Section 1: Introduction

Broad adoption of powerful devices such as smart phones and tablets combined with user expectation of data-accessibility 'anywhere, anytime', are fueling the rapid deployment of applications and services for mobile platforms. Today, the mobile subscriber number has reached over 3.2 billion. This trend is projected to increase to 4 billion by 2018, as reported at the latest Mobile World Congress Conference.


e-Commerce enterprises and entertainment providers are developing innovative, cloud-based applications, specifically targeting mobile platforms. To support this diverse range of mobile applications with varying throughput and quality-of-experience (QoE) requirements while providing coverage to a global subscriber-base, the wireless operators are migrating towards heterogeneous access networks (HetNets). A HetNet solution, composed of a mix of cell sizes, frequency bands and access technologies enables service providers to tailor the network resource capacity to match user demands and deliver high QoE, while lowering the cost of service.

As mobile data traffic multiplies, power consumption through the internet increases correspondingly. According to a recent study by Bell Labs and the University of Melbourne Centre for Energy Efficient Telecommunications, wireless access networks are becoming the dominant energy consumers in IT, with their energy consumption exceeding that of datacenters.


Until recently, major power saving initiatives were only developed for the datacenter arena. However due to the exponential rise in wireless network power usage, telecom service providers are under pressure to implement power saving strategies in wireless HetNets as well.

In this paper, we will outline the power-optimization strategies for HetNet base stations and discuss how they can be achieved through System on Chip (SoC) solutions.

Section 2 describes the factors driving the need for power optimization in HetNets. Section 3 gives a brief technical overview of a typical HetNet architecture and identifies the main components in a HetNet base station where power management is required. Section 4 examines some strategies for power management in HetNet base stations and section 5 lists the key technical considerations for a baseband communication processor and remote radio head (RRH) components for achieving power-efficiency. Finally section 6 highlights the features of LSI's Axxia® 5500 communication processor IC and the Axxia baseband platform with integrated...
digital front end (DFE) that enable a cost-effective power-management system in present day HetNets.

Section 2: Need for power management in HetNets

In today’s connected globe, nearly half of the world’s population uses mobile communications generating about 1.6 Exabytes of mobile data per month, as reported by Cisco’s Visual Networking Index (VNI) report (Figure 1). Worldwide is projected to increase to 11 Exabytes per month by 2017.

Exabytes Per Month

Source: Cisco® Visual Networking Index (VNI) report


This means that in addition to increasing the network capacity, telecom operators are also required to provide global coverage and manage wireless infrastructures composed of disparate network technologies and protocols.

In the same report, Cisco forecasts that by 2017, over 27% of mobile connections will be through smartphones. Tablets will see a compound annual growth rate of 46%. These powerful platforms enable more and more subscribers to use their mobile devices to access internet based business and personal entertainment services. According to the Smart Insights analysts, about 80% of mobile usage derives from accessing mobile Apps.

Source: http://www.smartinsights.com/mobile-marketing/mobile-marketing-analytics/mobile-marketing-statistics/

As the demand for superior quality mobile data service increases and the global subscriber-base grows, wireless networks are getting more dense and power-hungry. Telecom service providers are deploying HetNets to address these challenges.

A HetNet is a hybrid of disparate networks - it is composed of different radio access technologies,
frequency bands and cell types, working seamlessly to deliver optimum performance and coverage. By adjusting the use of network resources to match user-application demands, HetNet delivers optimum performance. To create a viable HetNet based strategy, the service provider has to consider the price, power and performance of access points i.e., base stations.

IT power management is a known challenge and until recently datacenters have been regarded as the major energy consumer. However, as wireless is becoming the pre-dominant mode of accessing the internet, this paradigm is shifting. Today the majority of the IT power is consumed by wireless base stations and WiFi/3G access points and not datacenters, as reported by the Bell Labs study mentioned earlier.

