Performance Analysis of a Live Mobile Broadband - HSDPA Network

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***Abstract*—Hutchison 3G is the first operator to launch a nationwide 3G UMTS network in the UK in 2003 to offer voice, video and data services to its customers. Hutchison 3G under the brand name of '3' launched 3GPP Rel 5 HSDPA networks worldwide. The network is capable of delivering data rates upto 14 Mbps nowadays. In Rel 7, 3GPP standardised HSPA Evolution (HSPA+) which was specified to deliver maximum user data rates upto 42 Mbps by using MIMO and 64 QAM in the Downlink. The data usage increased significantly once the High Speed Downlink Access (HSDPA) Rel 5 was deployed in the network. In order to deliver Mobile Broadband (MBB) services to its customers more efficiently, 3UK has started to focus on new features, which have been standardised by 3rd Generation Partnership Project (3GPP) in Rel 5/6/7/8 and the challenges ahead. Although HSDPA network performance was studied by other researchers, the aim of this paper is to analyse the Iub backhaul limitations with different traffic types through simulations. User traffic data was imported from the live network in Maidenhead and used in these simulations.**

I. Introduction

The High-Speed Downlink Packet Access (HSDPA) is the evolution of UMTS technology that supports high speed data (up to 21 Mbps) over 2x5 MHz bandwidth. HSDPA achieves short Round Trip Time (RTT) since some of the Radio Resource Management (RRM) functions are moved at the NodeB. The packet scheduling takes place in the NodeB rather than at the RNC in order to achieve faster RTT response upon fast link quality variations. The key technologies of HSDPA are Hybrid Automatic Repeat request (HARQ) and Adaptive Modulation and Coding (AMC). HSDPA was introduced with 12 categories (1 to 12) in Release 5. Each category supports different Transport Formats (TF), number of codes and as a result maximum user data rates. It is essential for operators to understand the performance of each HSDPA category before making large investment.

One of the important parameters to achieve high HSDPA performance is the available NodeB transmit power. HSDPA and voice traffic could be allocated to the same UMTS carrier. However, higher performance can be achieved when voice and HSDPA traffic occupy separate dedicated carriers. The scheduler in the NodeB uses an algorithm which could be optimised for higher cell or user throughput in the network [1]. Another important factor that should be taken into account during the network planning is the Iub capacity dimensioning. 3UK experienced significant variations in the cell performance with different Iub bandwidths. The simplest solution to eliminate the Iub backhaul limitation is to over dimension the Iub bandwidth. However, this approach increases the cost of operating a network significantly. Therefore, an operator has to understand the impact of Iub limitations on the cell throughput and User Experience before making significant investment.

3UK has developed a system level Monte Carlo simulator to be used in the planning and optimisation process. 3UK System Level Simulator or 3SLS was developed internally to analyse the performance of HSDPA service using input from real network measurements. The main emphasis in this paper is to evaluate the HSDPA performance using data collected from a real live network. In this paper, Maidenhead network was used to analyse the HSDPA performance, especially the Iub backhaul capacity limitations and a method was developed to dimension the Iub links using throughput distribution under different Iub backhaul configurations.

The remainder of this document is organized as follows: Section II give an overview about 3SLS. Section III highlights HSDPA throughput calculations. Section IV summarizes the simulation assumption adopted in this study and section V presents the simulation results. Finally, section VI concludes the paper.

II. 3UK System Level Simulator

3SLS which is based on NPSW (Network Planning Strategies for Wideband CDMA) is a MATLAB-based simulator for network planning and analysis [2], [3]. The simulator inputs are complete site information e.g. site location, antenna height, antenna tilt, the Iub bandwidth, User Equipment (UE) parameters, and user traffic distribution. 3SLS supports several propagation models such as Okumura-Hata, UMTS Pedestrian and Vehicular. 3UK developed 3SLS to support HSDPA with mixed data traffic i.e. web browsing, streaming and large FTP downloads. 3SLS is a dynamic simulator which supports Proportional Fair (PF) scheduling, power control, various voice and HSDPA traffic distributions. Most importantly, a flow control protocol fully compliant with 3GPP Release 5 has been added to the simulator to analyse the impact of Iub limitations on the user throughput.

