The role and impact of user equipment in HSxPA networks

White Paper

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1 Executive Summary

As an upgrade to an operator’s UMTS network, HSxPA offers higher data transfer rates and improved network capacity and therefore promises increased data revenues and lower costs.

However, in order to achieve these improvements, HSxPA introduces more complexity at the edge of the network - at the radio link that forms the boundary between the network operator’s own infrastructure and their customers’ mobile user equipment. Much of this complexity, in particular for HSDPA, results in additional processing demands on the user’s mobile device.

HSDPA data rates and network efficiency vary according to the prevailing radio signal conditions and the capabilities of the “baseband modem” of the user device, which processes the radio signal. The baseband modem is therefore a key factor in determining the user perception of (and therefore demand for) HSDPA services *and* the cost of service delivery.

UMTS and HSxPA are specified by the 3GPP organisation. Earlier 3GPP specifications define basic categories for HSDPA modem performance, each of which is associated with a *peak* data rate that the modem can support. However, some baseband modems with the same basic 3GPP category can only deliver low-speed data under poor radio conditions.

More recent 3GPP specifications describe “receive diversity” and “equalisation” as advanced modem processing techniques that offer improved radio performance. A “Type-3 advanced receiver” modem combines both techniques to offer improved performance across a wide range of radio conditions compared to a non-advanced modem of the same basic category. Operators whose customers’ devices feature Type-3 advanced receiver modems can expect to benefit from greater data revenues and lower operating costs.

Icera has developed a superior Type-3 advanced receiver architecture that uses an Adaptive Wireless® approach that continually optimises the modem performance for changing radio conditions. This approach delivers up to 140% higher data rates, over a wide range of radio conditions, compared to the previous generation of “rake receiver based” devices.

2 Introduction

2.1 What is HSxPA?

HSxPA (high speed packet access) is an enhancement to 3G UMTS networks that improves the way in which data traffic is transmitted over the radio interface between a base-station ("Node-B") and its connected mobile users.

HSxPA comprises two distinct, complimentary technologies: HSDPA (high speed downlink packet access – i.e. downloads to a user) and HSUPA (high speed uplink packet access – i.e. uploads from a user).

HSxPA improves the way in which uplink and downlink data is transmitted in packets over the radio interface, increasing peak data rates and improving network efficiency through dynamic allocation of resources. Within a cell/sector, HSxPA-enabled networks can offer theoretical peak data rates of up to 14.4Mbps for downloads and 5.76Mbps for uploads. HSxPA also delivers data with less delay (latency) between a request and start of transfer of data.

2.2 What are the benefits of HSxPA?

Mobile users who connect to an HSxPA network experience faster and more responsive services for web browsing, email, media streaming etc.

These significant improvements to the delivery of data services are likely to increase operator revenue by attracting and retaining higher-ARPU customers. Additionally, due to the greater efficiencies with which radio traffic is handled in HSxPA networks, operators can achieve improved network capacity for both data and voice, lowering overall operational costs.

With these improvements to both top-line and bottom-line results, HSxPA is a commercial necessity for all UMTS network operators.

2.3 How and when is HSxPA being introduced?

As an enhancement to earlier UMTS radio access networks, the introduction of HSxPA requires the deployment of upgraded radio networks (base-stations and radio network controllers (RNC)) and the availability of compliant user equipment. Additionally, in order to support the higher data rates generated by the radio network, operators may find that they also need to make upgrades to their backhaul links.

HSDPA-enabled base-stations that support up to 7.2Mbps HSDPA have been commercially deployed since 2005. HSUPA upgrades for HSDPA-capable equipment are due to follow in 2007. RNCs from many vendors will require only software upgrades to full HSxPA support.

Therefore, most of the operator CAPEX associated with the initial deployment of HSxPA relates to the installation of (or upgrade to) HSDPA-enabled base-stations. In order to manage this CAPEX, many existing network operators are introducing HSxPA in phases, starting with urban areas in which demand for data services is greatest. In order to provide backward-compatibility, HSxPA-enabled networks continue to support legacy UMTS handsets for voice and lower-speed data connections.

2.4 What are the key features of HSDPA?

2.4.1 High-speed shared channel

The HS-DSCH (high speed downlink shared channel) carries data to HSDPA users, with a theoretical maximum 14.4Mbps data rate (subject to radio conditions and device category).

