Freescale HSDPA Solutions

White Paper

Freescale Semiconductor, Inc.

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OVERVIEW

High Speed Downlink Packet Access (HSDPA) is a Third Generation Partnership Project (3GPP) Release 5 standard that promises to make Wideband CDMA networks faster and smarter. Network operators should consider upgrading to HSDPA for two basic reasons: HSDPA-enabled networks increase capacity, and increased capacity allows operators to offer richer services to more people. For operators who want to realize their investment in 3G networks, HSDPA can increase both the number of users on the network and the amount of revenue per user.

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The Market

In order to realize a better return on their investments in 3G licenses, network operators want to get existing and new customers onto 3G networks as quickly as possible. High Speed Downlink Packet Access (HSDPA) is a Third Generation Partnership Project (3GPP™) Release 5 standard that promises to make Wideband CDMA (W-CDMA) networks faster and smarter. With HSDPA, operators can expect to increase capacity, offer richer multimedia services and start getting their money's worth out of 3G.

There are two overarching reasons why operators want to migrate their customers to 3G: capacity and value-added services. By increasing capacity, operators can accommodate more customers. This leads to increased revenue, a larger customer base to sell services to and greater return on investment.

3G networks are more spectrally efficient than 2G networks, which means that operators can serve more standard voice customers. Transitioning to 3G networks also allows a greater variety of value-added data services such as video telephony, Web browsing and music and video downloads. Many data services that are available today don't need the promised megabit speeds of HSDPA—although future services will no doubt run at higher speeds. However, operators will need this extra bandwidth both to serve more standard voice customers and to provide higher-bandwidth data services. Without an enhancement such as HSDPA, operators will run out of capacity more quickly.

Revenue Up, Costs Down

Average revenue per user or per unit (ARPU) can benefit from HSDPA. HSDPA increases the efficiency of W-CDMA networks for both voice and data services. The improved voice efficiency frees more of the network for enhanced media services, which in turn offers the opportunity for increased ARPU. That increase in ARPU can help carriers offset the costs of subsidizing new 3G phones for their customers.

HSDPA can help reduce transmission costs and operating expenditures (OPEX) for network operators. It is estimated that delivering a 10 MB file with HSDPA will only be 20 percent of the cost of delivery with W-CDMA.

Some operators can implement HSDPA without high capital expenditure (CAPEX). This depends on the age of the W-CDMA network infrastructure. Older networks may require new hardware for the backplane and channel cards, for example. Most Node Bs installed within the past few years are already HSDPA-capable. The minimal cost to upgrade to HSDPA, balanced with the resulting network benefits, can help improve CAPEX. Terminal availability, rather than network capability, will set the pace for HSDPA uptake.

Operators are already investing heavily in HSDPA, with more capital expenditure to come. According to a Deutsche Bank report, worldwide CAPEX for W-CDMA and HSDPA network infrastructures will catch up with spending on GSM, GPRS and EDGE in 2006 and will exceed it by 2007. The report also predicts that W-CDMA/HSDPA spending will far outpace spending on CDMA2000™ Rel 0 and 1xEV-DV by the end of 2005.[1]

The first HSDPA devices are likely to be PCMCIA cards in laptops. However, the market will quickly shift to handheld terminals such as smartphones, entertainment phones and video phones. Figure 1 shows predicted W-CDMA handset growth.

[1] "3G Wireless Technology: HSDPA to the rescue?" by Brian T. Modoff and Jonathan L. Goldberg, Deutsche Bank Securities Inc. September 8 2004