As Figure 2 indicates, in 2012 the total energy consumption due to services accessed by wireless networks was around 9.2 terawatt/hour. In 2015, it is estimated that the energy consumption will increase to the 32-43 terawatt/hour. Of that cloud computing power usage, datacenters only account for about 9%; 90% of the power is predicted to be used by the wireless networks.

Until recently, IT power savings were achieved primarily by reducing datacenter power consumption. IT organizations use strategies such as server and storage virtualization to increase utilization of datacenter resources and plan to deploy servers implemented with power-efficient ARM processors instead of traditional X86 based processors. However, to reduce the overall IT power consumption, wireless HetNets need to be made more energy-efficient.

Among the wireless network components, base stations consume the most power, over 50% of the total power (Figure 3). To lower power consumption in wireless networks, base stations must be made more energy-efficient - this is driving the need for implementing effective power management solutions in HetNet base stations.
In the next sections we will briefly review a HetNet base station architecture and discuss strategies and solutions to lower base station power.

Section 3: Technical overview of HetNet components and base station

A high-level HetNet architecture is illustrated in Figure 4. A typical HetNet is composed of a combination of macro cells and small cells such as micro, pico and femto cells which are built around base stations of varying transmission power. HetNet support multiple radio access

Figure 4: HetNet Architecture

Source: 4G Americas, Developing and Integrating a High Performance HetNet, Oct 2012

The macro cells provide large capacity and wide area coverage to cellular networks and they coordinate with small cells to augment the network coverage and throughput capacity in high traffic areas. The performance requirements and power consumption of a base station are dependent on the cell-size. Small cells can be deployed anywhere as shown in Figure 4 - offices, commercial and residential buildings as well as other hotspots to extend network coverage and to offload the backhaul traffic from the main network. Typically their connectivity range is about 200M, they support up to 200 users and consume less than 5W. The macro cells provide a larger
coverage range, about 25 km. They can support up to 1000’s of users and their signal transmit power is greater than 10W/antenna.

The base station is the central component of a HetNet. Its major functional blocks are shown in Figure 5. It consists of a set of remote radio heads (RRH) and a base band processing unit (BBU). The RRH implements the RF sub-system including power amplifiers (PA), small signal RF chain and digital front end (DFE) functions. The RRH interfaces with the antenna and BBU as shown in the figure 4. The BBU is responsible for L1/L2/L3 network processing and supports wireless protocols such as LTE, LTE-A, WiFi, WCDMA. BBU interfaces with the backhaul network - internet and neighbor cells as indicated.

The HetNet architecture helps minimize overall wireless network power consumption. Since small cells can deliver high bandwidth coverage to users in hotspot areas at relatively small power consumption, especially indoors, they help reduce the transmit RF power of macro base stations. In addition, since mobile devices communicate with the small cell base station over a shorter distance, they have to transmit lower power RF signals. This preserves battery life and leads to fewer device recharges needed. We will focus on the base station power reduction in this paper.

Over 60% of the wireless network power is consumed in the base stations. The breakup of energy consumption among its functional components is shown below in Figure 6. Power amplifiers (PA) in the RRH and the feeders use more than half of base station power. The BBU, which uses up to 15% of base station power is another significant consumer. In the next section, we will discuss the strategies for minimizing power in these components.
Section 4: Strategies for improving base station power efficiency

The primary techniques for reducing power in the Radio module or a Remote radio head (RRH) and the BBU are described below.

Integration of base band processing functions in RRH and centralizing the remaining digital processing

In a conventional design, the Radio module housed in a cabinet connects to an external antenna via the feeder cable which causes significant power loss - 3db or more. Implementing a RRH that sits closer at the antenna as shown in Figure 7 will reduce this loss significantly.