The HS-DSCH resource is shared amongst all HSDPA devices within a cell/sector on a time and code multiplexed basis. There are 15 unique codes that are re-used in each 2ms "transmission time interval" (TTI). For each TTI, the base-station "fast-scheduling" algorithm allocates 0-15 codes to each user device currently awaiting data in the cell/sector. This concept is illustrated in Figure 1.

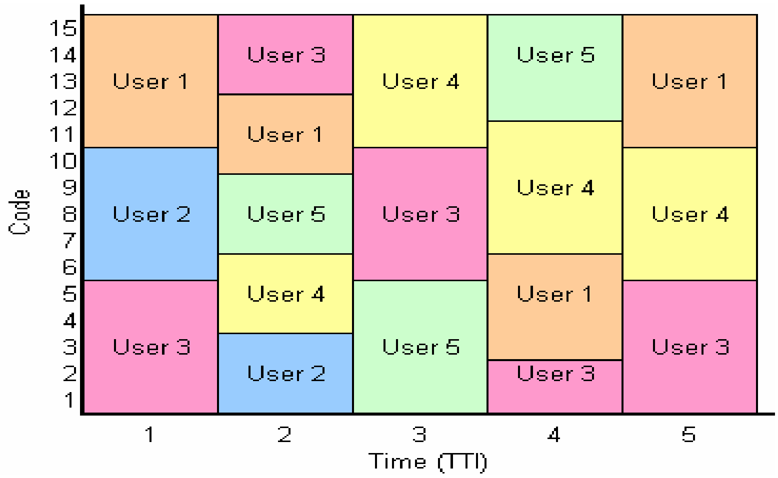


Figure 1: Conceptual example of HS-DSCH code allocation with time

In theory, each code can be used to deliver data with an effective rate of 960kbps (960kbps/code x 15 codes = 14.4Mbps). However, in practice, the base-station will have to select a lower effective data rate for each code due to a variety of factors that are explored in later sections.

2.4.2 Shorter TTI

The 2ms TTI used in HSDPA is considerably shorter that the typical TTI range of 10-40ms used in earlier UMTS releases. Because various transmission parameters can be modified within each TTI, a shorter TTI allows the system to adapt itself more quickly to changing radio conditions. A shorter TTI also reduces the round-trip latency for higher-level protocols (such as TCP/IP) that rely on a series of back-and-forth messages to complete each data transfer.

2.4.3 Higher order modulation

HSDPA supports 16QAM radio modulation, which can transfer data at up to double the rate of traditional UMTS QPSK modulation, for those users who have high cell geometry [1].

2.4.4 Fast base-station scheduling and adaptive modulation and coding

With fast base-station scheduling, each connected device is dynamically allocated a variable proportion of the shared HS-DSCH resource (i.e. number of codes, from 0-15), based on:

- the availability of data to be transmitted to the device
- the maximum download rate that the device can support (defined by the device category)
- the channel quality indicator (CQI) information that is reported by each device

The CQI value (from 0-30) reflects the current radio conditions measured by a device from the reception of known "pilot" data transmitted by the base-station. In addition to contributing to the scheduling decision, the CQI information is used to determine the adaptive modulation and coding (AMC) parameters that will reliably deliver the highest data rate to that device (the calculation is actually based on a 10% expected error rate to ensure that the system always runs close to the limit). AMC determines:

- the modulation scheme (16QAM or QPSK), and;
- the amount of error protection "overhead" to be used

Data to be sent by HSDPA is Turbo encoded to provide a high level of error protection - effectively tripling the amount of data that would have to be sent (i.e. 200% overhead). The AMC process determines how much error protection overhead can be removed according to the reported CQI.

Thus the "useful" data rate (after decoding) that is transmitted to each device is determined by the number of allocated codes, the type of modulation and the amount of error protection. In this way, fast scheduling and AMC attempt to optimise HSDPA transmission to increase the likelihood of successful reception by devices whilst ensuring the highest possible data rates.

This "useful" transmitted data rate is therefore directly related to the CQI reported by the device and can typically vary (for common device categories) between 69kbps/code for and 717kbps/code, compared to the theoretical maximum of 960kbps/code.

After completing fast scheduling, the base-station signals to the selected devices that they will receive data in the next TTI and informs them of the corresponding AMC parameters.

2.4.5 HARQ with soft combining

Some data will inevitably be corrupted in transit to the device and will have to be retransmitted. With HSDPA, data retransmission may be handled "locally" by the base-station improving response times compared to earlier UMTS networks (where only the more distant RNC could manage data retransmissions).