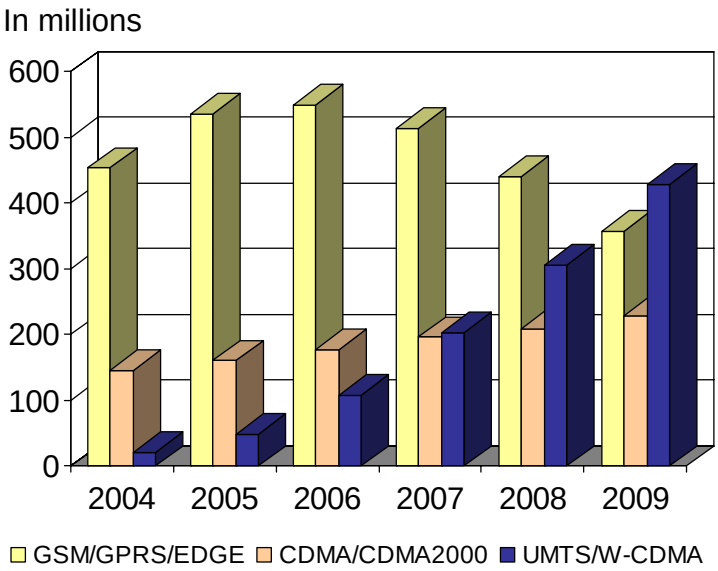


Figure 1. Predicted Cellular Market Handset Growth[2]

The Technology

HSDPA introduces advanced methods for modulation, error correction and bandwidth allocation and moves much of the call processing load from the core to the edge of the network. The main goals of HSDPA are efficient packet access, high data rates, reduced round-trip time for a signal between the network and the terminal and backward compatibility with Release 99. The theoretical downlink peak data rate for HSDPA is 14 Mbps, although interference and a user's location will likely limit real-world data rates to around 10 Mbps.

HSDPA is engineered to help solve performance issues at the W-CDMA network edge. In a "traditional" W-CDMA network, when a user at the edge of a cell is accessing the network at a high data rate, that affects the capacity of the rest of the cell because that one user takes up a lot of the base station bandwidth. A channel that is established at a certain data rate will remain at that data rate continually—so that one user not only takes up a lot of capacity, but could potentially occupy it for some time. With HSDPA, the base station can dynamically change the bandwidth allocation that's given to one user, based on the cell conditions at any one point. Users with better channel conditions are assigned higher data rates so that they require base station resources for a shorter duration, while users with poor channel conditions at the outer edges of a cell are serviced frequently. This "water-filling" algorithm greatly improves network throughput efficiency.

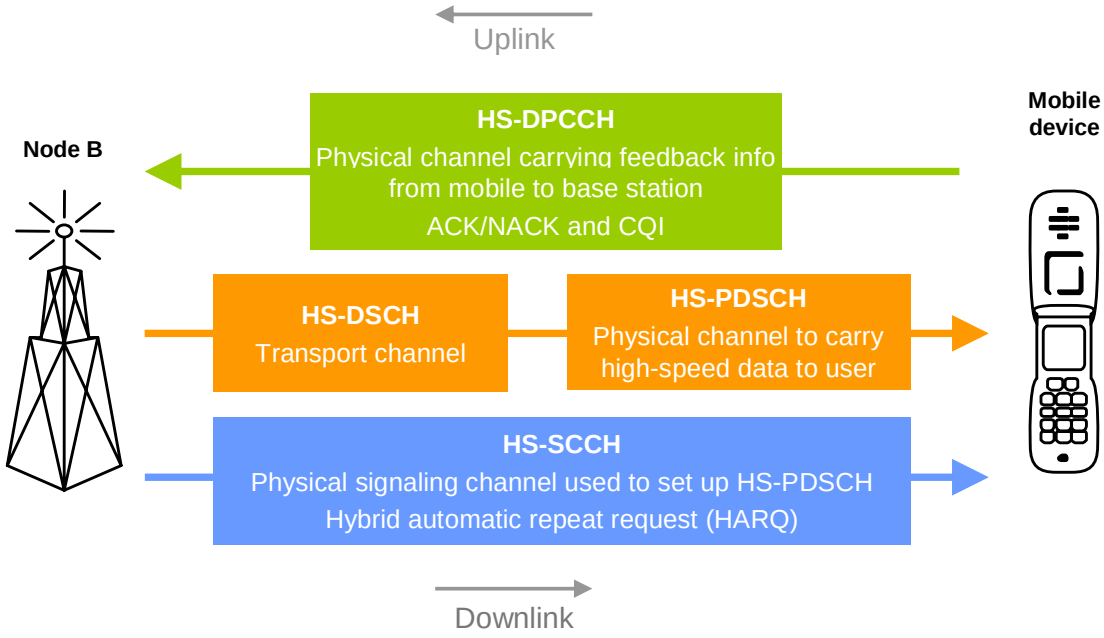
What's New in Release 5

3GPP Release 5 offers a number of improvements to Release 99. Important features that improve performance and network efficiency include shared channels, fast link adaptation, dynamic scheduling and fast retransmission of packet data.