In areas in the world where fiber is not widely installed, integrating the BBU into the RRH is a good option as this reduces the bandwidth requirements between the BBU and the RRH to only 1/10th of the bandwidth required when the RRH is remote from the BBU(Figure 7) allowing usage of DSL or similar technologies to feed BB data to cloud type or RAN equipment to save overall network power. This architecture is suitable for small cell applications.
For areas with a high density fiber deployment, cloud RAN can be set up where a high number of RRH are connected to a central base station server. It provides L1/L2/L3 processing by pooling BBU as shown in Figure 8. This increases the base station utilization as BBU resources are optimized for the traffic load i.e., applied where they are needed at a given time during the day (office vs. residential areas). As a result, the overall access network power decreases, as total RAN idle cycles are minimized. It also eliminates the need for local base station enclosures which would typically require air-conditioning.

- **Application-specific communication processor and hardware-accelerators**

In addition to minimizing power though optimal grouping of base band functions, power consumption can be lowered by performing protocol-processing on a dedicated application-specific processor (ASSP) platform instead of running software on general-purpose processors (GP-CPU). Since a HetNet is composed of complex and layered protocol stacks, GP-CPU cycles can be minimized by utilizing tailored modules for processing. Application-specific communication processors are architected to target network functions such as deep-packet processing, traffic management, and security. They incorporate function-specific hardware accelerators for these functions to improve efficiency and typically integrate technologies such as DSP which is highly suitable for signal processing for the baseband function. In the next section we will discuss the specific power-saving features of a SoC communication processor.

- **Increasing power amplifier (PA) efficiency**

The RF component of the base station consumes considerable power and this is primarily due to the low efficiency of PA. A PA transmitting signal with higher orders of modulation or multi carrier signals has a Peak to Average Power Ratio (PAPR) of 6-10db resulting in a low energy efficiency - typically in the range of 10-20% due to required back off of the PA. Improving the PA system architecture is another key strategy to minimize base station power. Design techniques such as enhancing linearization methodology of PA together with multi stage Doherty PA designs can be employed to increase its efficiency significantly. The next section outlines design requirements for improving PA power usage.
Section 5: Technical considerations for IC solutions to achieve power optimization in HetNet base stations

This section highlights the primary requirements for a wireless communication processor SoC to reduce base station power consumption without sacrificing performance. It also highlights some design techniques for improving PA efficiency.

Baseband communication processor SoC platform:

The baseband communication processor is responsible for intelligent protocol-processing in a base station. As shown earlier, it interfaces with the RRH and the backhaul network. Its primary requirements include:

- Support for integrated L1/L2/L3 packet processing

HetNet supports a variety of protocols. In order to process them with utilizing less power, the communication processor needs to consolidate packet-processing functions. Its architecture needs to implement advanced data-plane functions such as packet parsing, classification, editing and output queuing with very minimal CPU intervention. Function-specific hardware accelerators must be implemented to boost performance and offload the CPU. Support for advanced traffic management (TM) is very important, especially in macro cell applications. By implementing TM in the SoC, packet routing can be enabled within the macro cell subtended network itself, reducing the backhaul traffic and power.

- Power-optimized embedded CPU

The communication processor SoC relies on embedded CPU for a variety of management, housekeeping and configuration tasks. The embedded CPU can also be programmed to handle networking functions such as security and encryption. Often the L2 media access functions are executed on processors. Processors are expected to adjust to the dynamic mobile traffic patterns and handle peak-traffic situations. In addition, system vendors add proprietary features for product-differentiation through software APIs. To keep up with these requirements within power budgets, the communication processor should use embedded CPU cores which are highly optimized for power and which implement a number of power management options.

- Scalability

A HetNet is composed of diverse cell sizes to support different traffic loads and coverage requirements. Therefore the communication processor SoC architecture needs to be highly scalable to be optimized for any cell-size without idling processing resources and wasting power. For example, the processor for a pico cell application will require fewer resources such as CPU cores, hardware accelerators, packet-processing engines, memory caches and buffers compared to a macro cell. They may not require any advance traffic management features. The SoC architecture needs to scale easily to match applications needs with optimum resources. It needs to support multiple RRH by providing scalable interfaces to external baseband PHY.

