Delivering Technology Solutions for Broadband Communications

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Introduction

Today’s broadband solutions are quite complex and require semiconductor manufacturers to integrate a wide-variety of innovative technologies to offer low power, cost-effective system solutions that address the needs of original equipment manufacturers, service providers, and end-users. This paper provides an overview of the various broadband infrastructure, access and home networking technologies and examines the essential technology building blocks required to deliver end-to-end broadband connectivity from the infrastructure to end-point devices. Finally, this paper shows how Texas Instruments (TI) is uniquely qualified to deliver complete, end-to-end broadband solutions.

Evolution of Broadband Services

Broadband communications consists of the technologies and equipment required to deliver packet-based digital voice, video and data services to end-users. Broadband offers end-users high-speed, always-on access to the Internet while offering service providers the ability to offer value-added services to increase revenues. Due to the growth of the Internet, there has been tremendous build out of high speed, inter-city communications links that connect population centers and Internet Service Providers (ISPs) Points of Presence (PoPs) around the world. This build out of the backbone infrastructure or core network has been primarily via optical transport technology.

Broadband access technologies are being deployed to address the bandwidth bottleneck for the “last mile”, the connection of homes and small businesses to this infrastructure. The rollout of broadband access technologies is still very much in the early stages of deployment. For example, according to a recent Yankee Group study, fewer than 14 percent of U.S. residential Internet subscribers have broadband access to their home.

As broadband access becomes available to home users, it is truly changing the way people work and play. Users tired of waiting for web pages to download using dial-up modem Internet access are signing up for broadband access services. What they find is that not only does broadband access result in fast web surfing due to higher connection speeds but it also has several other benefits. The higher connection speeds enable multimedia applications such as real-time Internet audio streaming, posting and displaying digital photographs for friends and family, viewing video clips of news events, and movie trailers, and taking virtual tours of hotels and resort areas before making reservations. Since broadband access is always on, unlike dial-up access, there is no wait to connect to the Internet. Thus, people with broadband access tend to leave their PCs turned on and use the Internet for more mundane tasks such as checking TV listings and looking up phone numbers, tasks that were not worth the bother when a slow dial-up connection had to be first established. The presence of broadband access also means that the telephone line is no longer tied up when accessing the Internet. This saves the need to purchase a second phone line and enables the user to talk to some one on the phone while accessing information from the web.
Another important aspect of broadband access to the home is it allows people to telecommute effectively by providing a similar environment as when they are physically present in their office: simultaneous telephone and computer access, high-speed Internet and Intranet access for e-mail, file sharing, and access to corporate servers.

Once people obtain broadband access to the home, they find that this access needs to be shared with other members of the family using multiple PCs. This includes workers who use laptop PCs at their workplace and desire to be able to use the same laptop at home. As a result, people are installing local area networks (LANs) in their home. Once this LAN is in place, people want to use it to share files, printers and devices such as scanners. Once broadband access and home networking reaches critical mass in terms of market penetration, there will be a new class of end-user devices that will enable many new Internet-enabled applications. Already, people are able to perform functions remotely via the Internet such as monitoring and controlling their homes, viewing their children who are in day care centers, checking on live traffic conditions, and playing stereo quality music over Internet radios.

The key drivers for Broadband growth along with the resulting impacts are summarized in Figure 1. TI’s vision of the broadband home is that broadband multimedia, i.e., video, audio, voice, and data will be delivered to and within the home to personal endpoint devices. Services will be affordable, easy to use, and available to the average family and will be delivered quickly, securely and reliably. Moving forward, all things will be connected.

**Figure 1: Drivers of Broadband Growth and Impacts**

- Demand for high-speed connections, streaming video and audio
- Home networking: Multiple PCs and Internet appliances in the home
- Personalization: Services customized to the individual
- Shift from PC world to network devices world
- Backbone infrastructure will provide more capacity (and QoS)

**Impact**

- More Bandwidth consumed per home and office
- More Capacity needed from infrastructure
- QoS needed end-to-end
- Home Networking standards mature and co-exist
- Voice/Video/Audio distributed in-home and office
- Internet Appliances, End Points & Services through the home network
- Security needed to protect consumer, provider & content
Broadband Connectivity

Figure 2 shows how broadband connectivity is extended from the core infrastructure to end-users’ devices such as personal computers, PDAs, telephones, television sets, and digital cameras. Infrastructure gateway equipment provides broadband access to the packet-based infrastructure. Customer premise equipment (CPE) access gateways extend broadband access connectivity to end-user devices via one or more home networking technologies.

