Omnitele on HSPA Evolution:

The Bitrate Limits of HSPA+ Enhanced Uplink

Introduction

In 2009 mobile broadband is living its success story and demand for higher data rates is growing constantly. More advanced HSPA technologies have been released recently by manufacturers, and many operators have multiplied their offered downlink peak rates. In the uplink however, there has not been as much buzz around the new technologies lately. This is somewhat natural as traditional mobile traffic is highly asymmetric and weighted towards downlink. Downlink data rates are therefore the quantity most users and operator marketing departments are interested in. However, the uplink should not be forgotten as it can have big impact on the performance of both today's and future mobile services. User perceived performance of services such as web-browsing also depends on delays of request messages in uplink direction, and the delays are mandated by achievable uplink user data rates and latencies. Also overall uplink system capacity becomes an issue as mobile broadband usage increases significantly. Additionally, as traffic-symmetric services such as file sharing, social media and user generated content are becoming more popular, it can be foreseen that the uplink data rate becomes more relevant KPI in the future.

3GPP new releases promise high peak rates with Enhanced Uplink (EUL). There are however some major radio resource limitations for data rates, unique to the uplink direction. In this paper we present an analysis of the limitations of uplink data rates in current and future WCDMA networks.

WCDMA Enhanced Uplink

3GPP Release 5 defined HSDPA introducing increased bitrates in WCDMA downlink. Release 6 continued the path by defining Enhanced Uplink (EUL) improving uplink bitrates and latency. Together the technologies are often referred as *HSPA – High Speed Packet Access*. The next evolution step is Release 7 defining several new features and higher bitrates to HSPA which is then noted as *HSPA+* or *HSPA Evolution*.

The EUL enhances data rates by means of Fast NodeB scheduling, L1 Hybrid ARQ, Shorter Transmission Time Interval (TTI) and Multicode transmission. Many of the features are directly adopted from HSDPA. The idea of EUL is to make the network intelligence, resource allocation and decision making faster. This requires many of RNC's functionalities to be embedded inside the NodeBs. Multicode transmission introduces increased dynamics to the system, so that the 384kbit/s is no more the maximum single user channel bit rate. Figure 1 summarises the key features of EUL and their contribution to the system's performance.

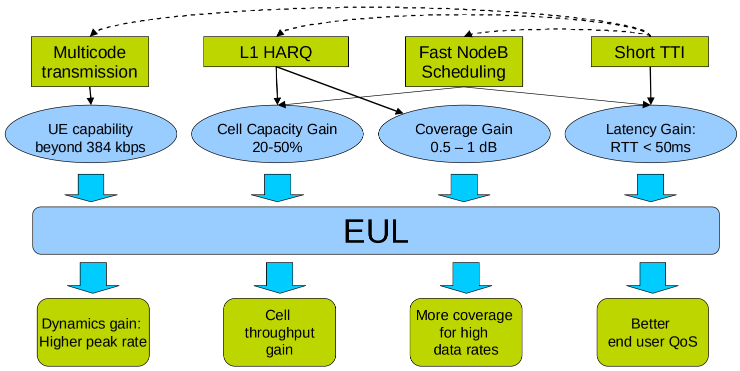

Figure 1: EUL Features

The typical understanding is that Release 6 HSPA uplink provides data rates of 5.7 Mbit/s, Release 7 doubling it with 16QAM to 11.5 Mbit/s. However, the terminal and network side feature limitations and capabilities in many practical networks currently (Jan10) limit the bitrates to 1.4 Mbit/s, which can be considered the current *de facto* EUL. EUL features and version differences are well described in [1]. Detailed properties are omitted here; instead we next focus on the limiting factors of uplink bitrates.

Uplink Resources and Limits

Generally WCDMA uplink user bitrate restrictions can be divided into three categories. Regardless of network software release, terminal category or network vendor the WCDMA uplink bitrates are limited by following attributes:

– **Path loss:** UE transmit power resources are not enough to overcome poor radio conditions although NodeB would allow higher transmit power.

– **Dynamics:** UE has enough transmit power for a high data rate and NodeB allows using it, but UE or NW capabilities restrict the bitrate. For instance R99 UE can not send more than 384 kbit/s no matter what features is supported by NW.

– **Noise rise:** Noise rise (RoT – Rise over Thermal) is the relation of received uplink power to thermal noise level. Operator defined noise rise limit prevents NodeB to allocate high transmit power i.e. high Ec/N0 which further converts to high data rate, to a user.

According to Omnitele investigations, the most significant of the limitations, and also the most obscure to wider audiences, is noise rise.

