bytes + Number of HS FP payload bytes. Observe that, in contrast to the AMR voice case, a single HS FP frame may be segmented and transported by different ATM cells, so, effectively, the FP overhead is diluted among several ATM cells. For instance; considering 7 bytes of HS FP overhead and 228 bytes HS FP payload, it results that the total HS FP frame could be segmented into 5 (235/47) ATM cells with average FP overhead of 7/5 bytes per ATM cell. Hence, for the particular case the total ATM and FP overhead would ~14% $(5+1+7/5)/53$. It clearly depends on the HS FP payload size. In addition, one must consider RLC AM related overheads, which are absent for AMR voice calls using RLC TM mode. Further, as the HSDPA functionality is distributed between RLC (at the RNC) and MAC-hs (at the Node B), it requires the support of flow control signaling between the RNC and Node B data buffers. In general, both the flow-control related signaling and the flow-control algorithm managing data flow to the Node-Bs will impact the backhaul utilization. It is important to note that SHO is absent for HSDPA (data plane) but present for the supporting signaling plane which is low-rate and thus does not impact significantly the backhaul overhead. Taking into account these aspects and the associated signaling related to support HS mobility; it is common practice to consider an overall HS ATM backhaul overhead, HS_{OH} , of 20% to 30% for HS data services. The HS overall overhead may vary from vendor to vendor. As a result the backhaul data rate seen on the backhaul for a given air interface HS throughput, R_{HS} , is given by

² SHO reduction factor typically applies to decreasing air interface resources to support SHO. In terms of the backhaul, this same factor implies increasing required backhaul resources to support Soft-handoff between Node Bs (Note: Softer-handoff does not require additional backhaul resources).

$$R_{HS_Cell} = (1 + HS_{OH}) R_{HS} \quad (4)$$

Observe that cell throughput values may be obtained from simulation considering Full Buffer and HTTP models. Further, the total expected average backhaul requirement per Node B, assuming same loading characteristics for each of its cells, is given by:

$$R_{HS_NodeB} = N_{CellsPerSite} \cdot R_{HS_Cell} \quad (5)$$

2.2.3 Iub Common Transport Channel Backhaul Overheads

By Common Transport Channels backhaul overhead one must understand, at least initially, the backhaul traffic impacts due to activity in the RACH, FACH & PCH transport channels. It is also, however, related to the signaling between Node B and RNC required to support: 1) Node Synchronization Mechanisms and 2) Transport Channel Synchronization Mechanisms as DL timing adjustments [5]. The assessment of this value, among others, requires the knowledge of call origination and termination statistics as well as user distribution and mobility in the serving cells coupled to proprietary implementation of paging and access control mechanisms. This paper assumes a backhaul bandwidth of $R_{Common} = 130$ kbps per Node B.

2.3 Overheads due to other protocol planes

2.3.1 Radio Network Control Plane Overheads (NBAP)

The radio network control signaling between RNC and Node B is based on the Node B application part (NBAP) which is transported over an AAL5 connection [6]. Among, others, the NBAP protocol provides the following functions [7] that directly impacts backhaul utilization: a) Common Transport Channel and System information management, b) Measurement of common resources in the Node B, c) Radio Link Management and supervision, d) compressed mode control, e) measurements on dedicated Resources in the Node B, DL Power Drifting Correction and e) reporting of general error situations. This paper assumes a configurable backhaul bandwidth of $R_{NBAP} = 128$ kbps per Node B for this purpose. This bandwidth may be a function of the number of voice or HSDPA users that have a signaling bearer assigned. While the paper currently assumes a static value, this can be configured based on UTRAN vendor feedback given implementation dependant variation.

2.3.2 Access Link Control Application Protocol (ALCAP)

The Transport Network Control Plane does not include Radio Network Layer information. The Transport Layer includes the ALCAP protocol that is needed to set up the transport bearers (Data Bearer) for the User Plane. It also includes the appropriate Signaling Bearer(s) needed for the ALCAP protocol(s). The Transport Network Control Plane is a plane that acts between the Control Plane and the User Plane (See Figure 2-1). The introduction of Transport Network Control Plane is performed in a way that the Application Protocol in the Radio Network Control Plane is kept completely independent of the technology selected for Data Bearer in the User Plane. When Transport Network Control Plane is used, the transport bearers for the Data Bearer in the User Plane are set up through a signaling transaction by the Application Protocol in the Control Plane, which in turn triggers the set up of the Data Bearer by the ALCAP protocol that is specific for the User Plane technology. This paper assumes a configurable backhaul bandwidth of $R_{ALCAP} = 64$ kbps per Node B for this purpose.

2.3.3 Node B Element Management Interface (Irf-B)

Interfaces between Network Elements are sometimes used to carry management information even though this may not be the primary purpose of the interface. An example is the Iub interface between Node B and RNC which may carry element management information between the Node B and its manager on the Irf-B Management Interface [11]. This paper assumes a configurable backhaul bandwidth of $R_{Irf-B} = 190$ kbps per Node B³. This can be configured based on UTRAN vendor feedback given implementation dependant variation.

³ This rate is based on typically activated UTRAN performance counters. Also, the rate is subject to some increase during software upgrades but these occur during non-peak traffic periods and hence are not considered in the calculations.

3 Backhaul Dimensioning Algorithm

This paper bases the estimation of the backhaul bandwidth requirements on a dimensioning algorithm. The Algorithm is basically divided in to four fundamental parts:

- 1) Air interface capacity simulation input curves
- 2) NW Operation set point
- 3) Backhaul overhead related inputs
- 4) Required backhaul data rate calculation

The air interface capacity simulation input curves are based on system level simulation results (explained in detail in Section 4) that provide a relationship between number of AMR calls to be supported in the system, available HSDPA power and corresponding HSDPA cell throughput achieved using Full Buffer or HTTP traffic. The NW operation set points allow definition of an operator specific deployment scenario based on number of AMR calls to be supported, HSDPA Network configuration, UE capability parameters and user traffic type. Selecting either Full Buffer or HTTP traffic types allows determination of typical upper and lower bounds of cell throughput achievable and corresponding backhaul requirements. The backhaul overhead inputs allow definition of overheads for AMR and HSDPA traffic, common channels as well as various network control plane protocol overheads. The backhaul data rate estimation is based on the selection of specific data from the simulation curves based on the NW operating points defined and applying the requisite overheads to provide a backhaul bandwidth estimate. As mentioned earlier, both upper and lower bounds of backhaul bandwidth are estimated by selecting Full Buffer and HTTP traffic types. Figure 3-1 shows a flow chart of the proposed simulation-aided HSDPA backhaul bandwidth dimensioning algorithm.

3.1.1 Air interface capacity simulation inputs

Section 4 describes all the simulation assumptions and related parameters for the air interface capacity simulations. Basically three types of results from the simulation engine are imported into the capacity dimensioning algorithm:

- **Type A Graph:** This graph provides an estimate of available HSDPA power in the cell as a function of the number of simultaneous AMR calls in the cell (most likely in a dynamic HS power allocation scenario). Power available to HSDPA is determined after accounting for power used by common channels and AMR traffic. Alternately, this graph may provide an estimate of the number of simultaneous AMR calls given a certain HSDPA power allocation (most likely in a static HS power allocation scenario),
- **Type B Graphs:** These graphs provide cell throughput as a function of HSDPA allocated (available) power for different UE Categories and HS-PDSCH and HS-SCCH configurations. There are results considering different receiver configurations (Rake and Equalizer) and different degrees of inter-cell interference
- **Type C Graph:** This graph provides an estimate of HSDPA cell throughput as a function of Number of HTTP users based on a conventional web browsing model (see the details in Section 4.4)

