Impact of the HSPDA-Based Mobile Broadband Access on the Investment of the 3G Access Network

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Abstract. There are several technologies for providing broadband services over wireless and cellular networks. The fundamental one in the evolution from 3G to 4G is probably the High Speed Downlink Packet Access (HSPA) technology. There are many works in the literature tackling the problem of HSPA performance and capacity. Most of the developed techniques involving HSPA capacity are related to the system operation. This approach is specially useful when the network planner tries to evaluate how the system works, however, it is not the case when the mobile network operator is doing the business plan and whise to evaluate the return of investment. This paper provides a simple and novel methodology for estimating the additional investment required to provide High Speed Down-link Packet Access (HSDPA) in a 3G mobile network given a user service profile. This method is useful for techno-economic studies for mobile operators, consulting firms and national regulatory agencies.

Keywords: HSPA, Dimensioning, Service Profile, Regulatory Studies.

1 Introduction

In the evolution from 3G to 4G, High Speed Packet Access (HSPA) (and its evolved version, HSPA+) technologies have become a milestone due to they allow the provision of high binary rate data services to mobile users [1]. Furthermore, they have produced a collateral effect that will become an important market opportunity for mobile network operators: the convergence, and even sometimes substitution, of the fixed broadband access (typically based on xDSL or HFC) by the mobile broadband access based on HSPA and HSPA+ [2].

Network design based on HSPA and HSPA+ technologies has been deeply studied in the literature. However most of the works are oriented to the study of the performance of HSPA and HSPA+ in the daily operation of the network. Furthermore, most of these studies are based on simulations of a particular environment [3,4]. To our knowledge, there are not any previous work related with the study of the network investment required to provide HSPDA based services on a wide area.

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In this paper we explain a simple methodology to estimate the number of Nodes B required to provide mobile broadband access in a specific area under a multi-service user profile. This method is applied to a nationwide scenario, to obtain an estimation of the network investment required by a mobile network operator to provide this service. This kind of strategic studies are a powerful tool for mobile network operators when analyzing the profitability of new services.

The rest of the paper will be structured as follows: Section 2 provides a summary description of the HSPA technology. In Section 3 we will describe the methodology that we apply to calculate the HSPA Node B cell range and hence to estimate the number of Nodes B required for providing coverage to an specific area. Section 4 provides the study at a nationwide level. Finally we show some conclusions on the study carried out and some lines of future work.

2 HSDPA Technology Background

HSDPA is a 3G mobile access technic specified firstly in the Release 5 of the 3GPP [5]. The main difference with the physical layer of the normal Wide-Band Code Multiple Access (WCDMA) is a new downlink (DL) time shared channel: the High Speed Physical Downlink Shared Channel (HS-PDSCH). This channel supports 2 miliseconds Time Transmission Intervals (TTI) where the user can request resources, with adaptive modulation and coding and fast physical layer ARQ. In the HSDPA architecture, the Node B is the responsible of link adaptation and packet scheduling. It has updated online information about the radio environment and the resources requests, and hence it allocates resources and flows according the service priority (by means of packet scheduling) and the best modulation and coding for the TTI due to the radio environment.

For the HSDPA dimensioning the following concepts have to be defined, see [6]:

- **Sub-frame duration:** The Transmission Time Interval-TTI (sub-frame) duration is 2 ms, thus a 10 ms WCDMA frame contains 5 HSDPA sub-frames.
- **Inter-TTI:** refers to the number of TTI between transmissions to the same user equipment (UE). All UEs must support a minimum Inter-TTI of 3 (i.e.: UE must be capable of receiving DL transmission every 3 sub-frames).
- **Modulation and Coding:** each sub-frame may carry data bits modulated with QPSK or 16 QAM levels. The fixed turbo coding rate of 1/3 is always used over both modulation levels.
- **Spreading factor:** is fixed (SF=16). Thus 16 channelization Orthogonal Variable Spreading Factor (OVSF) codes are available under each cell (each cell is identified with a 38400 chips Scrambling Code). Out of 16 codes, one is assigned for HS-SCCH transmission that carries the control data of its corresponding HS-PDSCH. Thus 15 channelization codes are available for data transmission.
- **Multi-code Transmission:** In one TTI, Multiple channel codes can be assigned to one UE in parallel. All UEs must support a maximum transmission of at least 5 parallel channels.