III. HSDPA Throughput Calculation

The main advantage of 3SLS is the capability of estimating the average HSDPA cell and user throughput cumulative distributions in the coverage area considering the number of channelization codes, Iub capacity limitations and traffic type. These throughput distributions could be used to dimension the network. The HSDPA throughput depends on several factors including allocated HSDPA power, UE category, R99 load, and the Iub capacity limitation. The following sections will explain the impact of each factor in more detail and their implementation in the simulator.

A. HSDPA Power

HSDPA power is the remaining transmitted cell power that is not used for R99 and control channels. The R99 traffic always has higher priority than HSDPA users in terms of radio resource allocation. Thus, if the number of R99 users in a cell increases significantly, the resources i.e. download transmitted power for HSDPA channel would be limited, which may lead to a reduction in the HSDPA throughput. An iteration-based algorithm in 3SLS is developed to calculate the power required for R99 and HSDPA until a steady state is reached. The HSDPA transmitted power is then used to estimate the additional interference on R99 users caused by HSDPA channels. The NodeB would admit a HSDPA user only if total downlink power were below a threshold [3]. Hence,

$$P_{\text{tot}} \leq P_{\text{threshold}}, \tag{1}$$

$$P(\text{HSDPA}) = P_{\text{tot}} - P(\text{R99}) - P(\text{control}), \tag{2}$$

where, P_{tot} is the total transmitted NodeB power. $P(\text{R99})$ and $P(\text{control})$ are the download powers for R99 and control channels, respectively. The values for P_{tot} and $P_{\text{threshold}}$ are vendor specific.

The Signal-to-Interference and Noise Ratio (SINR) on a HSDPA channel can be calculated by [3]:

$$\text{SINR} = SF_{16} \frac{P(\text{HSDPA})}{((1-\alpha)I_{\text{own}} + I_{\text{oth}} + N_o)}, \tag{3}$$

where SF_{16} is the spreading factor, $P(\text{HSDPA})$ is the user received power, I_{own} is the ”own-cell” received interference power, which is introduced by the same cell, I_{oth} is the ”other-cell” received interference power caused by the users and common channels in the neighboring cells and N_o is the noise power. α is the orthogonality factor which depends on multi-path conditions. Equation 3 would not reflect the real HSDPA performance in terms of coverage since cell coverage depends on Primary Common Pilot Channel (P-CPICH) signal to interference ratio (E_c/I_o). So, for network dimensioning purpose, we use the following formula [1]:

$$\text{SINR} = SF_{16} \frac{P(\text{HSDPA})}{\frac{P_{\text{CPICH}}}{E_c/I_o} - \alpha P_{\text{tot}}}, \tag{4}$$

where P_{CPICH} is the P-CPICH power. E_c/I_o should be clearly defined in order to get the minimum required HSDPA throughput on the cell edge.

The SINR values in dB can be mapped to HSDPA equivalent user throughput as described in Ref [1]. They were produced using link-level simulators in various radio environments. As an example, relationship between throughput (in Mbps) and SINR for 5 parallel codes by using second-order curve fitting can be expressed as [3]:

$$TP_5 = 0.0039 \cdot \text{SINR}^2 + 0.0476 \cdot \text{SINR} + 0.1421. \tag{5}$$