[1] Cell geometry defines the relative strength of the received signal at the user equipment, expressed as the ratio of signal strength from the local base-station (Îor) to the level of inter-cell interference at a particular location (Ioc). Lower geometries occur at the cell edge where the strength of the signal from the local base-station is diminished and the strength of signals from neighbouring base-stations (which appear as interference to the device) is increased.

HSDPA employs a “stop and wait hybrid automatic repeat request” (SAW HARQ) retransmission protocol between the base-station and the user device. With HARQ, each device checks the integrity of its received data in each relevant HS-DSCH TTI. If the data is correct, the device returns an “ACK” (acknowledging receipt of correct data) signal, in which case the base-station can move on to the next set of data.

If the data is not successfully received, the device transmits an “NACK” (negative acknowledgement) and the base-station retransmits the corresponding data. With “soft combining” at the user device, the earlier set(s) of corrupted data can be combined with subsequently retransmitted data to increase the likelihood of correctly decoding valid data.

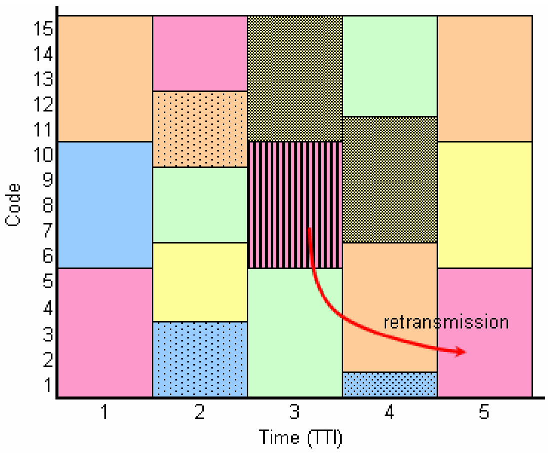
2.5 What happens when the downlink radio conditions degrade?

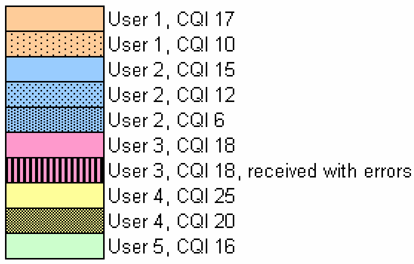
As radio conditions deteriorate a device will report a lower CQI. The base-station fast scheduler and AMC processes use the reported CQI to decide whether to transmit data to that device and, if so, what transmission parameters to use. As an effect of reporting a lower CQI, the device may experience the following changes:

- ❖ Fewer (or no) HS-DSCH resources are allocated to the device
- ❖ QPSK, rather than 16QAM, modulation is used
- ❖ Greater error protection is used

Each of these steps reduces the effective data rate delivered to the device. *Thus, the extent to which CQI reduces for a given degradation in radio conditions is a key device performance metric.*

When errors are encountered in the received data, one or more HARQ retransmissions will be necessary, further reducing the effective useful data rate. A conceptual example of the combined effect of this is shown in Figure 2.





	Effective data rate (averaged over 5 TTIs) / Mbps
User 1	1.38
User 2	0.55
User 3	1.21
User 4	2.32
User 5	0.86
Cell Total	**6.33**

Figure 2: The effect of transmission format and retransmission on average user and cell data rates

One observation from the illustration in Figure 2 is that the average cell/sector throughput, despite full utilisation of the HSDPA resources, is only 6.33 Mbps.

A device that can maintain a higher CQI for a given set of radio conditions may be allocated more code resources by the fast scheduler and will be able to receive higher data rates within those codes that are allocated (due to the need for less error protection in the transmitted data). Such a device consumes fewer network resources for a given amount of "billable" data.

2.6 What are the key features of HSUPA?

2.6.1 Enhanced dedicated channel

HSUPA introduces the concept of the E-DCH (enhanced dedicated channel) to transfer high-speed uplink user data from a device. Unlike the shared HS-DSCH resource in HSDPA, there is a unique E-DCH allocated to *each* HSUPA device. Dual-channel QPSK modulation is used. Shorter TTI

HSUPA uses a TTI of 2ms or 10ms, depending on the device capabilities. As with HSDPA, a shorter TTI allows the system to respond more quickly to changing radio conditions and also results in lower latency for "back-and-forth" protocols such as TCP/IP.