- **Scheduling Mechanism:** There are many of them: Round Robin, Max-Min Fair Throughput, Channel Quality based. In this study we will user Round Robin as the best simple approximation to the problem.

Depending on the type of user terminal, the resources required, the modulation and coding used and the link level parameters, the packet scheduler in the Node B will allocate resources to each user in the HSDPA Node B coverage area, as it is shown in Figure 1.

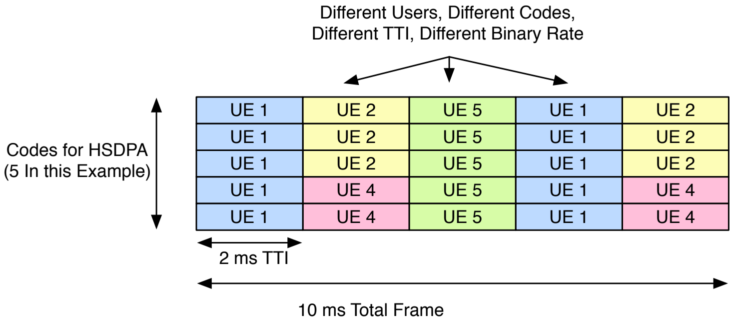

Fig. 1. Allocation of resources in the HSDPA frame to users

Note that depending on the link level parameters, including the Signal to Interference Noise Ratio (SINR) the Node B and the user terminal will agree a specific modulation and coding following Table 1.

Categories 13 and 14 of the table corresponds to HSDPA+. There are some more HSDPA categories but they use multiple input/multiple output (MIMO) techniques that are out of the scope of this work. A relevant parameter in Table 1 is the Channel Quality Indicator (CQI). It is a measure of the mobile channel which is sent regularly from the UE to the Node B. These measurements are used to adapt modulation and coding for the corresponding UE and it can be also used for the scheduling algorithms. It can take one of 30 values, depending on the Transport Block Size and the Modulation and Coding Scheme. Typical values are 15 for QPSK and 30 for 16QAM. This parameter is used for calculating the SINR based on Equation (1).

$$SINR\ (dB) = (CQI \cdot 1.02) - 16.62 \tag{1}$$

The parameter $SINR$ is used to calculate the UE receiver sensibility that is involved in the calculation of the cell range by propagation. This cell range by propagation is used as a starting point to obtain the total throughput required by the HSDPA users in the area under study.

Table 1. HSDPA Modulation and Coding Categories

Category HS-DSCH	Modulation	Number of codes	Inter-TTI	CQI	Speed (Mbps)
Category 1	QPSK	5	3	15	0.553
Category 1	16-QAM	5	3	30	1.194
Category 2	QPSK	5	3	15	0.553
Category 2	16-QAM	5	3	30	1.194
Category 3	QPSK	5	2	15	0.829
Category 3	16-QAM	5	2	30	1.792
Category 4	QPSK	5	2	15	0.892
Category 4	16-QAM	5	2	30	1.792
Category 5	QPSK	5	1	15	1.659
Category 5	16-QAM	5	1	30	3.584
Category 6	QPSK	5	1	15	1.659
Category 6	16-QAM	5	1	30	3.584
Category 7	QPSK	5	1	15	1.659
Category 7	16-QAM	10	1	30	7.205
Category 8	QPSK	5	1	15	1.659
Category 8	16-QAM	10	1	30	7.205
Category 9	QPSK	5	1	15	1.659
Category 9	16-QAM	12	1	30	8.619
Category 10	QPSK	15	1	15	1.659
Category 10	16-QAM	15	1	30	12.779
Category 11	QPSK	5	2	15	0.829
Category 12	QPSK	5	1	15	1.659
Category 13	QPSK	5	1	15	1.664
Category 13	16-QAM	10	1	25	7.212
Category 13	64-QAM	14	1	30	16.132
Category 14	QPSK	5	1	15	1.664
Category 14	16-QAM	10	1	25	7.212
Category 14	64-QAM	15	1	30	19.288

3 Model for HSDPA Cell Range Estimation

This section introduces a novel estimation method for calculating the area covered by a 3G Node B with HSDPA functionalities. This method does not provide exact calculations about the performance of the Node B, but only a simple method to estimate the network investment to be done. For better understanding of the model it is required to introduce before the user service briefcase we consider for the study.