[2] "Signals to Noise (S2N) #173: The Fall Campaign" by Brian T. Modoff, Jonathan L. Goldberg and Vijay Doradla, Deutsche Bank Securities Inc., September 6 2005

Shared Channels

The High Speed Downlink Shared Channel (HS-DSCH) is, as the name implies, a shared channel. This means that as more users come onto the network, bandwidth is further divided among each user. This is similar to the way that cable modems allocate bandwidth. New HSDPA channels are illustrated in Figure 2.



HS-DPCCH	High Speed Dedicated Physical Control Channel
HS-DSCH	High Speed Downlink Shared Channel
HS-PDSCH	High Speed Physical Downlink Shared Channel
HS-SCCH	High Speed Shared Control Channel

Figure 2. New HSDPA Channels

Fast Link Adaptation

Fast link adaptation enables the use of more spectrally efficient modulation when channel conditions permit. Favorable channel conditions use 16 Quadrature Amplitude Modulation (QAM), while unfavorable channel conditions use Quadrature Phase Shift Keying (QPSK).

In Table 1, for example, a coding rate of 1/4 means that error correction takes 75 percent of the bandwidth and the user data rate is only 25 percent of the maximum. Likewise, a coding rate of 4/4 means that the user achieves the maximum data rate, but there is no error correction, and therefore there will be many errors in the received data.

Table 1. Adaptive Modulation and Coding Rates for HSDPA

Modulation	Coding rate	Throughput		
		With 5 codes	10 codes	15 codes
QPSK	1/4	600 Kbps	1.2 Mbps	1.8 Mbps
	2/4	1.2 Mbps	2.4 Mbps	4.8 Mbps
	3/4	1.8 Mbps	3.6 Mbps	5.4 Mbps
16 QAM	2/4	2.4 Mbps	4.8 Mbps	7.2 Mbps
	3/4	2.4 Mbps	7.2 Mbps	10.7 Mbps
	4/4	4.8 Mbps	9.6 Mbps	14.4 Mbps

Adaptive modulation and coding (AMC) schemes fall within the limits of link adaptation. These schemes enable the system to change the coding and modulation schemes. The channel condition has to be measured or estimated based on the feedback of the receiver. Links with better transmission conditions are assigned a higher order modulation scheme and higher coding rates. The benefits of AMC include:

- Availability of high data throughput
- Low interference variation because it is based on modulation and coding-based link adaptation instead of variations in transmit power
- High effectiveness in combination with fat pipe scheduling (see below)

Link adaptation is the process of modifying transmission parameters to adapt to the current channel parameters. Higher modulation, in conjunction with channel coding, optimizes the use of a fading radio channel. By transmitting at constant power, the modulation and coding schemes (MCS) can be selected to maximize throughput on the downlink. The media access control (MAC) in the Node B selects the MCS that match the instantaneous radio conditions depending on the shortened HSDPA transmission time interval (TTI). The MCS selection depends on:

- Channel quality indication
- Instantaneous power of the associated dedicated physical channel
- Quality of service (QoS) demands of the requested service
- Waiting buffer sizes

Dynamic Scheduling

Fast scheduling shares the HS-DSCH channel among the users. This exploits multi-user diversity and allocates more bandwidth to users with more favorable radio conditions. The scheduler can base decisions on predicted channel quality, the current load of the cell and the traffic priority class (real-time or non-real-time services).

Another kind of scheduling is fat pipe scheduling. As shown in Figure 3, the Node B receives a channel quality indicator (CQI) from the handsets (UEs). The Node B schedules transmission of packets to all UEs over the shared channels. The channel or pipe is divided into 2 millisecond durations. Unlike Release 99, HSDPA allows constant CQI feedback from the handset to the Node B, which improves bandwidth efficiency.