- Flexibility and programmability

Flexibility to quickly adapt to dynamic data traffic situations and protocols is a key in a wireless HetNet application. Based on instantaneous radio conditions, the physical layer requires upper layers to change the routing or size of packet or alter data-plane functions to maintain
throughput and QoS requirements and provide a deterministic performance. It should offer a high degree of programmability so that the operator can select network processing functions based on applications. In addition, the architecture should be flexible so that the PHY or customer-proprietary modules can be easily integrated to provide low-power customized SoC solution.

- Power to power

Advanced power management strategy is critical for a base station processor. Depending on traffic and radio conditions, the embedded CPU cores, data plane processing engines, data paths must switch between active, sleep and standby modes instantaneously. The SoC must provide comprehensive power-save features such as clock gating. It should provide programmability to enable system software to identify and shut off idle blocks in a graceful manner and wake them up with minimum latency when required. It should seamlessly work with the power-save features of the embedded CPU cores to implement a holistic power down methodology.

**PA with advanced DFE technology**

As seen earlier, the RF part of the base station consumes up to 60% of power due to the need to transmit the user signal over the air. Emerging wireless standards demand higher data rates and broader bandwidth resulting in increased PAPR of a PA reducing its power-efficiency. Using advanced linearization techniques in DFE can increase the PA efficiency. DFE enables that the PA can operate with less back off hence in its non-linear region to decrease power consumption. The non-linearity of the PA is up-front compensated in the DFE using pre-distortion algorithm known as DPD (digital pre distortion). Furthermore a function called crest factor reduction (CFR) will clip the peaks of the signal so that the resulting error vector magnitude stays below the limits that are defined in the standards (e.g. 3GPP). This lowers the PAPR and allows the PA to operate closer to its areas of higher efficiency (close to the 1db compression point). The figure below gives an overview of how pre-distortion works and why it is needed.

In addition to the large amount of energy used to transmit the signal, a significant amount of energy is “burned” in the PA approximately only 50% of the power provided to teh PA is transmitted the other 50% are „transformed” to heat. In future, technology such as digital RF with Switch-mode PA designs will become feasible for commercial deployment and further increasing PA efficiency significantly over 50%.
Section 6: LSI’s solutions for designing power-efficient base station systems

This section highlights LSI’s state-of-the-art technology for achieving power-efficiency in wireless HetNet base stations. It outlines key technical features of LSI’s Axxia 5500 family of communication processors designed to accelerate performance and increase power efficiency for multi-radio base stations. It also talks about the Axxia baseband platform with integrated SoftDFE™ technology.

Axxia 5500 wireless communication processor

Axxia 5500 SoC integrates a comprehensive set of L2/L3 packet-processing capabilities and handles a variety of protocols. It implements function-specific programmable accelerators for the standard L2/L3 network tasks and for LTE protocols such as Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP). Autonomous execution of network processing functions without CPU intervention is a key power-saving feature. Data-plane functions such as parsing, classification and queuing are linked using its proven proprietary “virtual-pipeline” technology which achieves balance between power-efficient hardwired logic and flexibility of support for multiple functions. Axxia uses 16 ARM Cortex™-A15 processor cores which are power-optimized for mobile applications and ARM’s CoreLink™ CCN-504 low-latency interconnect. The virtual pipeline includes network accelerators such as the multi-protocol-processor (MPP) unit which can process up to 50Gb/s packet processing and the security processor with up to 20Gb/s of security processing. These accelerators enable Axxia to provide deterministic performance for massive mobile traffic.
Axxia 5500 architecture can be easily scaled by duplicating its functional blocks to match application needs. The number of its MPP, ARM cores and the baseband PHY interface ports can be selected to achieve the required performance for a power-optimized solution. For example, a low-cost, low-power pico cell processor can be designed by selecting minimum number of CPU cores, network engines and integrating the PHY and digital components of the RRH into a single chip. On the other hand, by increasing the number of CPUs and PHY ports and replicating the MMP engines and buffers, it can be deployed in a high-capacity macro cell base station. In addition, Axxia implements a switch to link ports to subtended base stations and a hierarchical traffic manager to minimize traffic and power in backhaul network.