Broadband Access Technologies

There are many competing broadband access technologies being brought to bear to address last mile connectivity, including:

- Cable modem
- Digital subscriber line (DSL)
- Fiber
- 2.5G and 3G cellular wireless
- Wireless Ethernet
Cable

As an alternative to existing copper phone wires, cable companies have been providing broadband access by upgrading their cable plant to carry data and voice services in addition to traditional video services. A cable modem termination system (CMTS) communicates with cable modems located at the customer premise to provide broadband access services. The cable modem typically provides an Ethernet interface to a PC or to a small router when multiple PCs are connected. Today's cable networks generally deliver data with download speeds roughly between 500 kbps and 2 mbps and upstream speeds of 128 kbps. Newer generation cable modem technologies will significantly increase the available bandwidth to further enable interactive applications such as videoconferencing and high-end online video.

IP telephony is one of the services that can be delivered over coaxial cable. For the cable operators, IP telephony enables them to offer voice services which, to date, have been the domain of the telephone companies.

DSL

DSL technology is a copper-loop transmission technology for transmitting high-speed data over ordinary telephone wires. A DSL modem is installed at the customer premise and at the CO. Different variants of DSL exist to address different technology trade-offs that can be made regarding different network environments and applications. One of the key trade-offs is distance (referred to as reach) from the Central Office (CO) and data rate. Asymmetrical DSL, or ADSL, is primarily used for residential services. ADSL takes advantage of the fact that there is more cross-talk interference at the CO end of a copper pair than at the subscriber end due to the large bundles of cabling entering the CO. ADSL can provide data rates up to 8 Mbps from the network to the subscriber direction, and up to 1 Mbps from the subscriber to the network direction. The asymmetry of ADSL works well for today’s home applications where the majority of bandwidth is consumed in the network to user direction.

Symmetrical DSL, or SDSL, is a cost-effective solution for small and medium enterprises, offering a competitive alternative to T1 and E1 lines. A recent new standard that is a replacement for proprietary SDSL is the ITU-T standard G.991.2, which is also known as g.shdsl. G.shdsl offers data rates from 192 Kbps to 2.3 Mbps while providing a 30 percent longer reach than SDSL.

Very-high-bit-rate DSL, or VDSL, can support symmetrical or asymmetrical services. Asymmetrical VDSL is capable of providing data rates to the user of up to 52 Mbps making it suitable for transporting high-speed applications such as real-time video streaming. The trade-off for this high speed is restricted reach. This requires that the customer be located close to the CO or the infrastructure access gateway resides outside the CO (and closer to the customers) in a remote terminal.
**Fiber**

For new infrastructure build-out, where copper wires are not currently present, the installation of fiber is being employed. Fiber-optic technology, through local access network architectures such as fiber-to-the-home/building (FTTH/B), fiber-to-the-cabinet (FTTCab), and fiber-to-the-curb (FTTC) offers a mechanism to enable sufficient network bandwidth for the delivery of new services and applications. A fiber optic cable is run from the CO to the neighborhood. Passive optical splitters are used to provide point-to-multipoint connectivity. This is referred to as a Passive Optical Network or PON. In the case of FTTCab or FTTC architectures, the signal is converted to provide connectivity to the subscribers via copper pair wires. Since these cabinets are collocated in a neighborhood, the copper pair run is typically less than 3,000 feet; thus enabling high-performance xDSL access to be achieved.

**2.5 and 3\(^{rd}\) Generation (G) Cellular Wireless**

Next generation cellular is providing high-speed data capabilities in addition to traditional voice. Current 2G cellular services only offer data service rates on the order of 9.6 kbps. The emerging 2.5G services will boost available bandwidth to the user and facilitate always on data services. For 2.5G networks, there are two primary technologies: general packet radio service (GPRS), and enhanced data rates for GSM and TDMA (IS-136) Evolution (EDGE). Third-generation wireless communication technologies support even higher data rates. The packet switching is IP-based, making for efficient routing of data from the Internet through the carrier's gateway. The higher bandwidth should allow for better integration of voice, data and video signals. Delivery of data services over cellular offers the promise of ubiquitous high-speed data access, including while in moving vehicles.