2.6.2 Fast base-station scheduling

Since there are multiple "high speed data transmitters" in HSUPA (the devices) rather than the single high speed data transmitter of HSDPA (the base-station), the system must control and coordinate ("schedule") all of the device E-DCH transmissions to minimise their interference. This scheduling is based on resource requests made by the devices and granted by the local base-station(s).

2.6.3 HARQ

The HSUPA receiver (base-station) sends an ACK/NACK signal to the transmitter (device) informing it whether transmitted data was correctly received. As with HSDPA, HSUPA uses a SAW HARQ approach such that no further data is transmitted by the device until an ACK is received from the base-station. If the device receives a NACK, it retransmits its data.

The retransmitted data can be used with chase combining or incremental redundancy, which can be performed at the base-station or at the RNC. If the device receives an ACK, it moves on to transmit its next block of data. Any neighbouring base-station can send an ACK to the device, allowing the soft handover of the device to a base-station with better reception.

3 Why is user equipment so important in HSxPA networks?

The interactions between the user device and the base-station are paramount in delivering fast and responsive HSxPA services. The extent to which a deployed HSxPA network delivers on the performance and profitability promises of the technology is heavily influenced by the capabilities of the devices that are chosen by the operator’s customers.

Operators of all mobile networks suffer lost revenues if their users’ devices drop calls or cannot provide a reliable data connection due to poor radio conditions. However, with HSDPA, the introduction of a shared data resource and the use of an adaptive modulation and coding scheme mean that operators are more exposed to any weaknesses exhibited by the user devices attached to their network.

In a 2G network, the “cost” to the operator of an under-performing device is isolated to its respective user, from whom revenue cannot be generated during times of disconnection. This “isolation” is a feature of traditional circuit-switched radio systems which provide a separate, fixed speed, “all or nothing” connection to each device. If the connection to one user fails completely, the resource can be reallocated to another user. If the connection degrades partially without failing, corrupted data may have to be retransmitted by the network over the same connection. In this case the retransmission “overhead” affects only that user, who experiences a lower effective data rate from their “dedicated” channel.

In contrast to this isolation, HSDPA provides a single high-speed downlink data channel that is shared by all attached devices in the cell/sector. The idea is that the network can manage this bandwidth dynamically – usually delivering consistently higher average data rates for all users and with the opportunity of significantly higher peak data rates. This “statistical multiplexing” approach to handling the data traffic for multiple users is a key benefit of packet-based (rather than circuit-switched) networks.

Each HSDPA base-station must frequently make a scheduling decision regarding which of the “competing” user devices should receive data in the next transmission burst. Ideally the base-station will be able to allocate more of its finite resources to devices that are currently reporting good radio reception, delivering proportionately more billable data. However, if some or all of the devices are reporting poor radio conditions, the base-station will have to scale-back the data rates for those users whilst consuming the same amount of network resources.

Thus, whilst the base-station scheduler may attempt to allocate resources to devices when their radio reception is at its best, there is an “opportunity cost” of servicing devices that report consistently lower radio reception. Where users have a network quality of service contract, there may be no alternative to regularly servicing those devices with poor signal reception.

Thus the operating cost of delivering HSxPA services is variable and the profitability of the network is determined by the aggregate performance of the connected users, rather than by the peak theoretical capacity of the operator’s infrastructure. The widespread deployment of user devices that can successfully maintain higher-rate data connections for a given set of radio conditions will improve the profitability of the network.

4 What differentiates HSxPA device performance?

The “modem” sub-system of an HSxPA device is responsible for managing the radio interface and is the area of greatest potential performance differentiation.

The 3GPP specifications define basic categories of HSDPA and HSUPA modem performance, as shown in Table 1. These are often quoted by modem manufacturers (e.g. “Category 6 HSDPA, Category 2 HSUPA”).

HSDPA modem category	Maximum Data Rate
1, 2	1.2 Mbps
3, 4	1.8 Mbps
5, 6	3.6 Mbps
7, 8	7.2 Mbps
9	10.2 Mbps
10	14.4 Mbps
11	0.9 Mbps
12	1.8 Mbps

HSUPA modem category	Maximum Data Rate
1	0.73 Mbps
2, 3	1.46 Mbps
4	2.0 / 2.92 Mbps (*)
5	2.0 Mbps
6	2.0 / 5.76 Mbps (*)

(*) Some HSUPA categories have operation modes that offer different maximum data rates

Table 1: Simplified 3GPP HSDPA and HSUPA modem categorisation

For HSUPA, the modem must encode and modulate the E-DCH data in strict accordance with the 3GPP specifications, leaving little room for modem differentiation. However for HSDPA, the basic 3GPP categorisation defines only the theoretical maximum data rate under idealised radio signal conditions, which are rarely likely to be experienced by a modem “in the field”. In practice, different HSDPA modems of the same basic category can be better at handling less than perfect radio signals, offering considerable scope for modem differentiation.