3UK internally developed throughput formulas further for 10 and 15 codes using the same curve fitting technique:

$$\begin{aligned} TP_{10} \;=\;& 1.827 \times 10^{-11}\text{SINR}^8 + 1.411 \times 10^{-9}\text{SINR}^7 + \\ & 7.841 \times 10^{-9}\text{SINR}^6 - 2.885 \times 10^{-}6\text{SINR}^5 + \\ & 6.114 \times 10^{-5}\text{SINR}^4 - 8.641 \times 10^{-5}\text{SINR}^3 + \\ & 0.003417\ \text{SINR}^2 + 0.0542\ \text{SINR} + \\ & 0.1441. \end{aligned} \tag{6}$$

$$\begin{aligned} TP_{15} \;=\;& 2.437 \times 10^{-12}\text{SINR}^9 - 3.676 \times 10^{-10}\text{SINR}^8 + \\ & 2.059 \times 10^{-8}\text{SINR}^7 - 4.69 \times 10^{-7}\text{SINR}^6 + \\ & 1.095 \times 10^{-6}\text{SINR}^5 + 9.364 \times 10^{-5}\text{SINR}^4 - \\ & 0.0004675\ \text{SINR}^3 + 0.002714\ \text{SINR}^2 + \\ & 0.05982\ \text{SINR} + 0.1488. \end{aligned} \tag{7}$$

The user throughput distribution in Maidenhead is shown in Fig 1. It is important to note that the user throughput increases as the users get closer to the base station. Therefore, the cell size is an important factor in radio design to guarantee the minimum required data rate. As the cell size reduces, the Cell edge user throughput increases.

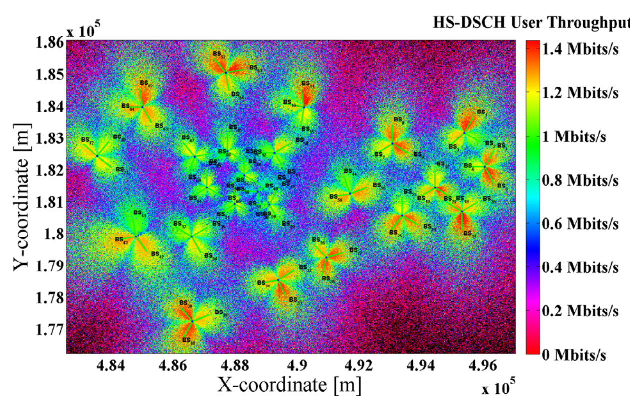

Fig. 1. Estimated HSDPA throughput per location in Maidenhead town.

B. Iub capacity

In HSDPA, the MAC packets are transmitted over Iub interface to the NodeB. The NodeB buffers these packets and according to the scheduling algorithm, it transmits the packets to users over the air interface. Each user's flow belongs to one CmCH-PI group (Common transport Channel Priority Indicator) and has its own buffer in both RNC and Node-B. In 3GPP Specifications [4], two options for the transport Bearer are defined;

1) One Transport Bearer per HS-DSCH Transport Channel.
2) One Transport Bearer for Multiple MAC-d flows for Multiple UEs.

In option 1, each HS-DSCH MAC-d flow that belongs to one priority group is carried on a separate Iub transport bearer. Option 2 is an alternative approach to allow multiple UEs to share the same transport bearers over Iub. In the second option and depending on the vendor specific requirements, the following configuration can be used;

- One transport bearer per cell, for example if Node-B has 3 cells then 3 transport bearers.
- One transport bearer per priority group (1-15 transport bearers).
- Only one transport bearer in Node-B (in this paper, the simulations are based on this option).

The actual number of credits that have been pre-allocated i.e. queue size for each priority queue in a Node-B is vendor specific. However, in [5], it is recommended that the size of the queue (q) per MAC-d flow is

$$q = d \cdot B_{\text{max}}, \tag{8}$$

where, B_{max} is the maximum number of bits which can be scheduled for a UE over the air interface according to its SINR. d is an integer number and calculated depending on the latency over the Iub interface [6], which can be calculated according to:

$$d = \frac{Iub_{\text{(delay)}}}{\text{TTI}}, \tag{9}$$

where $Iub_{\text{(delay)}}$ is the packet delay over the Iub interface. According to the Eq. (9) there will be enough credits in the buffer while the MAC-d is still being transferred over Iub interface. Two factors should be taken into the account to decide the buffer size, the latency over Iub interface and the probability of mobility events in the target area. As a result, the latency limits the minimum buffer size and the mobility limits the maximum size. In this analysis 3UK simulated the performance of HSDPA under multiple E1 links. Each E1 link corresponds to 2 Mbps Iub capacity.