Axxia’s flexible architecture enables OEMs to add proprietary functions as hardware blocks or software for additional integration and customization. It is bundled with software for common transport and security protocols including IPSec, IPV4, IPV6 and LTE MAC - this can be used to offload some data plane functions to achieve power-performance balance to meet diverse application needs.

In addition to using the power-optimized ARM Cortex-A15™ CPU, Axxia implements several power management features. They are easily programmable with ARM’s built-in power-save features including dynamic high-level clock-gating, and CPU sleep-modes through clock disabling. During idle periods, data plane engines can also be put into sleep/standby modes and clocks to inactive logic is automatically disabled.
**Axxia platform for Baseband and DFE integration**

Axxia 5500 SoC can be integrated with LSI’s SoftDFE module to develop an integrated Axxia / DFE platform.

The SoftDFE technology from LSI addresses the main challenge that OEMs face with radio modules i.e., support for various frequency bands, air standards and types of PA in a given radio platform. In addition, the integrated DFE solution should be agile to support the latest PA technology and algorithms developed. Unlike the hard-wired DFE, LSI’s programmable SoftDFE technology enables its customers to develop application-specific, power-efficient RF DFE modules for the PA. It supports the latest linearization techniques so that the PA is operating closer to its peak efficiency for the given instantaneous output power requirements. Using LSI’s SoftDFE block, the customer can build a single platform to support its RF module needs and simply re-program for a dedicated version of a RF module. This block can be used in a standalone SoC (e.g. for RRH) or can be part of a larger Axxia based SoC (e.g. Micro cell). The SoftDFE block is be able to support the entire algorithms required for a DFE to increase PA efficiencies to over 50%, and as a result saving significant amount of energy. The functions such as CFR and DPD have been explained in the DFE section.


Tier 1 base station OEMs typically have proprietary ASIC implementations of the L1 Baseband functions and the DFE for the RF module for product differentiation. LSI’s Axxia platform can seamlessly integrate customer’s L1 baseband and the DFE part of the RF module into the Axxia 5500 series of processors to deploy a highly integrated, customized, power-efficient IC solution for base stations, that is scalable from macro to micro and pico base stations in HetNets.

**Conclusion**

The ongoing global proliferation of mobile devices and services with superior QoE requirements is resulting in a data deluge. As a result, wireless access networks are surpassing datacenters in energy consumption. Telecom service providers are adopting HetNets as a strategy to keep up with the network throughput demands within cost and power budgets. HetNet, which is composed of different cell sizes, disparate technologies and protocols, delivers optimum performance by calibrating its capacity to suit the application needs. In order to optimize power consumption for HetNets, the power consumption of wireless base stations must be reduced. Power amplifiers and wireless communication processors account for the majority of power consumption in a base station and hence the service providers are looking for power-efficient and scalable IC solutions which can be deployed across HetNet access points. Power consumption in a baseband communication processor can be reduced by integrating L1/L2/L3 packet-processing and baseband functions, using energy-efficient processors and function-specific, programmable network accelerators to boost performance without sacrificing power. LSI’s Axxia 5500 SoC combines power-optimized ARM Cortex-A15
cores and scalable CoreLink CCN-504 interconnect technology with specialized data plane processing capabilities and protocol-processing engines to provide a scalable, flexible wireless communication processor. Axxia 5500 series is a scalable platform that can integrate baseband and RF SoftDFE functions to enable integrated, power-efficient base station SoC systems for wireless heterogeneous networks.