Traditional 3G modems and early HSDPA modems were expected to use a single receiver antenna and to utilise a rake receiver architecture (in which a set of correlators are used to track the individual multi-path signals). This type of modem provides baseline performance.

However, a traditional “rake receiver” based modem may have difficulty in distinguishing the different signals when multi-path delays cause interference between replicas of the same code channel (self interference) and other code channels (multi-access interference). These types of interference are better dealt with using advanced “Equalisation” processing.

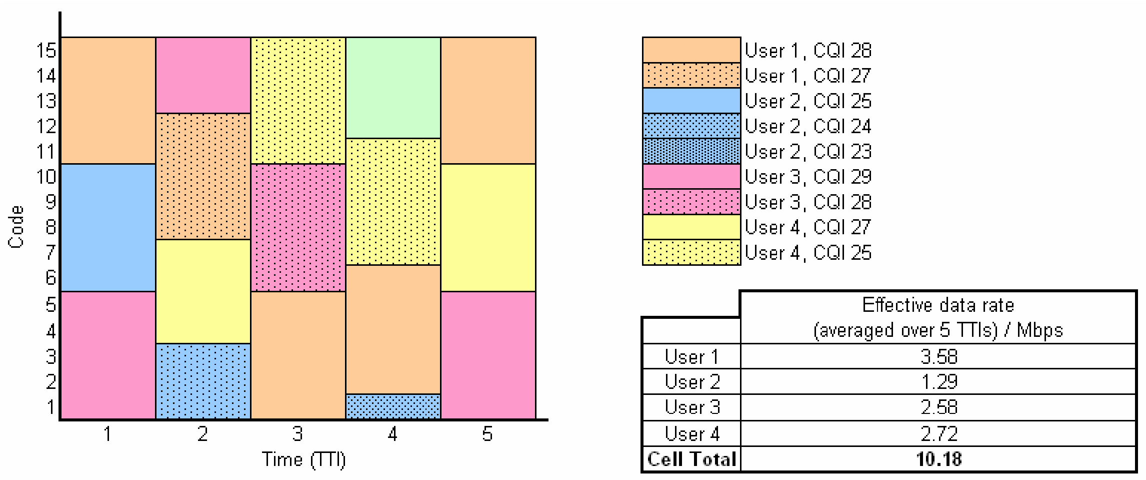
Performance can also be further improved with the use of “receive antenna diversity” (i.e. using two or more device antennae). Each antenna, even if separated by a small distance as in a mobile device, offers a different receive path for the transmitted signal. Each path may have encountered different delays and amounts of thermal noise and radio interference. A modem with diversity support can process the data from multiple antennae to more accurately recover the originally transmitted data. The use of receive diversity potentially doubles modem performance across all cell geometries.

Later updates to the 3GPP HSDPA specification define “advanced receiver” modems that use equalisation-based detectors and/or antenna diversity, as shown in Table 2. These modems typically report higher CQI values and therefore deliver higher data rates, over a much wider range of signal conditions, than non-advanced modems of the same basic modem category.

Advanced receiver type	Receive diversity	Equalisation
Type 1	✓	
Type 2		✓
Type 3	✓	✓

Table 2: Types of HSDPA advanced receiver

An illustration of the effect of higher CQI values on overall cell throughput is shown in Figure 3, where the cell/sector efficiency has improved by 61% compared to the example in Figure 2. This means more 61% more billable data delivered to customers for the same network cost.



	Effective data rate (averaged over 5 TTIs) / Mbps
User 1	3.58
User 2	1.29
User 3	2.58
User 4	2.72
Cell Total	**10.18**

Figure 3: The effect of advanced receiver modems on average user and cell data rates (higher CQI)

5 What are the advantages of Icera's HSxPA solution?

Icera's Livanto® ICE8020 is a high performance, low power, single-chip baseband modem for user devices that can support a variety of radio standards, including full HSxPA support.