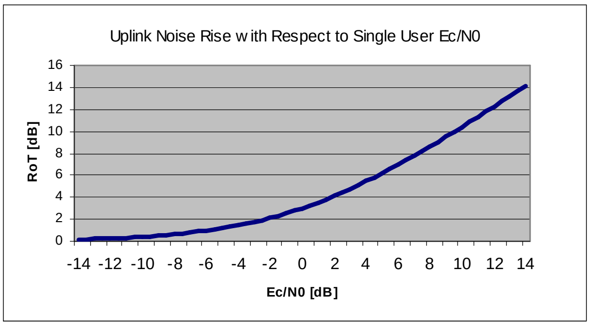

Figure 2: Relation of single user Ec/N0 and noise rise

In HSPA downlink the *shared resource* is NodeB transmit power, which can be allocated to a single user at a time on per TTI basis. In uplink the same is not possible as users have their own transmitters and the system's uplink transmit power is distributed throughout the network. In uplink users transmit simultaneously and fast power control is applied to ensure that different users' signals are received with equal powers in the NodeB. This prevents the so called *near-far-problem* in non-orthogonal WCDMA uplink. If there are too many users in the cell, the RoT increases too much preventing users at cell edge to use the system. Users in poor radio conditions simply do not have enough transmit power to overcome high RoT and they are out of uplink coverage. This RoT relation to coverage effect is known as *cell breathing.* To prevent too aggressive cell breathing, live networks are configured to apply load control if RoT increases too much. As higher bitrates require higher Ec/N0 values, and higher Ec/N0 values produce higher RoT, RoT can be considered the uplink *shared resource*. The relation of single user Ec/N0 and uplink noise rise is presented in figure 2. How this affects the achievable bitrates is depicted in the next section.

Bitrates in Practical Networks: 1.6 Mbit/s

Considering measured EUL performance, according to Omnitele experience it is typically not the UE power resources (path loss), nor the system dynamics but the RoT limits restricting uplink bitrates. Bitrates around 1 Mbit/s are often measured even in higher path loss conditions. Typical planning figures for RoT limits in practical EUL networks are around 8 dB. Figure 3 is a plot from Omnitele's EUL capacity planning tool illustrating the relation of cell throughput and RoT. With practically chosen Eb/N0 and interference constraints, RoT of 8dB yields 1.59 Mbit/s for the cell. The pole capacity,

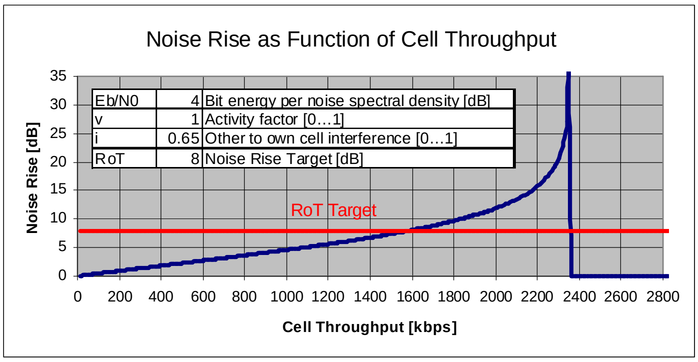

Figure 3: Uplink cell capacity and noise rise

i.e. the maximum cell capacity with infinite RoT (zero coverage) is 2.35 Mbit/s. However, in the case of very little inter-cell interference the pole capacity can be notably higher, even 15 Mbit/s and above. In this case, assuming only a single user in the cell, the NodeB could allow very high RoT and bitrate to the user. As soon as another user enters the system, power control will be applied accordingly to repair uplink coverage. Discussions within the industry indicate that some vendors will support such scheduling features in the near future. In such cases it is likely that in low load networks the 5.7 Mbit/s (5.4 Mbit/s RLC) may actualize occasionally with Release 6 EUL.

Increase cell capacity with the expense of coverage?

As explained earlier, WCDMA uplink has *cell breathing* property, which makes it possible to make a trade-off between capacity and coverage. From figure 3 we see that by increasing RoT from 8 to 11dB, cell capacity would increase 20% from 1.6 Mbit/s to 1.9 Mbit/s. Calculating with path loss exponent *PLE* = 4 (2 = free space loss), the 3dB increase in noise rise yields 1.4-fold site density. Figure 4 illustrates the estimated site density effect to uplink cell capacity in our case example. Some key observations: Site density's effect on uplink capacity decreases as cell throughput approaches pole capacity. Still, the effect on total network capacity is notable, 30% increase in site density converts to 17% increase in average cell throughput and thus 1.5 fold increase in total network capacity.