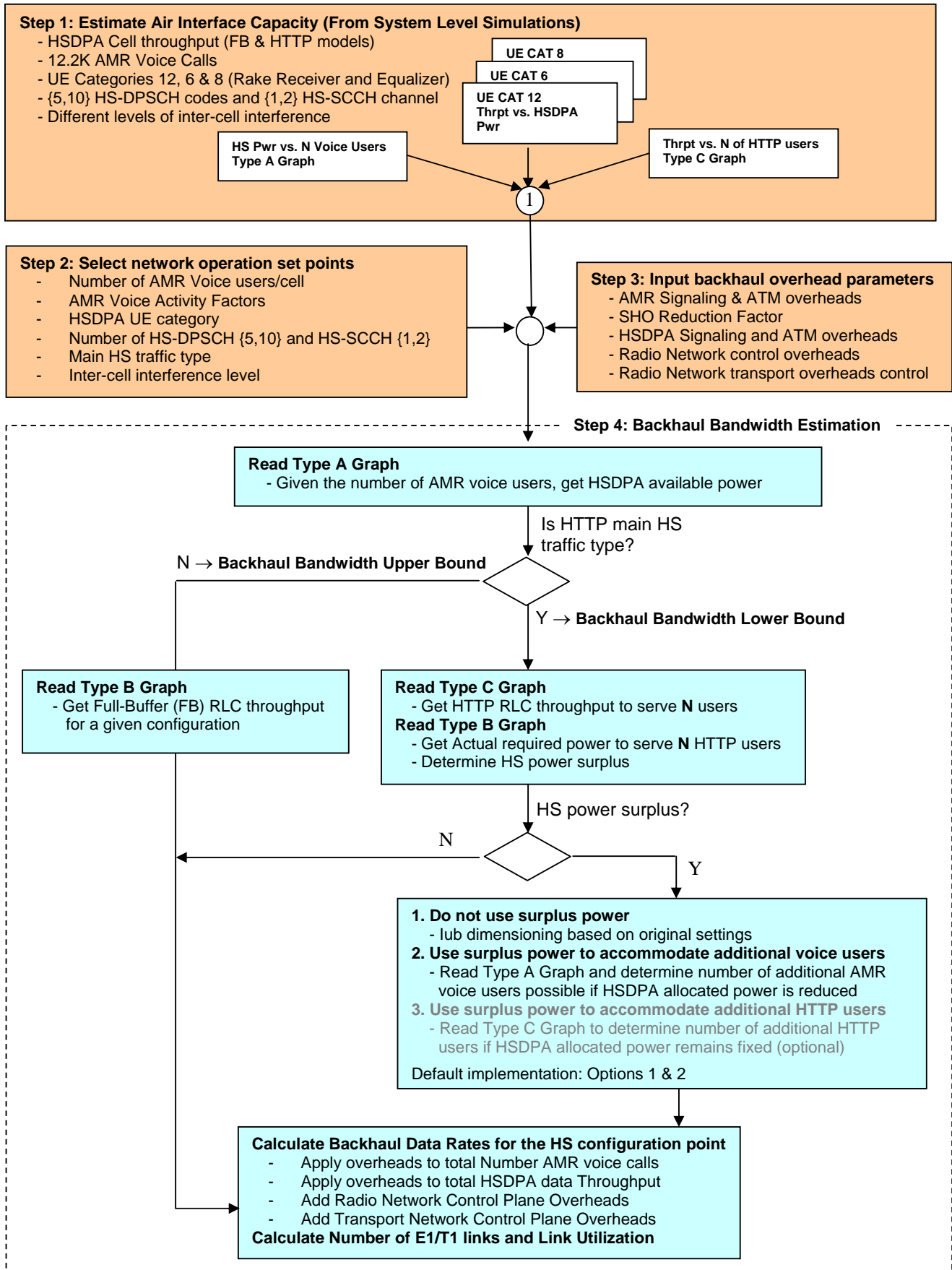


Figure 3-1: Backhaul dimensioning algorithm

3.1.2 Network operation set points

The network operation set point is defined through the proper settings of:

- **Number of simultaneous AMR voice calls per cell:** This setting indirectly defines the amount of available power for HSDPA. The HSDPA available power would be the remaining power after discounting the power used to serve the specified number of AMR voice calls and overhead channels and can directly be obtained from the Type A graph. Additional AMR voice call related parameters are covered in Section 2.2.1.
- **Main HSDPA UE category type:** This setting allows selecting either Category 12, 8 or 6 UE (Observe that a network with a mix of different UE categories is not considered at this time)
- **Number of HS-DPSCH and HS-SCCH:** This setting represent the number HS-DPSCH SF16 reserved codes for HSDPA and the number of HS-SCCH support channels configured in the system (if the number of configured HS-SCCH is greater than 1, it is directly considered that the system supports code division multiplexing (CDM) in a per TTI basis)
- **Main data traffic type:** This information is important to determine HSDPA air interface per-cell throughput. Currently, two options are defined: Full Buffer (or FB) for upper bound backhaul capacity calculations and web browsing (HTTP) for lower bound calculations.

3.1.3 Backhaul overhead input parameters

lub backhaul overheads on the user planes for the Radio Network and Transport layers (see Figure 2-1) and Common channel overheads as defined in Section 2.2 should be considered. Additionally, Network and Transport control plane overheads as explained in Sections 2.3 should also be considered as an input to the algorithm. In our specific implementation all these overheads have default values and are easy to change based on vendor specific values.

3.1.4 Backhaul bandwidth calculation

Using the defined number of AMR voice users, $N_{\text{VoiceUsers}}$, the first step of the algorithm reads Type A Graph, to get the available HSDPA power. Immediately from Type B Graphs and considering specific UE categories, number of HS-DPSCH/HS-SCCHs and specified average inter-cell interference, the average Full-Buffer (R_{FB}) throughput for the specified available HSDPA power is obtained.

The next step is to verify if the user intends to dimension the backhaul based on HTTP traffic model instead of the aggressive Full Buffer model. If this is the case, then the HTTP average throughput for a specified number of HTTP users, $N_{\text{HTTPUsers}}$, should be obtained reading Type C Graph. Please note that, this average HTTP throughput is highly dependent on the parameter settings of the HTTP model (see Section 4.4) and it does not necessarily mean all $N_{\text{HTTPUsers}}$ are simultaneously downloading at a given observation time based on a specific reading time. In general, it is expected that the HTTP average throughput would be below or at most equal the FB throughput obtained in the first steps. Therefore, an HS power surplus compared to the original HS power settings for the FB case is expected. The issue here is how this power surplus could impact backhaul utilization and the algorithm allows three different analysis options:

- Simply let the surplus power unused and do not allocate additional users
- Allocate additional Voice Users: Get the number of additional voice users that could be supported from Type A Graphs (preferred and implemented approach)

- Allocate additional HTTP users: Get additional HTTP users from Type C Graphs that can be accommodated without HTTP service outage

Once the HSDPA average throughput for either FB or HTTP traffic has been determined and once the final number of AMR Voice calls has been established, the algorithm then proceeds to calculate the total average backhaul per Node B including all overheads:

$$R_{Iub} = R_{HS_NodeB} + R_{AMRVoice_NodeB} + R_{Common} + R_{NBAP} + R_{ALCAP} + R_{Irf-B} \quad (6)$$

3.1.5 Average vs. Peak Air Interface throughputs for Iub bandwidth dimensioning

The HSDPA Iub dimensioning approach presented in Section 2.2.2 assumes that a common Iub resource was shared among all HSDPA users served by the same Node B. In effect, the HSDPA Iub capacity corresponds to an expected average air interface throughput corrected by a backhaul overhead factor.