We define a set of services, S resulting from different reports of the UMTS Forum [7]. All these services are based on the set of 34 parameters that we have defined in our simulation tool. The most relevant for our work are described below.

- Service name / Service identifier
- Binary Rate, Rb_i
- Service penetration (Percentage of customers using the service).
- Individual traffic per user in the business hour, a_i
- Percentage of traffic running direcly over HSDPA (only for data services) DR_i.

Last parameter applies only for 3G native data services. In the case of *mobile broadband service*, that is a pure native HSDPA service, this parameter does not apply.

The objective of the algorithm is to find a value of the 3G-HSDPA Node B cell range that makes the Node B resources be enough to fulfil the capacity resources demanded by the users in the area under study.

Calculations are done in terms of bandwidth per user that it is obtained following Equation (3):

$$Throughput = MB_{guaranteed} + \sum_{i=1}^{S} a_i \cdot DR_i \cdot Rb_i \tag{2}$$

where:

- Throughput: is the demanded binary rate per user
- $MB_{guaranteed}$ is the minimum binary rate of the mobile broadband service that is guaranteed to the customers in the area under study.

From the desired bandwidth calculated in Equation (3) the category that best fits the user's necessities can be obtained from table 1. The SINR can be calculated by knowing the category and the CQI, following Equation (1).

The next step is to obtain the cell radius by propagation, in order to evaluate the number of potential users in the cell area under study, and therefore, the bandwidth demanded by all the potential users of this cell. To do this we consider the Okumura-Hata propagation model described in [8].

Then the maximum bandwidth offered by the cell is calculated, using the maximum number of codes, fifteen for traffic, and the corresponding category inter-TTI. Both bandwidths, demanded and offered, are compared and the calculated radio is iteratively reduced until the required condition is satisfied. Once that the bandwidth offered by the cell is higher than the bandwidth demanded by the users in this area, the final cell radius is obtained. This iterative process is shown in Figure 2.

4 Experiments and Results

In this section we apply the algorithm described in previous section to a nationwide scenario in Spain. This scenario is composed of 5400 entries, named districts, that are composed of one or several cities, towns and villages, representing 100 % of the Spanish population and terrain. Each district is divided into urban, suburban and rural area, depending on the topography and demography of each area.

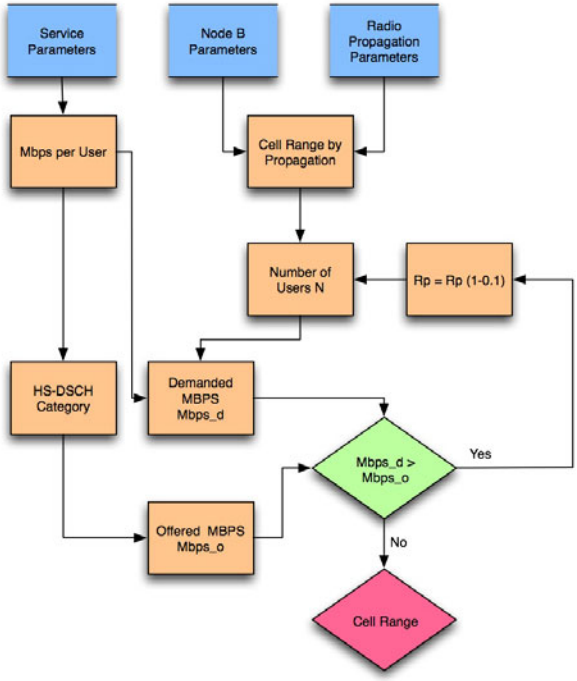

Fig. 2. Scheme of the HSDPA cell range estimation model

The model explained in previous section is implemented in the tool presented in [9]. This tool implements the algorithms for dimensioning 2G and 3G networks. It considers several types of Node B for the dimensioning: macro, micro and pico Node B with 1, 2 and 3 sectors, with different costs. This allows the tool with a large flexibility in order to optimize the estimation of the network investment.

In this study we consider a hypothetical operator with 20% of Martket Share, working with a single 5 MHz spectrum block in the 900 MHz frequency. We have selected this band because, although the native 3G band is in 2.1 GHz, the European countries are involved in a frequency rearranging process. We compare the investment cost of deploying a pure multi-service 3G access network in each area (urban/sub-urban/rural) with the cost related to introduce a mobile broadband service, based on HSDPA, considering different guaranteed binary rates, different market penetrations, and also the different areas of the districts. The service briefcase for the study is shown in Table 2.