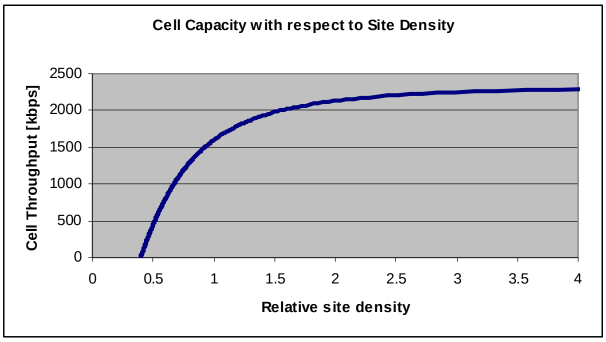

Figure 4: Cell capacity with respect to site density, reference 1.6 Mbit/s

Marginal improvement from 16QAM

Release 7 adds 16QAM support for EUL doubling the theoretical air interface peak rate to 11.5 Mbit/s. But actually we will see that there is little or no use for higher order modulation in WCDMA uplink. It is for this reason that 16QAM was excluded from Release 6 EUL when 3GPP carried out the EUL Feasibility Study [5]. 16QAM indeed doubles the theoretical bitrate, but on the other hand it requires more than doubling of Ec/N0 compared to QPSK. In other words, energy cost per bit is increased. Higher bit energy demand yields decreased amount of uplink *shared resource,* and thus will not improve system capacity in multiuser scenario. That is, assuming more than one simultaneous user in the system, a 5.7 Mbit/s capable terminal will perform equally as the advanced 11.5 Mbit/s capable one does. The highest spectral efficiency is achieved with QPSK, not with 16QAM. A more elaborative approach of the concept can be found in [2]. On the other hand, if an arbitrarily high RoT value would be allowed in single user case, then higher bitrates of 16QAM EUL might occasionally see daylight, slightly increasing average cell throughput. Omnitele considers such scenarios to be rare especially in the future as mobile broadband terminal penetration increases.

Real Means to Enhance EUL Bitrates

16QAM is not the way to increase system capacity or the spectral efficiency of EUL. There are however other performance enhancements available. Data rates in mobile environment are dominantly affected by multipath propagation. To counteract multipath effects, state of the art HSDPA terminals nowadays have adaptive chip equalisers and so called G-RAKE receivers. Similar methods can be used in uplink as well yielding increased spectral efficiency. Another hot topic discussed widely is the IC - *Interference Cancellation* (a.k.a. *Multi User Detection* – MUD). The idea is to suppress interference generated by code multiplexed users after bit detection. These methods are nothing new from communications theory point of view, but real life implementations have been missing due to lack of calculation power. Manufacturers have indicated that G-RAKE capable NodeB equipment will soon be introduced to the market. The curves in Figure 5 illustrate simulated performance of such receiver. Comparing the values for example to the ones presented in [4] for normal RAKE, several observations can be made: Chip equalisation introduces a notable gain in bitrates. With an Ec/N0 of 0dB G-RAKE reaches 4Mbit/s, whereas the baseline RAKE only achieves ~2.7 Mbit/s. On the other hand, for Ec/N0 requirement of 2 Mbit/s, there is a ~2 dB gain for G-RAKE. Worth noting is also 16QAM applicability: In multiuser Ec/N0 ranges (Ec/N0 < 0 dB) 16QAM is practically useless.

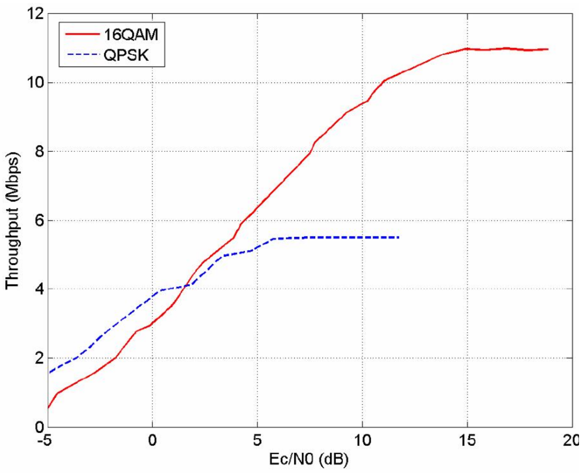

Figure 5: EUL Throughput as a function of Ec/N0 in Pedestrian A channel for uplink, with G-RAKE receiver, ideal channel estimation [4]

Besides new receiver architectures there is another way to increase uplink bitrates: increasing the bandwidth. That is, assign two carriers for a single user simultaneously as is the case with Dual Cell HSDPA of Release 8. Release 9 enables the same for uplink, doubling the peak PHY bitrate up to 23 Mbit/s. A so called *progressive power control* is also a widely studied topic. The idea is to increase capacity by compromising bitrate of cell edge users, which then produce less interference to neighbouring cells. The peak rates as well as estimated cell capacity evolution of discussed features are presented in Figure 6. Cell capacities are based on theoretical modelling, Omnitele's EUL capacity planning tool and publications from the industry.