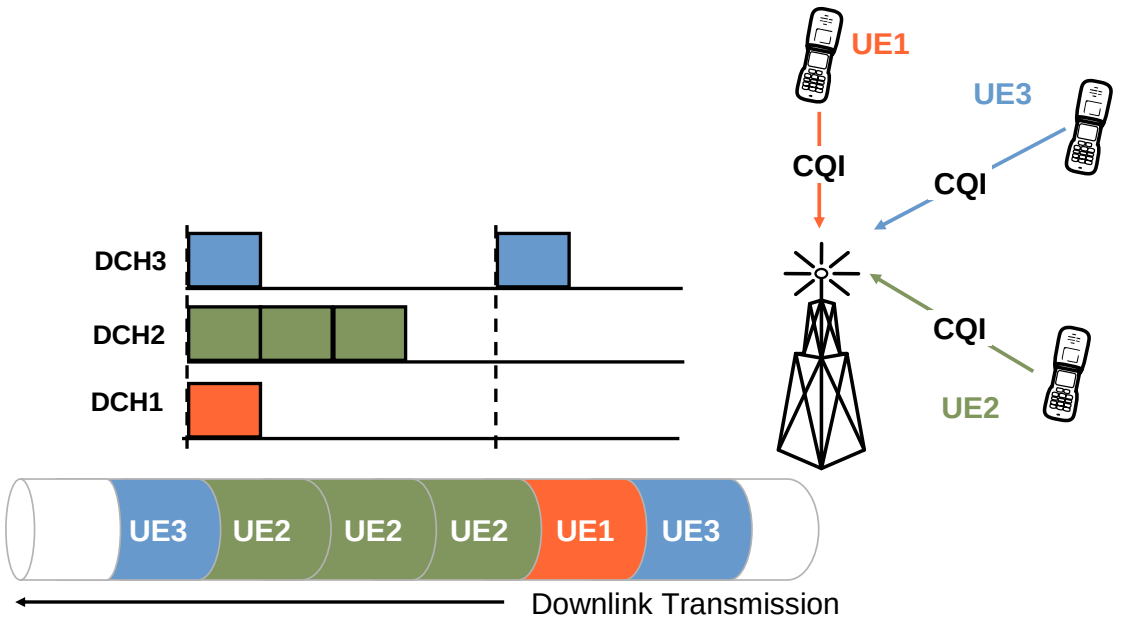


Figure 3. Fat Pipe Scheduling

Retransmission of Packet Data

Fast automatic repeat request (Hybrid ARQ) rapidly requests the retransmission of corrupted data. This method can use soft combining, which combines the information of the original transmission with the retransmitted information. This way the network doesn't request re-transmission of all the data. With incremental redundancy, the user receives more information about the transmitted packets with each re-transmission until the error-free data can be reconstructed. This improves network efficiency.

Hybrid ARQ improves performance and robustness by fine-tuning the effective code rate and compensating for errors in link adaptation. If all the information is correctly decoded, an acknowledgement (ACK) is sent to the Node B using the uplink control channel. If the data is decoded incorrectly, retransmission is requested immediately. After the retransmission, the handset combines the original data with the retransmitted data (soft combining). Hybrid ARQ resides in the Node B which means that retransmissions can be requested rapidly.

Services Are the Key

Services are a key issue for operators. These operators will have to convince 3G subscribers to upgrade their handsets yet again, on top of paying another premium for higher-speed services, in order to take advantage of HSDPA. This means that they will have to come up with compelling services—and competitive and appealing ways to price them.

Both companies and consumers are expected to drive HSDPA adoption. Enterprises often have the need for more bandwidth and more mobility, and the resources to pay for it. Business data services could include voice over IP, conferencing and Web browsing. Consumer applications could include music downloads and streaming video combined with telephony—for example, downloading MP3 files while having a simultaneous voice conversation. HSDPA is also designed to improve IP Multimedia Subsystem services such as presence-based services (instant messaging), push-to-talk, push-to-view and multi-player gaming.

(For more information about mobile services, see the Freescale paper “Driving Seamless Mobile Entertainment,” available at http://www.freescale.com/wireless.)