The question here is if instead of using average cell throughputs we should be using peak air interface throughput numbers. Clearly, total average cell capacity is below peak data rates: 1.94 Mbps with 80% of HS power allocation against theoretic peak of 3.6 Mbps for UE Category 6, for instance. This shows that there is no need to dimensioning the backhaul transmission capacity according to the nominal peak except in the case when there is a desire to provide continuous maximum data rate with a single user being located in excellent RF conditions. Observe also that Iub dimensioning based on average capacity eventually could allow for such high peak nominal rates thanks to Node B buffering. On the other hand, as the individual cells have capacity variations due to interference variations and momentary locations and channels conditions of the terminals, some additional margin needs to be added to the average throughput numbers to ensure that the momentary favorable channel conditions can be utilized with HSDPA and that achievable air interface capacity is not reduced too much. This safety margin can be explicitly added or implicitly incorporated through different inter-cell interference levels as in our current algorithm design (10 W vs. 5 W surrounding cell loading).

An alternative dimensioning approach, would consider a specific percentile of the Full Buffer cell throughput, but this method requires cell throughput CDFs (Cumulative Distribution Function), rather than simply average points, for every particular scenario. Section 5.3 provides further numerical insights into this approach.

4 AMR and HSDPA Air Interface Capacity Simulation Models

4.1 Network Layout

For the purpose of system simulations, an outdoor macro-cell scenario with a hexagonal network layout of 19 Node Bs has been selected, cf. Figure 4-1. A single 5 MHz carrier is simulated. Each site is equipped with three cells adding up to a total of 57 cells. Only the 3 center cells (colored green in Figure 4-1) are actually loaded, while surrounding cells loading is set statically to 25% or 50% resulting in an average radiated power of 5W or 10W. This setup provides high accuracy at reasonable simulation run time.

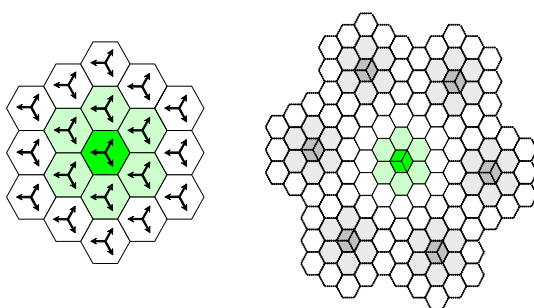


Figure 4-1: System simulation network layout: 19 Node Bs with 3 cells each and wrap-around to avoid border effects

4.2 Channel Modeling and link budget basic parameters

The study has been conducted based on an urban channel model with 25% pedestrian and 75% vehicular users. (Pedestrian: TU3 channel – Pedestrian B at 3 km/h. Vehicular: TU30 channel – Vehicular A at 30 km/h). The link budget is dimensioned to sustain a REL-99 PS connection at 64 kbps at the cell edge. The link budget is summarized in Table 4-1.

Table 4-1: Link budget values used for the system level simulations

Parameter	Value	Parameter	Value
Node B Tx Power (dBm)	43	UE noise Figure (dB)	8
Node B Antenna Gain (dBi)	18	UE Antenna Gain (dB)	0
Node B Cable losses (dB)	3	Slope in dB per decade	-35.7
In-building penetration loss (dB)	18	Log-normal fading std dev	12
Body loss (dB)	1	Cell radius (km)	1.02
Antenna beam-width	70	Path gain 1m intercept (dB)	-19.3

4.3 HSDPA simulation configurations

As mentioned earlier, in the simulations it is assumed that all the cells of the center Node B can transmit at full power while the surrounding cell transmit power (loading) is set to either 5W or 10W (25% or 50% loading) respectively: Power dedicated to overhead

channels (pilot and synchronization) is set to 20% of the maximum Node B power. This means that 80% of the power can be used for HSDPA. When lower HSDPA power allocations are selected, the remaining power is assigned to AMR calls, or vice versa, to always simulate a fully loaded center Node B. The HSDPA power comprises the HS-PDSCH and HS-SCCH channels. The HS-SCCH channels are power controlled based on CQI feedback information. The downlink associated DPCH is modeled with Soft-handover and both Inner/Outer loop power control. Thus, some power is used for the DPCH after accounting for the common channels slightly reducing HSDPA available power.

The simulations and HSDPA capacity estimated cover various scenarios as summarized in Table 4-2. Various HSDPA power allocations in the range of 40-80% (in steps of 10%) suggest the maximum possible power available to HSDPA. Some part of this power is used for the Associated DPCH to support the R99 signaling plane for HSDPA. Simulations were also run for lower power allocations of 10-30% to determine additional AMR capacity when HTTP traffic is used. While these power allocations may not be used in a static manner, the average HSDPA power available in a dynamic allocation scenario given existing R99 voice and data power usage allows us to provide an estimate of HSDPA air-interface capacity achievable.

Multiple HS UE categories with different receiver architectures are considered – Category 12 (5 code, QPSK, Rake Receiver), Category 6 (5 code, QPSK/16QAM, Equalizer) and Category 8 (10 code, QPSK/16QAM, Equalizer). The Equalizer implemented is a Time-domain LMMSE receiver using a single sample per chip and an equalizer window of 20 chips. Both the Rake and Equalizer receivers assume ideal channel estimation.

Simulations consider either 5 or 10 HS-PDSCH codes with support for Code division multiplexing (CDM) using up to 2 HS-SCCH codes. These scenarios have been selected keeping in mind realistic network deployments with support for different categories of UEs, UTRAN CDM support and R99/HSDPA traffic mix. The per-user HSDPA power allocation depends on UE category and the maximum number of codes allocated for HSDPA per cell on the Node B. In a scenario where up to 5 SF16 HS-PDSCH codes are allocated per cell, a Category 12 UE (5-code) can use all available power. However, when 10 HS-PDSCH codes with 2 HS-SCCH codes are allocated per cell, each Category 12 UE can use only half the available power.

A Proportional Fair (PF) scheduler⁴ is implemented at the Node B and configured to ensure fairness, maximize cell throughput, prioritize re-transmissions and use all available power for HSDPA users. No OCNS is simulated within each cell of the center Node B (i.e. Downlink loading in the center node is purely function of AMR or HSDPA traffic).

Table 4-2: HSDPA Air Interface capacity simulation scenarios

HSDPA UE Category	Receiver Type	Number of HS-PDSCH codes	Number of HS-SCCH codes	Available HSDPA Power [%]	Surrounding cell load [W]
12	Rake	5	1	10-80	5, 10
12	Rake	10	2	10-80	5, 10
6	Equalizer	5	1	10-80	5, 10
6	Equalizer	10	2	10-80	5, 10
8	Equalizer	10	1	10-80	5, 10
8	Equalizer	10	2	10-80	5, 10

⁴ PF schedulers implemented by UTRAN vendors may not necessarily assume perfect fairness (or may provide configurable parameters to control PF priority/fairness) while attempting to improve system capacity.

4.4 HSDPA data traffic modeling

Two different traffic models are considered. A full buffer model is considered to determine peak air interface data capacity and 30 uniformly distributed users are considered for this scenario. Additionally an HTTP model is considered with up to 60 users to determine lower bounds for air interface capacity utilization. In this case, the number of embedded page objects is defined by a truncated Pareto distribution and the size of embedded objects by a truncated log-normal distribution with reading times following a exponential distribution. More details of the implemented HTTP model are available in [8]. Table 4-3 summarizes the main parameters for the HTTP model used in the simulations:

Table 4-3: HTTP Model Parameters

HTTP Model Parameters	Values
Mean reading time (sec)	30
Main object size - sigma	1.37
Main object size - mu	8.35
Min Main object size (bytes)	100
Max Main object size (bytes)	2000000
Embedded object size - sigma	1.69
Embedded object size - mu	7.52
Min embedded object size (bytes)	50
Max embedded object size (bytes)	2000000
Number of embedded objects - alpha	1.1
Number of embedded objects - k	2
Number of embedded objects - m	55
HTTP mean parsing time (sec)	1.3

4.5 Relevant RLC and MAC-hs configurations

At the RLC layer, a transmit window of 4096 is considered using 336 bit RLC PDUs⁵ including 16 bit PDU headers and a 8 bit control overhead per RLC SDU. No RLC Receive window limitations are modeled.

MAC-hs is configured with 6 HARQ processes with a 12 ms RTT and a maximum number of 4 retransmissions. No MAC-hs re-ordering queue or timer mechanism is modeled.