IV. Simulation Assumptions

Live data was used in 3SLS to analyse the HSDPA performance of 3UK network in Maidenhead. 3UK's HSDPA network in Maidenhead town consists of 24 NodeBs each having 3 sectors, as it is shown in Figure 1. The simulations were based on Monte Carlo method, which consists of multiple iterations each lasting 5 minutes. In each iteration, HSDPA and R99 users were uniformly distributed independently across each cell coverage area. The user traffic for each cell was obtained from the live network in Maidenhead. The CPICH coverage for each cell was estimated using Hata model. Hence, the best server for each user was the cell with the highest CPICH level at the user location. All users were considered to be in-door with 8 dB penetration loss. The channel was assumed to be constant in each TTI. Other simulation parameters are summarized in Table I.

TABLE I
Simulation Parameters

Parameter	Value
Total NodB transmitted power	43 dBm
HSDPA power threshold	41.7 dBm
CPICH power	33 dBm
Carrier frequency	2100 MHz
System bandwidth	5 MHz
Path loss model	$127 + 30\log_{10}(R/1000)$
Shadowing	Log-normal with 8 standard deviation
Channel model	PedB (with 6 taps)
Antenna tilt	according to site information
Antenna height	according to site information
Iub delay	15ms
TTI	2ms
Scheduling	Proportional Fair
MAC-d size	160 bits

V. Simulation Results

A. Cell and User Throughput Comparison

The simulator was used to evaluate the cell and user throughput distributions in Maidenhead as the number of users increase in the network. The results have been obtained in good radio channel conditions using a PF scheduler with different Iub bandwidths. In the simulations, it was assumed that all active users were receiving data continuously. As shown in Figure 2, increasing the number of active users reduces the average throughput for each user as expected. However, regardless of the number of users, the cell throughput is approximately same. It is due to the effective utilization of the scheduler and large Iub bandwidth.

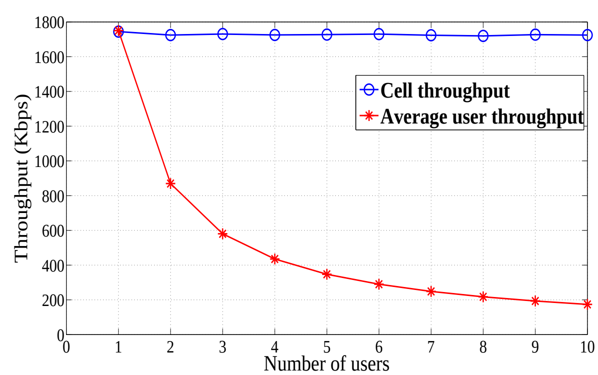

Fig. 2. Cell and HS user throughput with no backhaul limitations.

B. The performance of different UE categories

The simulation results also showed that higher UE categories supporting higher number of codes can achieve higher user throughput. As shown in Figure 3, the HSDPA performance with 10 and 15 codes have similar performances at low SINR values [1].

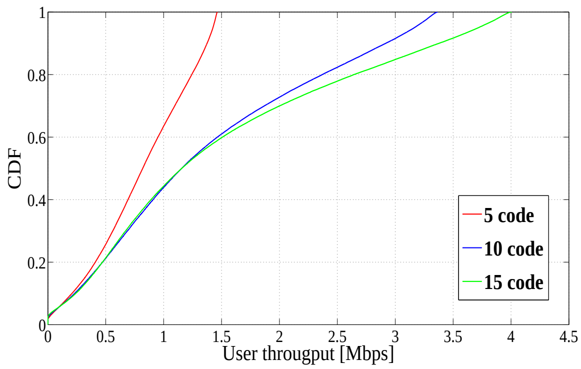

Fig. 3. Cumulative distribution of user throughput distribution in Maidenhead.