Different services will require different speeds. Release 5 specifies 12 new categories of downlink speeds for end user devices. This wide range of speeds gives device manufacturers more leeway to use different combinations of scheduling and tolerance to radio channel conditions to achieve various data rates. Table 2 outlines these categories.

Table 2. Adaptive Modulation and Coding Rates for HSDPA[3]

HS-DSCH category	Maximum number of HS-DSCH codes received	Minimum inter-TTI interval	Maximum number of bits of an HS-DSCH transport block received within an HS-DSCH TTI	Total number of soft channel bits	Transport user rate (Mbps)
Category 1	5	3	7300	19200	1.2
Category 2	5	3	7300	28800	1.2
Category 3	5	2	7300	28800	1.8
Category 4	5	2	7300	38400	1.8
Category 5	5	1	7300	57600	3.6
Category 6	5	1	7300	67200	3.6
Category 7	10	1	14600	115200	7.2
Category 8	10	1	14600	134400	7.2
Category 9	15	1	20432	172800	10.2
Category 10	15	1	28776	172800	14.4
Category 11	5	2	3650	14400	0.9
Category 12	5	1	3650	28800	1.8

Reference class
Only QPSK is used

As the transport user rate increases, more complex applications and a richer user experience are possible. Figure 4 shows some examples of multimedia applications that will be enabled as category speeds increase.

[3] Extracted from 3GPP25306 and 3GPP25308. It is likely that the QPSK-only phones category will disappear after Release 5.

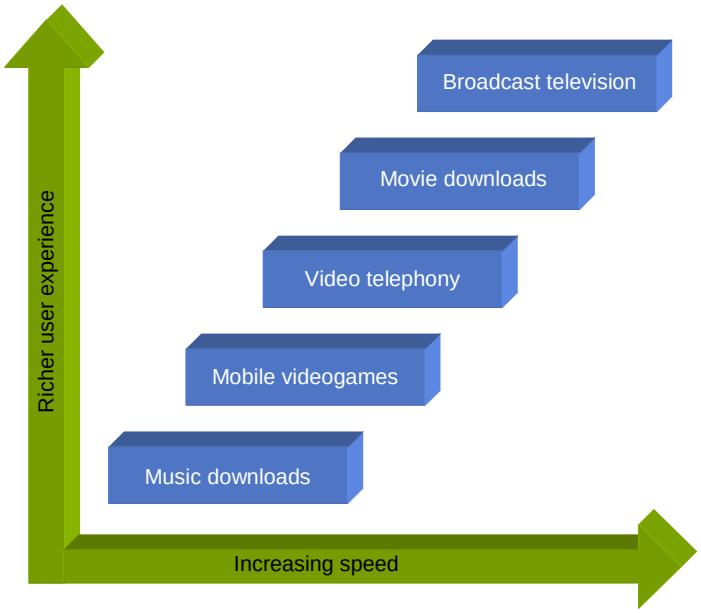


Figure 4. Increasing HSDPA Speeds Enable Richer Multimedia Experiences

The HSDPA Advantage

Whether you call them 3G, 3.5G or even 4G, there are many technologies that promise high bandwidth and mobility. These include CDMA EV-DO, orthogonal frequency division multiplexing (OFDM), Wi-Fi® and WiMax.

CDMA EV-DO is already available from operators such as Verizon. The highest theoretical data rate for this technology is 2.4 Mbps, compared to HSDPA's top limit of 14 Mbps. Wi-Fi operates in an unlicensed band, which means that it requires no spectrum licenses. However, it has limited range and is not intended for wide-area network uses. OFDM is a proprietary solution that is targeted for non-cellular bands.

Perhaps one of the strongest alternatives to HSDPA is WiMax. The WiMax theoretical peak data rate is faster than HSDPA, at 70 Mbps per sector, although real data rates are about the same. However, WiMax is not as mobile as HSDPA. WiMax requires new infrastructure and lacks a large enough network for mobility. For true mobility, you need well-engineered handoffs. Handoffs are among the most technologically complex aspects of high-speed mobile services. The general consensus is that HSDPA, being a cellular technology, has the advantage over WiMax in this regard.