4.6 AMR voice calls simulation assumptions

For the 12.2K AMR calls, system capacity simulations were run considering short term Eb/Nt link-level results and a BLER target of 1%. Further, a SHO factor of 1.7⁶ including soft and softer links to estimate the power utilization for R99 voice calls and estimate the remaining power left for HSDPA was considered.

⁵ Commercial UTRANs will use 656 bit RLC PDUs for Cat 8 UEs to achieve higher peak rates with limited DL RLC window size (2048 PDUs). The simulation model used for this paper does not assume any RLC window size limitations and hence using 336 bit RLC PDUs are used for Cat 8 UEs as well.

⁶ Well optimized deployed UMTS networks typically may observe a SHO reduction factor of ~1.5 depending on RF optimization and terrain. 1.7 was selected as a value used in dense-urban networks with small cell radii.

5 Air Interface Capacity and Backhaul Bandwidth Results

5.1 Air Interface capacity simulation results

5.1.1 HSDPA power allocation v/s voice capacity results (Type A Graphs)

Figure 5-1 presents the power available to HSDPA as the number of AMR users is increased. The simulation results are obtained based on the assumptions stated in Section 4. It should be observed that the number of AMR users will not increase much beyond 60, given OVFS code limitations⁷ (SHO factor of 1.7) and BLER outage requirements.

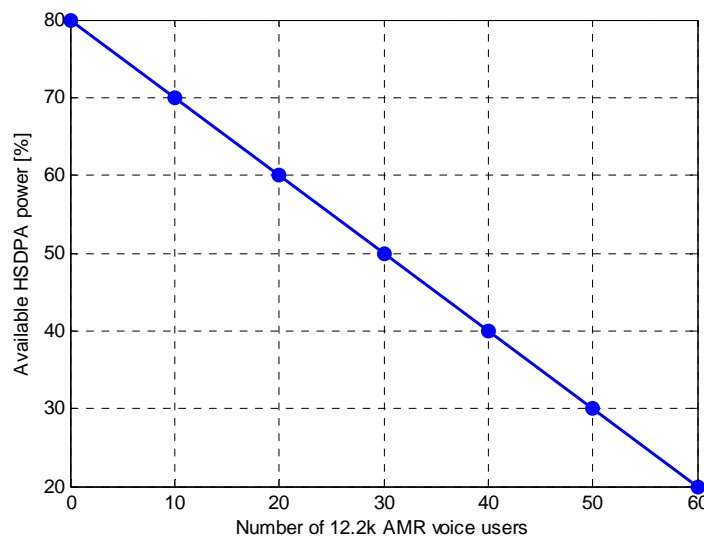


Figure 5-1: Number of AMR users vs. Available HSDPA power (Type A Graph)

5.1.2 Full-Buffer HSDPA Cell throughput results (Type B graphs)

HSDPA Cell throughput simulation results for all scenarios using full-buffer traffic model as out-lined in Table 4-2 are shown in Figure 5-2 below. While simulations have been run for even lower HSDPA power allocations (<30%) it is not expected to typically see deployed networks with much less than this average total HSDPA power to realize note-worthy cell HSDPA throughput.

5.1.2.1 Single user per TTI slot results (No CDM, UE category 12, 6 and 8)

As expected, cell throughput increases for all scenarios as the HSDPA available power increases. Comparing results for Cat 12 and Cat 6 UEs without any CDM (1 HS-SCCH), the average HSDPA cell throughput increases around 50% in favor of cells with UE Cat 6 where the surrounding cells loading level is 5W (Figure 5-2 a), but only around 30% when the surrounding cells loading level is 10W (Figure 5-2 b). Since the number of maximum supported HS-PDSCH codes is the same for both UE categories, the cell throughput

⁷ In deployed networks it is common to see DL power limits per cell for AMR calls to be reached prior to OVFS code limits owing to higher Eb/Nt requirements, terrain and RF optimization impacts

difference is due to the presence of equalizer receivers and 16QAM support in UE Cat 6. Also the difference in gain between both loading scenarios is clear given that lower average CQI reporting is expected as a function of increased inter-cell interference in the surrounding cells, which naturally affects more UEs with higher data rate capability than UEs with lower data rate capabilities. On the other hand, comparing results between Cat 6 and Cat 8 UEs; the average HSDPA cell throughput increases around 40% towards cells with Cat 8 UEs when available HSDPA power is 80% in both cases (Figure 5-2 a and b). Observe that the gain of UE Cat 8 over UE Cat 6 diminishes as the amount of HSDPA available power decreases. Note also that in this case, the additional gain comes from larger number of codes supported by the UE (up to 10 HS-PDSCH codes in Cat 8 compared to 5 in Cat 6 UEs) rather than receiver architecture since both UEs receivers consider an equalizer.

Notice that the cell throughput estimates for a Cat 8 UE might be slightly optimistic when considering available HSDPA power below 40%. This can occur, since there may be only within 8-10 HS-PDSCH SF16 OVFS codes available in these cases due to large number of AMR users (40-60). Note, however, that if field conditions are such that while supporting, for example, 40 AMR calls only ~20% power is available for HSDPA (lower than system simulation results) and 9 SF16 OVFS are available for HSDPA, the overall backhaul estimate (as explained in section 5.2.1) for Full Buffer traffic scenario may be higher than required.

5.1.2.2 CDM results for UE category 12, 6 and 8 (2HS-SCCH)

Now consider the CDM scenarios with up to 2 HS-SCCH codes and 10 HS-PDSCH codes. For Cat 12 UEs, CDM provides up to 25% cell throughput gain at 80% HSDPA power allocation (Figure 5-2 a). Further, observe from Figure 5-2 a) and b) that CDM gain decreases for lower values of available HSDPA power or higher values of Inter-cell interference. For UE Cat 12 and 5W inter-cell interference, CDM gains are only apparent for HSDPA power values larger than 40% (Figure 5-2 a). In case of Cat 6 UEs, the CDM capability brings gains in cell throughput up to 50% at 80% of HSDPA power. This can be explained based on the presence of the Equalizer receiver for Cat 6, which improves SNR requirements⁸ (by effectively reducing multi-path Inter-symbol interference) and may reduce the amount of power per code channel for a given performance or allow the UEs to request increased CQI values. As a result, the Node B scheduler can achieve significantly higher cell throughput gains with CDM for the Cat 6 UEs as compared to the Cat 12 UEs. In case of Cat 8 UEs, CDM does not seem to provide HSDPA cell throughput benefit⁹ (slight degradation seen) especially in case of 10 HS-PDSCH codes being allocated per cell on the Node B. This is an expected result since Cat 8 UEs can support up to 10 HS-PDSCH codes, reducing significantly the power and code space available to other UEs in a CDM scenario where the maximum number of available HS-PDSCH codes is 10.

The cell throughput estimates for a Cat 12/6/8 UE with CDM might be slightly optimistic when available HSDPA power below 40% due to the same reasons as mentioned in Section 5.1.2.1. In such scenarios as well if the available HSDPA power after accounting for AMR calls is lesser than system simulation results, the overall backhaul estimate (as explained in Section 5.2.1) for Full Buffer traffic scenario may be higher than required.