Icera's Adaptive Wireless® HSxPA physical layer software for ICE8020 delivers Type-3 advanced receiver Category 6 (3.6Mbps) HSDPA performance with a software-only upgrade path to Category 8 (7.2Mbps) HSDPA performance with HSUPA.

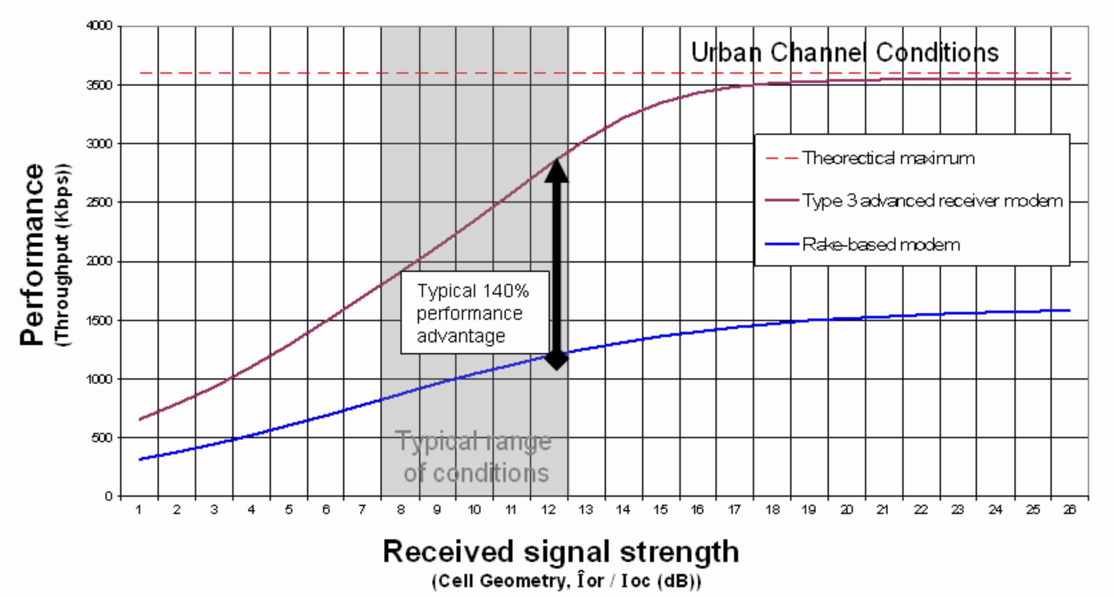


Figure 4: The relative Category 6 HSDPA performance of a type 3 advanced receiver compared to a rake-based modem

The Adaptive Wireless® physical layer software dynamically manages the modem to respond to varying channel conditions by switching between various advanced algorithms, such as enabling receive diversity and channel equalisation and varying the parameters for both rake and equaliser operation. The result is much improved HSxPA data throughput across all radio conditions compared to traditional solutions.

By adopting a "lean modem" approach of using a dedicated single-chip baseband, HSxPA device developers can create differentiated products using best-in-class components. The Icera ICE8020 can be used in highly integrated datacard and embedded solutions, requiring minimal additional components. For feature-rich smartphone and connected media devices, Icera ICE8020 can be tightly integrated with a range of 3rd-party application and multimedia processors.

By offering high performance, low power and competitive unit cost and by enabling "lean modem" system partitioning, Icera's Livanto® and Adaptive Wireless® solution represents a compelling baseband choice for HSxPA device developers.

6 Conclusions

User devices play a key role in HSxPA networks because HSxPA operates dynamically to trade-off network resource usage for data transfer speed.

Devices that can support higher data rates whilst consuming few resources result in greater network profitability and more satisfied users.

The relative performance of HSxPA devices is largely determined by the type of baseband modem that is used. Whilst there are basic 3GPP performance specifications for HSxPA modems, these define only peak HSDPA performance. Actual HSDPA performance is variable depending on the prevailing radio signal conditions and the modem implementation.

Certain advanced modem processing techniques, such as “receive diversity” and “equalisation”, can provide better HSxPA performance over a much wider range of radio signal conditions compared to the traditional “rake-based” approach.

Therefore, the widespread adoption of user equipment that provides Type-3 advanced receiver performance, such as Icera’s Livanto® ICE8020 with Adaptive Wireless®, is essential for operators seeking to achieve the highest revenue and lowest operating costs for their HSxPA networks.

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