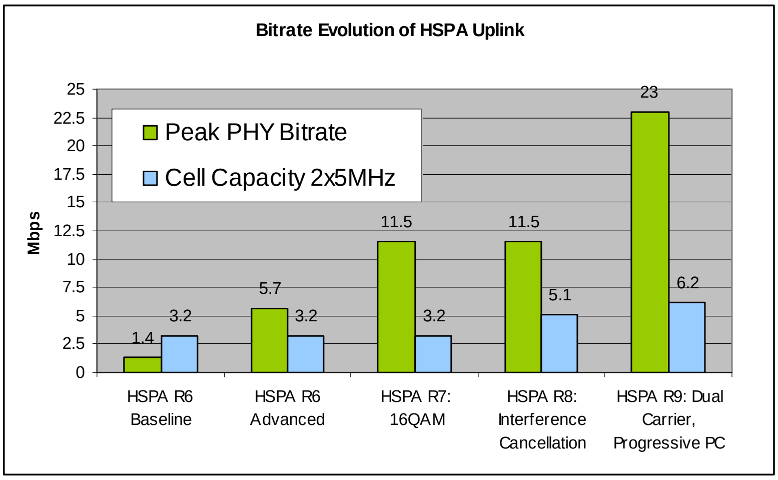

Figure 6: Bitrate Evolution of HSPA Uplink

Conclusions

WCDMA uplink data rates are expected to become more important for future mobile service, but so far they have got less attention in the industry compared to downlink figures. In this paper we analysed achievable uplink bit rates of EUL in practical network topologies. The analysis showed that unless network hardware is upgraded with new type of receivers, user bitrates in multiuser scenarios are likely to saturate below 1.6 Mbit/s even with the most advanced terminals. That is, a 1.4 Mbit/s capable terminal will perform similarly as a 5.7 Mbit/s terminal in most cases. In single user scenarios, the greater dynamics of higher category terminals may prove useful. More than just advanced terminals are needed to increase cell capacity.

Release 7 defines 16QAM for EUL but there is little or no use for it in practical networks. In multiuser scenarios 16QAM provides poorer spectral efficiency than QPSK. Higher order modulation is thus a peak bitrate application and not a system capacity enhancement. EUL system capacity can still be further increased with advanced uplink receivers applying equalisation and interference cancellation. Multiuser detection and progressive power control will be future ways to increase EUL performance.

The higher uplink bitrates, meaning 5Mbit/s and above, require extremely high Ec/N0 values which are hard to achieve in practical macro cellular networks due to noise rise limitations. High Ec/N0 values introduce high RoT and decrease coverage due to WCDMA cell breathing. Achievable uplink bitrates in macro cellular networks will be notably smaller than the promised *marketing bitrates* of today's EUL and future evolution. The key message is that cell capacities will not linearly follow the peak rate evolution. WCDMA uplink is generally not limited by dynamics, thus introducing only greater dynamics to it will not yield high gains. -Instead new receiver solutions are needed.

The proven but expensive way to increase the uplink capacity of the network is simply increasing site density. The *cell breathing* property of WCDMA uplink enables increasing the uplink cell throughput by compromising the coverage. In the studied case example a 30% increase in site density yielded 50% increase in total network capacity.

Omnitele Background

Omnitele Ltd. is a pioneer within the wireless industry with twenty years of leading edge network and business consulting experience worldwide. Omnitele was founded in 1988 to set up the first GSM operator in the world and is owned by Finnish national telecom operators and an external investor. Omnitele's strengths lie in mobile network planning and development, technical consulting and operator business development. We aim to increase and improve overall operator performance and quality of services, and we thrive to provide best solutions for deploying new technologies. Omnitele mobile broadband strategy consultancy services include analyses with realistic technology simulations and well educated terminal penetration and data traffic modelling. Combined with the key economical inputs, Omnitele has created a leading edge model for mobile broadband profitability analysis.

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