⁸ This is a function of the channel models selected for the simulations. Especially with PB3 (multiple strong paths) being selected, 75% of the time the equalization brings benefits for SF16 OVFS codes used (which if most apparent for HS-PDSCH)

⁹ This behavior may be a function of Node B scheduler power management and may vary slightly based on UTRAN vendor implementations and it can change if the number of HS-PDSCH is further increased

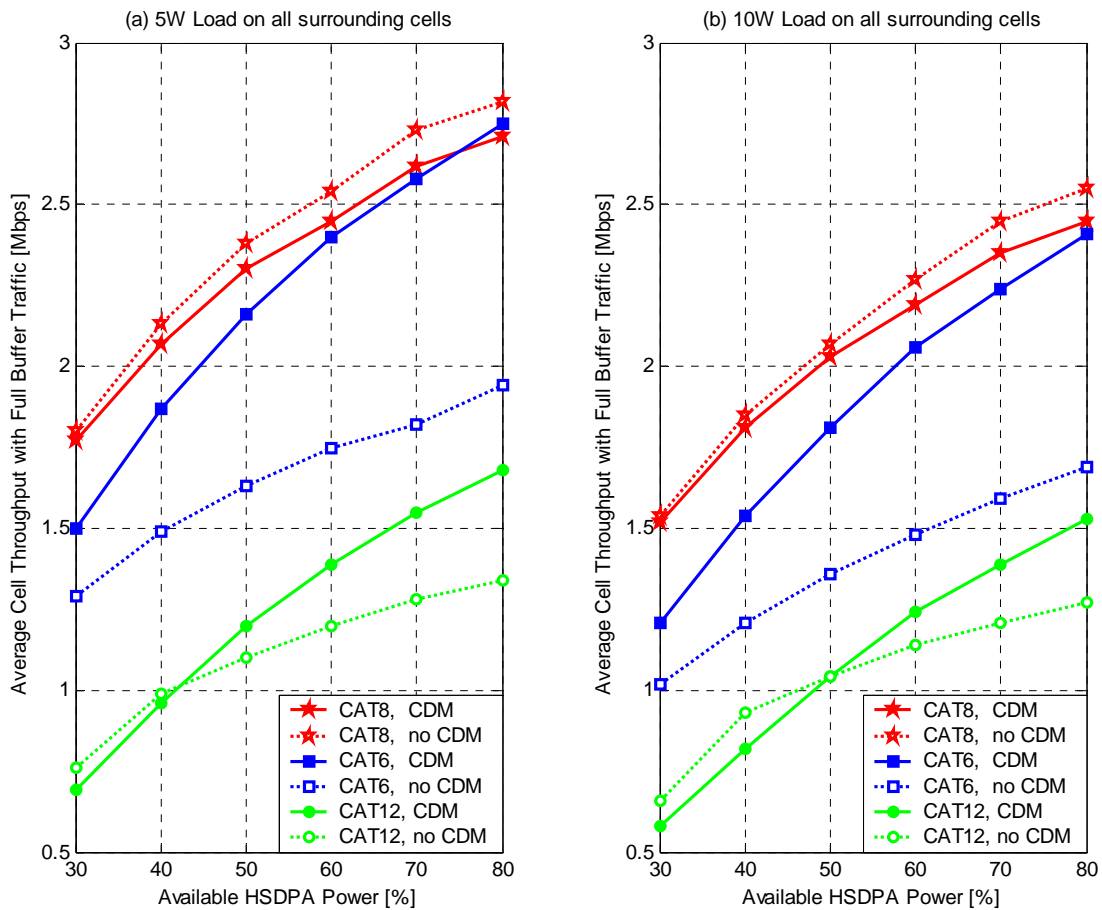


Figure 5-2: HSDPA Cell Throughput (Type B Graphs)

5.1.3 HSDPA Cell throughput with HTTP traffic (Type C Graphs)

The HTTP simulation results can be seen in Figure 5-3 for a Cat 12 UE in absence of CDM and with up to 80% HSDPA power. This suggests an almost linear increase in cell throughput with increasing number of users. The non-linearity is introduced due to slightly increasing packet delay that reduces the HSDPA cell throughput.

The cell throughput with up to 60 HTTP users (based on HTTP model assumed) is also not seen to be impacted significantly by HSDPA power allocation down to 40%. In this case, while there is an increase in delay, the corresponding drop in cell throughput is small given that the average per user HTTP throughput request rate is low.

In our backhaul bandwidth estimations, we have assumed the same HTTP cell throughput independent of UE category and CDM support on the UTRAN. This is because same average throughput values are expected for this type of traffic for the enhanced receivers in UE Categories 6 and 8.

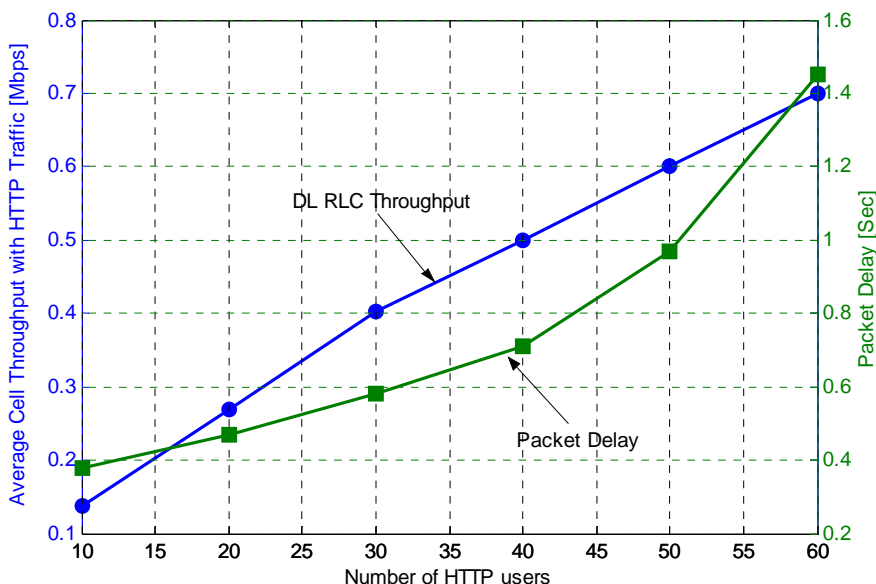


Figure 5-3: HSDPA Cell Throughput with HTTP Traffic (Type C Graph)

5.2 Backhaul Bandwidth Results

Given the flexibility of the algorithm and simulated scenarios, many different possible configurations and backhaul impacts can be analyzed. The interested reader may want to try the developed tool for many other possible configurations by its own [12]. The results presented hereafter, for brevity, are organized as follows. Section 5.2.1 presents a complete backhaul dimensioning example considering UE Category 6. Section 5.2.2 presents a comparative analysis in terms of backhaul utilization among UE Categories 12, 6 and 8.

5.2.1 Iub Dimensioning Example: UE Category 6 case

A. Full Buffer Traffic Analysis (Upper Bound)

Figure 5-4 shows the backhaul bandwidth impacts when UE Category 6 is considered with Full Buffer traffic assumption and simultaneous AMR voice traffic. Observe that in this case, Node B takes advantage of the whole left over power after attending the AMR calls to provide HS data services. The total cell throughput, as shown in the figure, includes the HSDPA user traffic, HSDPA overheads, AMR voice traffic and its associated overheads and all control plane associated overheads as described in Section 2. To obtain the total per Node B backhaul bandwidth or data rate, assuming same loading level among all cells in the Node B, it is enough to scale up the curve by the number of cells per Node B.

The full buffer traffic assumption is, with no doubt, an upper bound in terms of backhaul dimensioning. Observe, however, that even considering a full buffer traffic model, the average per-cell air interface capacity utilization is still well below the theoretic maximum possible (3.6 Mbps for UE Category 6). It is also worth noticing that even dimensioning the Iub interface based on Full Buffer average results, still it is possible having air interface throughput spikes close to the theoretical maximum in good RF conditions thanks to proper Node B data buffering and flow control, but it may result expensive if there is not enough sustained data load at the Node Bs.