HSDPA can be thought of as a mobile alternative to broadband asymmetric digital subscriber line (ADSL) and cable modems, although mobile handset processing power doesn't yet match that of a PC. HSDPA, ADSL and cable have similar real-world throughput rates and provide faster speeds in the uplink than in the downlink.

Freescale Solutions

Freescale is one of the early platform vendors to develop an HSDPA solution. The i.300-30 Innovative Convergence™ Platform and the i.300-33 platform are expected to support 3.6 Mbps (Category 6).

Table 3. Planned Availability of Freescale's HSDPA-Enabled Solutions

HS-DSCH Category	Transport User Rate	Available
Category 6	3.6 Mbps	3Q 2006
Category 8	7.2 Mbps	2007
Category 10	14.4 Mbps	2007

A Distinctive Combination

Freescale's combination of the i.300 platform and the Mobile Extreme Convergence (MXC) platform can help OEMs, ODMs and designers to save both time and money. These platforms reduce component count without sacrificing speed or power. The MXC's single-core modem architecture can significantly reduce design complexity. MXC architecture also frees the ARM11™ processor purely for applications. This architecture allows MXC-enabled devices to take full advantage of the high data rate that HSDPA provides, enabling the richer media and applications that need greater local processing capability.

Because the i.300 and the MXC are the same hardware platform, differentiated by software, manufacturers have a rare choice—to use a traditional architecture or a single-core modem architecture, using the same silicon. This in turn reduces time-to-market and time-to-money.

i.300 Cellular Platform

The i.300 platform is the first dual-mode EDGE Class 12 capable, tri-band W-CDMA/HSDPA, quad-band GSM 3G platform, optimized for open operating systems, with best-in-class integrated UMTS technology.

The Freescale i.300 mobile communications platform is designed to give best-in-class integrated UMTS technology performance and includes an advanced chipset, image and video processing options, an industry-leading development environment and support for rapidly building feature-rich multimedia mobile cellular devices. The i.300 platform chipset includes an industry-leading digital baseband with a dual core modem; an ARM® core applications processor; a 3G ultra-low noise direct-launch modulator integrated circuit (IC); a highly integrated multi-band GSM/GPRS/UMTS receiver IC; a multi-band UMTS/W-CDMA direct conversion receiver IC; a GSM/EDGE/W-CDMA digital transceiver IC; integrated on-chip synthesizers; PA modules that can operate with a single voltage power supply; and a power management and audio interface IC.

Key advantages of the i.300 platform include:

- Integrated UMTS feature radio
- 3.6 Mbps HSDPA Rx / 384 Kbps Tx
- EGPRS Class 12
- Videoconferencing
- Reduced chip count and power consumption RF
- Integrated dual-core baseband

- Dual core modem protocol stack architecture
- Support for real time operating system and open operating systems

MXC Cellular Platform

The MXC platform, the size of a postage stamp, can equip virtually any product—a smartphone, an MP3 player, a handheld DVD player, a digital camera—to become a fully functional smart mobile cellular device. MXC is designed to significantly reduce the materials and development effort required to deliver mid- and high-tier mobile devices. Designed to be inserted in an existing footprint, MXC allows developers to use a single platform to target multiple product designs currently delivered through as many as 300 to 400 components.

Freescale's MXC architecture represents a radical simplification of the architecture for smart wireless devices while providing a secure environment for content-rich applications. Incorporating more features in a smaller, integrated package reduces complexity, which results in a lower bill-of-materials (BOM) cost than other, more traditional approaches. It can help reduce OEMs' time-to-market for new converged mobile products by as much as six months and allow software developers to deploy applications across a broad range of devices.

The reduction in complexity and cost is achieved through advances in DSP architecture and communications protocol stack design that enable a single StarCore® DSP core to support the entire communications protocol stack. This breakthrough enables the RISC microcontroller unit, based on the ARM11™ core, to exclusively serve the user application environment. Application processor performance improvement over current discrete application processors is realized by an ARM1136™ core equipped with level 1 and level 2 caches. The L2 cache decouples the CPU from external memory and reduces the need for off-chip memory.