Note that we have not fixed the service penetration and the binary rate for the mobile broadband service because they are two parameters that we will vary in our study. For the experiments we have defined the following scenarios, see Table 3.

Note that in *Scen-1*, HSPDA is not provided, and therefore Scen-1 may serve as a reference value to calculate the increment in the investment due to HSPDA

Table 2. User service briefcase for the study

Service	Rb_i Kbps	a_imErlangs	Service Penetration (SP) %	DR_i %
Voice	12.2	6.22	100	0
RTS	64	0.21	100	50
Streaming	64	0.31	100	80
Guaranteed Data	144	0.62	100	80
Best Effort	144	0.13	100	80
SMS	64	0.25	100	20
MMS	64	0.25	100	20
Mobile Broadband	–	95.86	–	100

Table 3. Scenarios for the Experiments

Scenario	Urban	Suburban	Rural	MB Market %	MB *Rb* Kbps
Scen-1	UMTS	UMTS	UMTS	0	0
Scen-2	UMTS/HSPDA	UMTS	UMTS	1	400
Scen-3	UMTS/HSPDA	UMTS / HSPDA	UMTS	1	400
Scen-4	UMTS/HSPDA	UMTS	UMTS	10	400
Scen-5	UMTS/HSPDA	UMTS / HSPDA	UMTS	10	400
Scen-6	UMTS/HSPDA	UMTS	UMTS	1	1000
Scen-7	UMTS/HSPDA	UMTS / HSPDA	UMTS	1	1000
Scen-8	UMTS/HSPDA	UMTS	UMTS	10	1000
Scen-9	UMTS/HSPDA	UMTS / HSPDA	UMTS	10	1000

in the rest of scenarios. Table 4 shows the results of the runs of the different scenarios in terms of:

- Absolute investment in the radio access network, *Ac*.
- Investment increment over a pure 3G access network, *Inc*.
- Relative increment over a pure 3G access network, *Rinc*.
- Relative cost per Kbps for the HSDPA Service, *Rc*. This parameter is defined as $(Inc/NC) \cdot TU$, where NC stands for the number of customers and TU stands for the throughput per user.

The experiments offer the following interesting results.

- There are very important investment increments when the target population goes from 1% to 10 % so, the investment depends critically on the traffic, more that in propagation
- If the mobile operator want to offer HSPDA services to a relevant part of the population, 10 %, the additional cost over a pure 3G network will be between 13 to 26 %.
- There are only slight differences (less thant 4 %) in terms of investment between offering a guaranteed service of 400 Kbps or 1000 Kbps.

Table 4. Results of the experiments

Scenario	Ac M€	IncM€	$Rinc$%	Rc
Scen-1 3669	0	0	0	
Scen-2 3673	46.3	0.13	0.03	
Scen-3 3721	52.1	1.42	0.32	
Scen-4 4149	48.1	13.1	0.3	
Scen-5 4512	84.3	22.9	0.52	
Scen-6 3707	38	1.04	0.09	
Scen-7 3827	15.8	4.31	0.39	
Scen-8 4232	56.3	15.35	0.14	
Scen-9 4653	98.4	26.82	0.24	

- The combination of a high market penetration with a high guaranteed binary rate service will lead to low cost per Kbps, due to the economies of scale
- The decision of having HSDPA on suburban and rural areas is very important, it is required a high market penetration to justify the investment. Otherwise the cost per Kbps will almost double.

5 Conclusions and Future Work

This paper provides a novel method for the estimation of the investment required to provide HSDPA service in a 3G access network. This method, based on a iterative algorithm, provides the network planner with a flexible and powerful tool to make regulatory or economic studies. Note that most of the work related with the calculation of the HSDPA range are based on simulation and therefore they are not valid for the application to a nationwide study.

This method has been applied to a particular study in Spain. We have shown, in different scenarios, the increment of the investment over a pure native 3G network. The conclusion is that to guarantee the HSDPA mobile broadband service for all users nationwide a very important investment in new 3GHSPA Node Bs is required.

The algorithm presented in this paper is a first version of a most depurated one that we are working on. The new version will consider different simultaneous modulation and coding schemes and variable user density. Another improvements are the design of a High Speed Uplink Packet Access (HSUPA) and the extension to more HSPA+ categories.

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