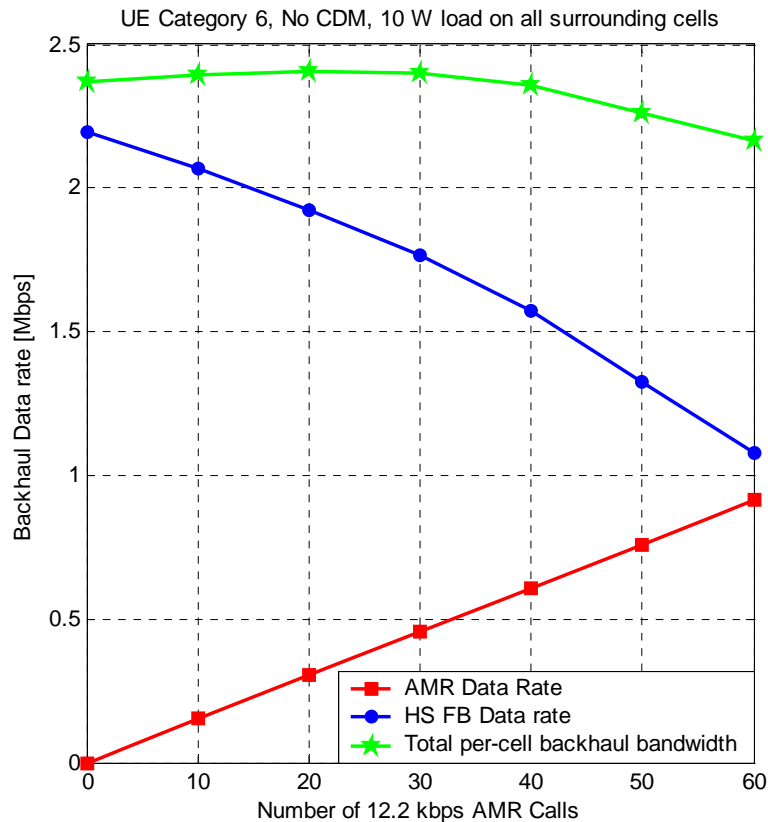


Figure 5-4: Backhaul Data Rates UE Category 6 (Full Buffer)

B. HTTP Traffic Analysis (Lower Bound)

Given that the HTTP traffic model in this paper considers a reading time of 30 seconds, HTTP traffic model is used to complement the upper bound vision of the Full Buffer approach. In effect, considering that HTTP service is not a delay sensitive traffic, an HTTP service outage could be defined entirely in terms of meeting a minimum required per-user average data rate. Using this concept, Figure 5-5 depicts an interesting scenario with 30 HSDPA Cat 6 UEs in active HTTP sessions within a cell.

Again, as in the full buffer case, the total cell throughput shown in Figure 5-5, includes the HSDPA user traffic, HSDPA overheads, AMR voice traffic and its associated overheads and all control plane associated overheads as described in Section 2. To obtain the total per Node B backhaul data rate, assuming same loading level among all cells in the Node B, it is enough to scale up the curve by the number of cells per Node B.

From Figure 5-5, it can be seen that the 30 HTTP users require an HSDPA average throughput ~500 kbps on the backhaul. Further, assuming a chosen operating point of 20 AMR simultaneous voice calls, there is a required backhaul bandwidth per cell of ~1Mbps (or ~3Mbps per Node B), but there is also around 50% of unused power. In this case, dimensioning the lub based on the AMR chosen operating point and HTTP average cell throughput may result in air capacity limitation given large amount of unused Node B power. Increasing the per-cell backhaul capacity to 1.5 Mbps the backhaul would be able to accommodate up to 50 AMR voice users with the same HTTP 500kbps data traffic allowing better Node B power resource utilization (20% unused), but still insufficient to support aggressive full buffer traffic.

Therefore, the lub dimensioning problem is a soft dimensioning problem where the network operator needs to tradeoff between saving operational costs and being able to advertise higher average peak data rates. There is no brick wall rule for that process and the proper dimensioning depends on how the network operator faces the technical advantages/disadvantages of a specific lub bandwidth decision. This decision must consider

the economical impacts in terms of cost savings (due to backhaul bandwidth reduction) and profits (coming from effective air interface capacity utilization).

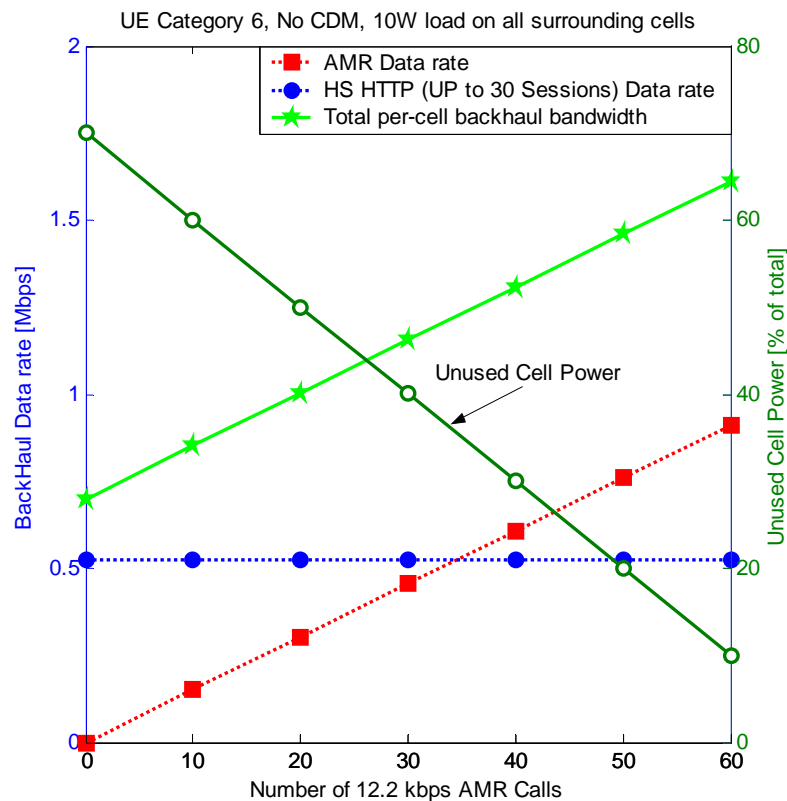


Figure 5-5: Backhaul Data Rates UE Category 6 (HTTP traffic)

5.2.2 Comparative backhaul requirements for Category 12, 6 and 12

A. Full Buffer Traffic Analysis (Upper Bound)

Based on the lub dimensioning algorithm and overheads described in Section 2, Figure 5-6 presents the backhaul utilization estimates in terms of number of T1s considering Full Buffer traffic scenario for UE categories 12, 6 and 8 as a function of different AMR voice traffic load and full remaining HSDPA power utilization. The results in Figure 5-6 are in the absence of CDM on the Node B, 5W (25%) surrounding cell loading and 3 cells Node Bs. In the case of Cat 12 UE, Cat 6, and Cat 8 UEs, the number of required T1s remains almost flat around 4, 5 and 7, respectively. Observe also that Category 8 shows larger variation as function of the number active calls voice calls in the cell.

Figure 5-7 provides details of the lub throughput generated by AMR traffic, HSDPA full-buffer traffic and total lub traffic for different HSDPA UE categories and HSDPA power allocation scenarios considered. Observe that there is compensation between the full-buffer traffic based cell throughput and AMR traffic that result in the total lub throughput remaining close to constant across most of the AMR call allocations for both the Cat 6 and Cat 12 UEs. A slight reduction in the number of T1s is seen in Figure 5-6 in case of the Cat 12 UE at highest power allocation 80% as the number of AMR calls goes to zero and the HSDPA throughput increase is not as significant.

In case of the Cat 8 UE, the number of T1s estimated increases above 7 with reduced number of AMR calls (increased HSDPA power) as there is a notable increase in HSDPA cell capacity which is much greater than the original AMR lub bandwidth utilization.

Now consider the operating point of 40 AMR calls (up to 40% HSDPA power available, see Figure 5-1) and 30 Cat 12 UEs uniformly distributed in a deployed network, each with Full

Buffer traffic model, without CDM support in the Node B, 5W surrounding cell loading and 3 cells per Node B. In this scenario, we estimate, from Figure 5-6, the upper bound lub requirement to be 4 T1s per Node B. In the next subsection, we contrast this to the lower-bound lub requirement considering HTTP traffic.