MXC can support open operating systems without a discrete applications processor and without requiring a third processor and a second memory system. For a data call there is no need to turn on the integrated MCU core, which saves power over alternative solutions that must run upper layers of stacks in the MCU core. The MXC has clean separation between the communications engine software (modem core) and the applications software (application core), a simpler software architecture that results in shorter software development times.

Two Architectures, One Chipset

The i.300 platform and the MXC architecture have the same silicon, and are differentiated through software. This provides the flexibility of being able to use one chipset as either a traditional dual-core modem architecture or the MXC single-core architecture.

Using the MXC architecture, OEMS and ODMs will be able to lower their costs for HSDPA-enabled communication subsystems. MXC will enable vendors to provide a smartphone solution at a mid-tier price point. Smartphones were previously restricted to high-tier price points. The reason for this cost savings is that MXC removes one processor and two memory ICs. Freescale estimates that this reduction can save between $10 and $11 US for each chip, and a 20-30% reduction in BOM for handsets (depending on tier).

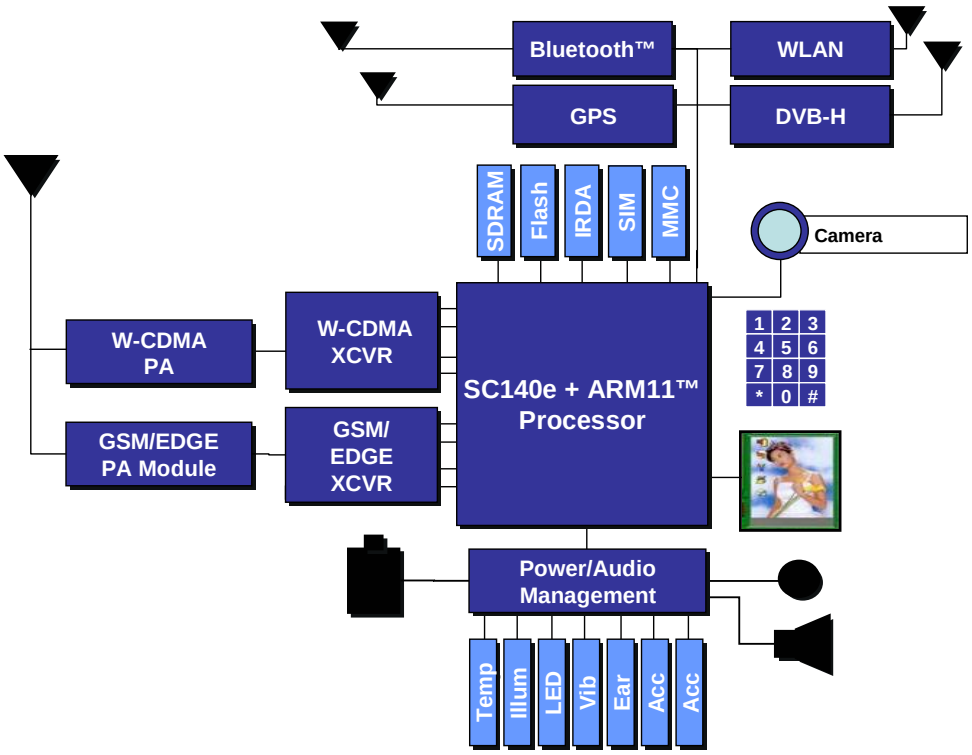


Figure 5. Block Diagram of Shared MXC and i.300 Architecture

Speed Challenge

Between 2003 and 2007, Freescale projects that to meet the needs of 3G and 3.5G mobile platforms with multimode functionality, ARM core speed would have to grow from 200 MHz to about 4 GHz in that five year span—a 20-fold performance improvement. This is because mobile devices are adding more connectivity and multimedia capabilities that will be used simultaneously. It is expected that users will not only be able to download videos, use location-based services or check data across a wireless network, they will be able to perform all these functions simultaneously, at higher resolutions, while playing a mobile game or participating in a conference call. Because it is impossible to meet the performance requirement through sheer ARM core processing while meeting the low power requirements, Freescale chooses to use Smart Speed™ technology. This allows the architecture to achieve that 20x performance improvement, without the 20-25x clock speed increase.