Hence, use of 15 codes does not offer a benefit in the network if the SINR values in the network are lower than 14 dB. Therefore, the network should be designed to deliver higher SINR to make full use of 15 codes. The SINR depends on many factors, orthogonality, cell radius and UE receiver sensitivity. One way to increase orthogonality is to reduce the effect of the multi-path on the handset by deploying equilisers. Figure 4 shows that a significant improvement in the HSPDA cell throughput can be achieved with increased orthogonality factor.

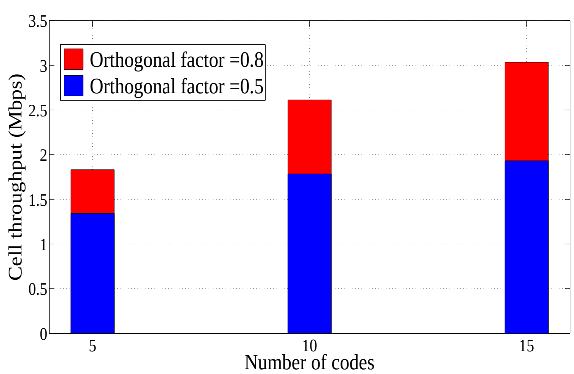

Fig. 4. Average cell throughput with 5, 10 and 15 Codes as a function of orthogonality .

C. The impact of Iub Capacity on HSDPA user Throughput

If Iub resources are limited, the user throughput reduces significantly as shown in Figure 5. In this scenario, the backhaul capacity was first limited to 1×E1 link i.e. 2 Mbps, then increased to 2×E1 i.e. 4 Mbps link under a full buffer scenario i.e. large file downloads. As a result the HSDPA user throughput distribution in the area was severely limited with the number of E1 links. Throughput for 50 % of users in the sample area almost doubled from 250 Kbps to 450 Kbps as the backhaul links increased from 1×E1 to 2×E1. The user throughput distributions for different Iub configurations could be used to dimension Iub links.

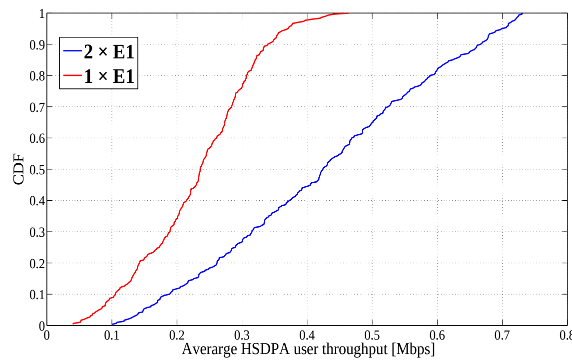

Fig. 5. CDF of the average user throughput.

D. Optimum Iub Capacity

Increasing the number of backhaul capacity does not always result in the same level of increase in cell throughput. As shown in Figure 6, the averaged site (three cells) throughput increase in a 5 HSDPA code cell is very small with increased backhaul. This is due to the limitation at the air interface. However, the site throughput increases significantly as the number of E1 links increases in a 15 code since the air interface capacity is much higher with 15 codes. The actual Iub bandwidth depends on several factors i.e. the radio interface capacity, the number of codes per cell, the traffic types, the allocated HSDPA power per cell and the R99 voice traffic volume.

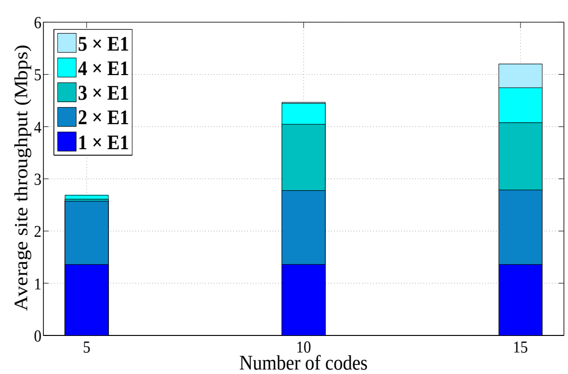

Fig. 6. Site throughput as a function of backhaul capacity.