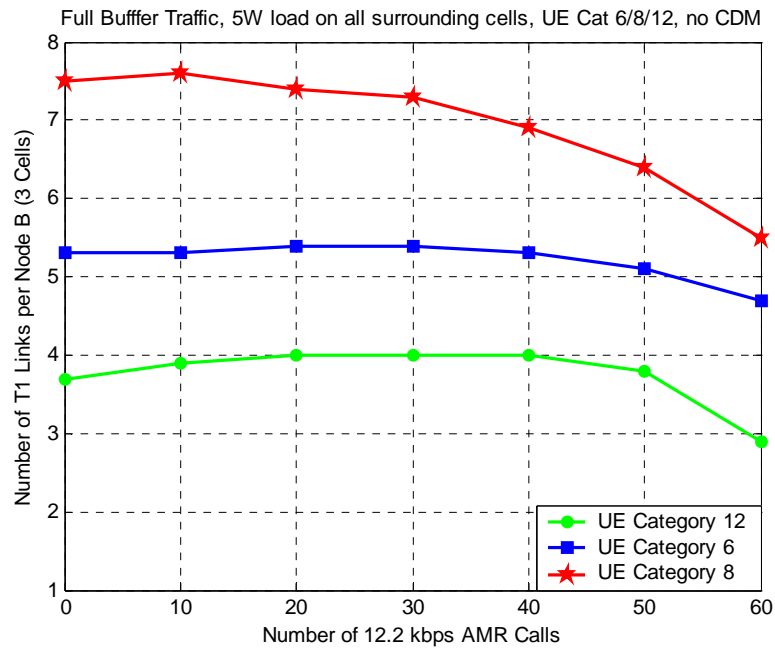


Figure 5-6: T1 Utilization with Full Buffer Traffic (UE Cat12, 6 and 8)

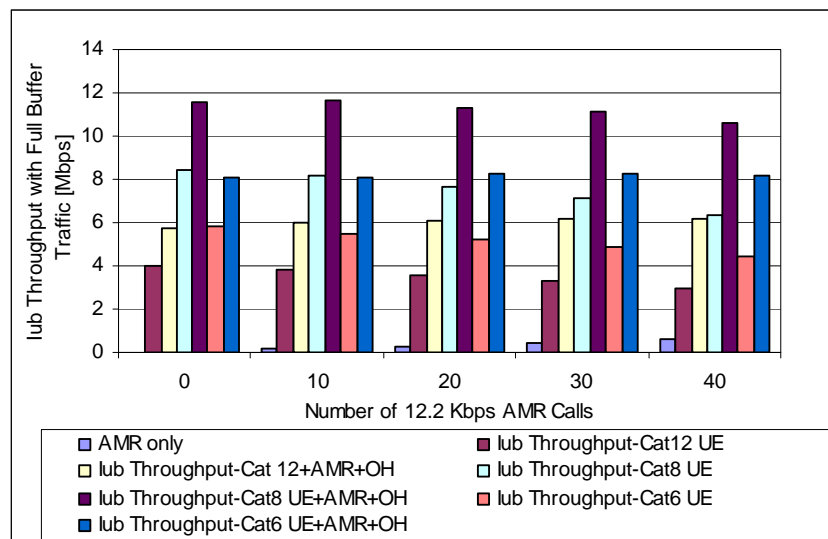


Figure 5-7: lub Throughput with Full-Buffer Traffic

B. HTTP Traffic Analysis (Lower Bound)

HTTP traffic has been considered to provide lower bound estimates of backhaul requirements. Based on the HTTP traffic model defined in Section 4.4, HTTP traffic based lub utilization estimates are provided in Figure 5-8 for 20, 40 and 60 HTTP users respectively without CDM on the Node B, 5W surrounding cell load and 3 cells per Node B. The presented results are for Cat 12 UEs though minimal differences are expected compared to Cat 6, 8 UEs. The reason for this is that delay performance improves for these UE categories, but required average HTTP throughput remains the same since it is driven by the HTTP traffic model instead. This is confirmed through Figure 5-3 where it is shown

that up to 60 HTTP active sessions require no more than 0.7 Mbps and can be attended in a sector with pure category 12 UEs. Therefore, average HSDPA cell throughput based on the HTTP model is expected to be similar for all UE categories.

Figure 5-9 provides information about the lub throughput generated by AMR traffic in comparison to the HTTP throughput generated by 20, 40 and 60 users respectively and the total lub throughput.

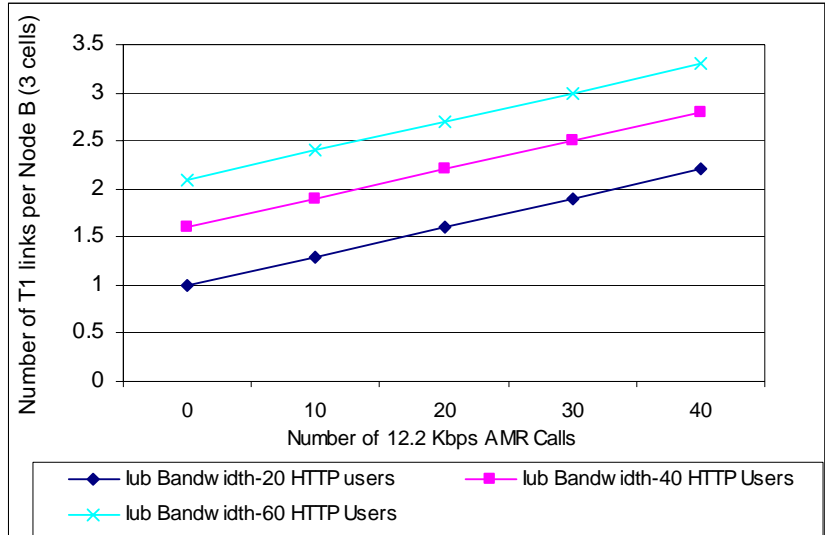


Figure 5-8: T1 Utilization with HTTP Traffic

In case of HTTP and AMR traffic mix the T1 bandwidth requirements are significantly driven by the AMR user traffic in the cell. This is apparent, since the HSDPA cell HTTP traffic throughput does not increase as the HSDPA power available increases. Further, as the number of AMR calls is reduced and the HSDPA power available increases, the lub bandwidth requirement in case of 20, 40 and 60 HTTP users reduces. For example, in case of 60 HTTP users, as the number of AMR calls are reduced from 40 to 0 (available HSDPA power increases from 40% to 80%), the T1 requirement reduces from 3.3 T1s to 2 T1s as seen in Figure 5-8.

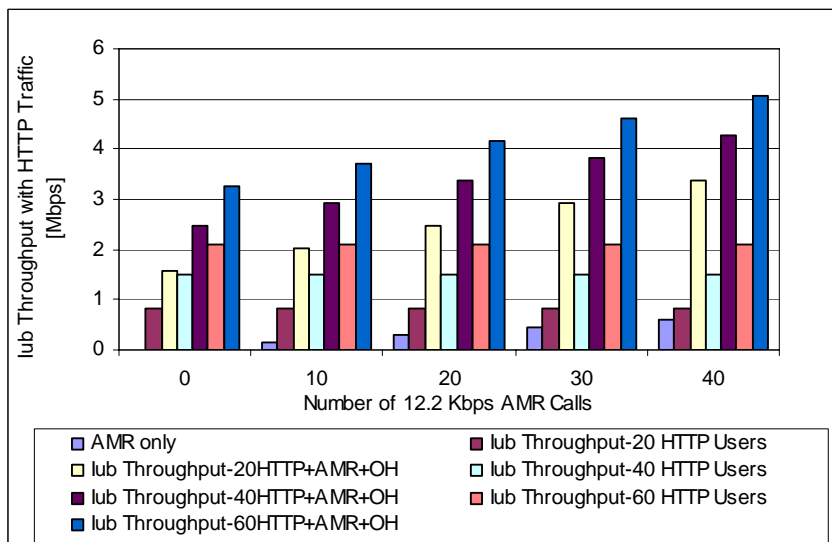


Figure 5-9: lub Throughput with HTTP Traffic

Figure 5-9 provides insight in to the lub throughput, suggesting that the lub throughput due to AMR traffic reduces as the available HSDPA power increases (AMR calls decrease). On

the other hand the lub throughput due to the HTTP traffic for 20, 40 and 60 users remains constant. As a result for all HTTP user scenarios, the overall lub throughput including AMR, HTTP traffic and overheads decreases as the available HSDPA power increases as a consequence of reducing number of AMR calls. This explains the trend for the reducing number of T1s in Figure 5-8 as the available HSDPA power increases.