The unique Smart Speed power management switch extends battery life even when a user is multitasking. Smart Speed works through a combination of temperature sensing, voltage regulation and on-the-fly frequency adjustment. This means that a Freescale processor can provide performance that is equal to or better than a processor that has a higher clock speed. In an average processor, higher clock speed means greater battery drain—so being able to provide the same performance at lower clock speeds is a power advantage.

Freescale's HSDPA Approach

According to an article in cellular-news.com, HSDPA handsets will need "Hardware in the form of advanced baseband chipsets […] to handle the high data throughput while consuming little power; diversity receive circuitry may be required to handle the 16-QAM of HSDPA; and increased handset memory will also be needed." [4] Handsets made with Freescale silicon are expected to be able to do all that and more.

Advanced Receiver Architecture

The i.300-30/MXC300-30 platform has two equalizers to help improve performance, particularly at high data rates. 3GPP has endorsed this architecture for Category 6 and above. The i.300-30 also has diversity support for two receive antennas. This provides a 3 to 6 dB performance improvement. The shared silicon of the i.300 and MXC provides a range of platforms that scale performance through software, from Category 4 to Category 8.

Balancing Software and Hardware

Freescale has implemented HSDPA as a software radio. Flexible hardware is supported by software that can configure the hardware in many different ways. This means that our time-to-market is shorter than it would be with a dedicated hardware solution, because performance can be modified through software. New generations of technology (i.e. modems) can carry applications forward along an evolutionary path. This could reduce time-to-market for consumer products by 6-9 months for each new technology (i.e. 3.5G, 4G, 4.5G, etc.)

The Freescale approach hits an optimal balance of power and cost. Because HSDPA is a recent technology, flexible solutions are required. The most flexible solution is in software—it requires high performance in the DSP, but at higher cost and power consumption. The least flexible solution is hardware, but hardware provides the lowest power and cost. Freescale's balance is to perform most high-performance operations (chip rate operations) in hardware, and allow software to manage the hardware and perform the symbol rate operations that manage the data from multiple receivers and power control. This allows flexibility where it is most needed, while not imposing a high and expensive DSP load.

In a conventional architecture, the DSP processor, which does all the software processing for the stack, executes from local on-chip memory. Recent generations of DSPs have some cache on board that allows them to execute instructions from external memory. Freescale's approach provides caches for instruction and data, and an L2 cache.

For a DSP cache-based architecture, Freescale's L1 and L2 cache hierarchies on the DSP allows high performance from the DSP when executing code that is stored in external memory. This lowers overall system costs, because the main store for code and data is in external memory. External memory comes in multiple megabytes, so it has the lowest cost per bit, while on-chip memory only come in kilobytes and is expensive to implement.

Managing Performance and Power

Because HSDPA is bursty by nature, peak DSP load varies. This requires high peak performance but in a low power and area implementation. To provide this, Freescale's solution has a turbo mode in the DSP. This turbo mode increases DSP core frequency (and voltage) to increase DSP performance for the short period of the peak load. To reduce power consumption, the turbo mode uses dynamic voltage and frequency scaling to reduce DSP core frequency and voltage outside of these peaks. This helps reduce power consumption and costs.

[4] "Upgrading to HSDPA is 90% Software and the Other Half is Hardware", cellular-news.com, June 29, 2005, http://www.cellular-news.com/story/13291.php

Onward to HSUPA

High Speed Packet Uplink Access (HSUPA) is the next step, expected in 2007. As the name implies, HSUPA is engineered to improve the spectral efficiency and latency for the W-CDMA uplink. HSUPA will help improve symmetric applications such as videoconferencing, e-mailing large files back and forth, and transferring files. It is expected that HSUPA will use HSDPA techniques such as adaptive modulation and HARQ to improve both signal speed and quality.

Freescale has been active in 3GPP, working to set standards for High Speed Packet Access (HSPA), which encompasses HSDPA and HSUPA. We expect that we will establish the same standards leadership for major innovations in the UMTS standard. We are currently developing flexible transmitters and accelerators for HSPA, which we expect to test in the field in 2006. We also anticipate that we will develop scalable solutions that address all the data rates in HSPA.

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