E. Bursty Traffic Mix

It is important to consider the characteristics of traffic bursts and the user behavior. The Iub capacity limitation becomes more apparent if the streaming and large file downloads increase in the network. The user throughput and the cell performance also vary significantly between the traffic types i.e. large file download and bursty traffic mix. In order to demonstrate the user behavior, a FTP browsing session is illustrated in Figure 7. The session consists of sequence of smaller packets followed by random time duration called Reading Time. During the reading time, the user will be inactive and the scheduler will allocate the resources to the other data users, and hence the performance of the other active users will increase [7].

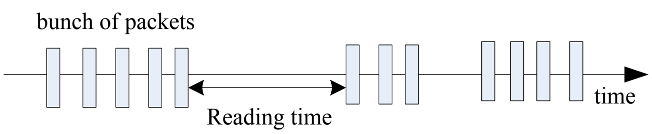

Fig. 7. An example for bursty traffic model.

In order to simulate real user for web browsing, a traffic generator is embedded in the simulator. The simulator uses the traffic model shown in Figure 7 for 10 simultaneous active users. It randomly generates data sessions with different volume. The reading time is set according to the traffic modeling associated with an application as specified in 3GPP [8]. In this analysis, the traffic types were distributed so that the 70% of the traffic were web browsing and 30% were downloading large files using FTP. The traffic model parameters used to evaluate performance of HSDPA with the mix traffic are listed in Table II [8]. In the simulation, the average user throughput was calculated when they were in active mode excluding the reading time. As shown in Figure 8, the Iub capacity limitation with 'mixed traffic' case using 1×E1 Iub link is not as severe as 'full buffer' case because of the user behavior i.e. user activity as described above. the simulation results show that the average user throughput with mixed traffic and 1×E1 Iub link is 220 kbps per user. If all 10 users were using a large file download simultaneously i.e. full NodeB load, the average throughput for each user would be significantly lower to 90 kbps per user as shown the Figure 8. Additionally, increasing the capacity of Iub to 2×E1 will not improve the averaged user throughput significantly i.e. 260 Kbps since some of the users are in the reading state.

VI. Conclusion

The aim of this study was to investigate the performance of 3 UK's HSDPA network as the Mobile Broadband traffic significantly increases in the network and discuss a method to dimension Iub links. Increased traffic results in capacity limitations and lower user throughput. One of the most critical capacity limitations occurs at the Iub. 3 UK has developed an HSDPA System level Simulator, 3SLS to analyse the impact of Iub backhaul capacity under different traffic types. The Maidenhead HSDPA network was used as an example to analyse the HSDPA performance using the simulator. Live traffic data was collected from the data as an input to the simulator.

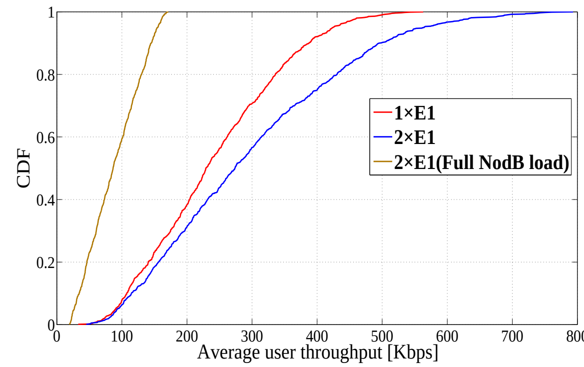

Fig. 8. CDF of the average user throughput with backhaul limitation.

TABLE II
TRAFFIC MODEL

Web service	
Page size	Lognormal Distribution μ =8.37 σ =1.37
Reading time	Exponential Distribution Mean=30 seconds
Max page size	1858 byts
FTP service	
File size	Lognormal Distribution μ =14.45 σ = 0.35
Reading time	Exponential Distribution Mean=180 seconds
Max file size	100 Mbyts

The simulator estimates the user throughput distribution in a specified area with different Iub backhaul configurations. The throughput distribution was then used to dimension the Iub links.

Acknowledgment

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