Now consider the same operating point of 40 AMR calls and up to 40% HSDPA power as detailed in Section 5.2.2 (Upper-bound). In case of HTTP traffic with 20 and 60 users respectively, the T1 requirement ranges from 2.2 to 3.3 T1s which is much lower than the 4 T1 requirements for Full-buffer traffic.

This suggests that the data traffic profile of the users plays an important role in defining the lub bandwidth requirements. It can be seen that the lower and upper bounds are evidently based on HTTP or Full-buffer traffic only scenarios.

5.3 Cell Throughput Variation and its Impacts in Backhaul Bandwidth Dimensioning

The cell throughput achievable with Full Buffer traffic varies throughout the simulation time as a function of both: the number of simultaneous active users and their geographic distribution in the cell. As discussed earlier, this paper considers average cell throughput to provide backhaul bandwidth estimates considering 30 users uniformly and randomly distributed in the cell. However in Section 3.1.5 it is recognized that alternately specific percentile points could be selected from the CDFs of the observed cell throughput to determine backhaul bandwidth estimates. To illustrate this concept further, Figure 5-11 and **Error! Reference source not found.** show the average and standard deviation variation of the Full Buffer cell throughput as a function of the number of active users in the cell¹⁰. The scenario considered here corresponds to Category 6 UEs, CDM on the Node B (2 HS-SCCH), up to 80% available power for HSDPA on the serving cell and 5W surrounding cell load. The cell throughputs achieved are function of the simulation setup and assumptions as explained in Section 4.

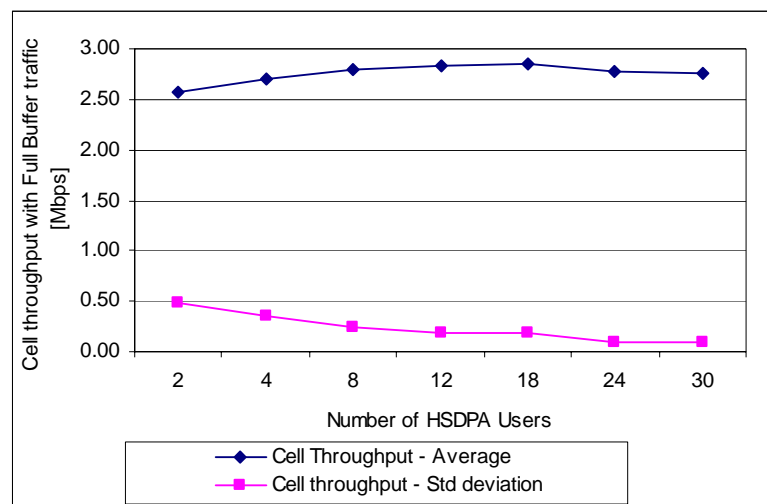


Figure 5-10 Average and Std. deviation of Cell throughput

Figure 5-11 and **Error! Reference source not found.** illustrate that the standard deviation of the estimated cell throughput decreases when the number of active users in the cell increases. This is possible due to the fact that a small number of users may end up in a high geometry scenario together resulting in the Node B PF scheduler being able to deliver a

¹⁰ Observe that the total number of samples is kept constant for all the simulation runs in this case. If the number of users is decreased, the number of drops is correspondently increased.

higher peak cell throughput as compared to a very large number of users all of whom are less likely to be in a high geometry condition together. Figure 5-11 also suggests that the standard deviation of the cell throughput is below 10% of the average value when there are 12 or more users in the cell while for 30 users this value is ~3%.

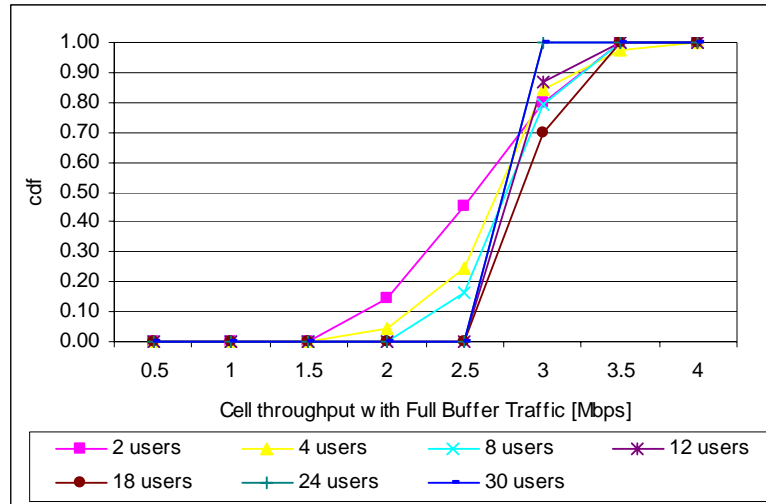


Figure 5-11 Distribution of Cell Throughput with Full Buffer Traffic

Based on the analysis above, if the backhaul dimensioning goal is to support a small number of users with a higher data rate per user (better user-experience) it is preferable to dimensioning based on higher percentiles values of the CDF (for instance 80-90%), rather than the 50 % provided by the average. On the other hand, if the backhaul dimensioning problem considers a larger number of active users (≥ 12) or 30 as considered in this paper, dimensioning the backhaul based on average cell throughputs would provide adequate estimates.

6 Summary

This paper presented a simulation-aided approach for the dimensioning of the ATM-based Iub interface. It considered the peculiarities of the radio protocols above and within the backhaul transport infrastructure to estimate Iub utilization and also provided insights on the WCDMA/HSDPA air interface capacity in different traffic scenarios and UE categories (e.g. 12, 6, 8).

Since R99 PS (Packet Switched) services are less spectrally efficient and there is a clear trend to replace such services with HS (High Speed) services in most WCDMA networks, the paper focused on the analysis on HSDPA PS (Packet Switched) data services and only considered R99 radio bearers for AMR voice calls.

By comparing various backhaul bandwidth requirements considering a mix of voice and data traffic and further considering different data traffic models (HTTP and Full-Buffer) it was clear that the per-user traffic profile and the traffic distribution among the users in the cell play an important role in defining Iub bandwidth requirements. With this regard, the paper presented Upper and Lower bounds to aid the final backhaul bandwidth decision.

In general, it has been found that the Iub dimensioning problem requires minimizing backhaul bandwidths (reducing costs) while maximizing air interface capacity utilization (increasing profit). There is no brick wall rule for that and the proper dimensioning depends on how the network operator itself faces the technical advantages/disadvantages of a specific Iub bandwidth decision in front of the economical impacts in terms of cost savings, due to backhaul capacity reduction, and profits coming from effective air interface capacity utilization. This paper focused on the technical challenge of determining proper backhaul bandwidth as a function of different air interface capacity utilization without considering the economical tradeoffs. The general idea of appropriate dimensioning is to prevent the Iub interface from being the bottleneck for the UTRAN transmission interface.

Furthermore, to aid in the Iub dimensioning process for particular scenarios a spreadsheet tool is also available on request [12].

Given the trend of IP-based backhaul deployments, a possible extension of this work will include backhaul bandwidth requirement comparisons between IP and ATM-based backhaul implementations.

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