**Wireless Ethernet**

In addition to cellular-based wireless data services, wireless Ethernet, traditionally a home and enterprise networking technology (see below), is being used for broadband access in public areas such as airports, hotels, sports arenas, convention centers, and coffee shops. This allows users to take their laptop and PDA devices with them and use a common access technology to deliver high-speed Internet services in their office, home and while on the road.

**Home and Enterprise Networking Technologies**

While most corporations today have some form of wired Ethernet LANs to address their networking needs, most homes do not have any form of networking infrastructure. There are several competing home networking technologies including:

- Ethernet
- HPNA
- HomePlug
- Bluetooth™
- Wireless Ethernet
Ethernet is the most ubiquitous LAN technology and as such, very low-cost Ethernet adapters exist for PCs and other devices. However, installing Ethernet cabling in existing homes is expensive as it involves labor-intensive work to snake cables through existing walls, install outlets and repair drywall. As such, installation of Ethernet cabling is typically relegated to new construction. As an alternative, technology has been developed to use existing phone wiring to run LAN traffic simultaneously with voice. The Home Phone Networking Alliance (HPNA) defines standards for interoperability using this technology. Unfortunately, most homes have a limited number telephone jacks for access to the wires. Thus, the expense of adding new wires must still be dealt with. Technology has been developed to use existing home AC wiring to run LAN traffic. Since most rooms have multiple AC outlets, there is access to the LAN from practically anywhere. This still requires the device accessing the LAN to be tethered since it must plug into the AC outlet.

As an alternate to wired networks, wireless standards exist including Bluetooth and wireless Ethernet (Wireless LAN or WLAN). Bluetooth was developed to replace the need for interconnect cabling between devices for short-range and relatively lower data rates. Wireless Ethernet is a standard developed by IEEE (802.11) that preserves Ethernet compatibility and data rates. It is gaining wide traction for home, enterprise, and public access networking.

The current standard for Wireless Ethernet is 802.11b and it offers 11 Mbps transmission rates using Direct Sequence Spread Spectrum (DSSS) technology. The standard, also known as Wi-Fi™, is widely used in offices, campuses and homes. Radio transmission is in the 2.4 GHz band. The 802.11a variant of the standard operates in the 5 GHz frequency band and offers transmission rates up to 54 Mbps using orthogonal frequency division multiplexing (OFDM) technology, in which the devices determine a set of non-interfering frequencies, multiplex these frequencies, and use them in parallel to achieve greater bandwidth. A recent addition to the 802.11 standard is 802.11g, which extends DSSS operation to 22 Mbps and also supports OFDM operation in the 2.4 GHz frequency band.

Wireless standards must address potential transmission interference with other devices including microwaves, cordless telephones and other wireless standards that operate at the same frequency. Also, since it is wireless, solid encryption is required for security purposes.

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<tr>
<th>Networking Standard</th>
<th>Description</th>
<th>Type</th>
<th>Installation Requirements</th>
<th>Maximum Data Rate Mbps</th>
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<td>802.3 Ethernet</td>
<td>Highest capacity; commodity hardware</td>
<td>Wired</td>
<td>New wires</td>
<td>10/100</td>
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<tr>
<td>802.11 Ethernet</td>
<td>Wireless Ethernet</td>
<td>Wireless</td>
<td>No wiring required</td>
<td>11/22/54</td>
</tr>
<tr>
<td>HPNA</td>
<td>Home networking using existing telephone wires</td>
<td>Wired</td>
<td>Some new wires</td>
<td>1/10/32</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>Short range cable replacement</td>
<td>Wireless</td>
<td>No wiring required</td>
<td>1</td>
</tr>
<tr>
<td>HomePlug</td>
<td>Home networking using existing AC power</td>
<td>AC Wires</td>
<td>No new wires</td>
<td>10</td>
</tr>
</tbody>
</table>

**Figure 3: Home Networking Technologies**
Broadband Building Blocks

This section looks at the technology building blocks required for developing broadband solutions. The challenge of the semiconductor manufacturer is to design silicon and software with a complete solution focus and not just chips or chipsets. As shown in Figure 4, customers have many needs that require a multitude of core competencies for semiconductor manufacturers to satisfy. First of all, customers desire flexible solutions that can accommodate a range of densities to meet requirements scaling from end-point devices to customer premise equipment to carrier class equipment. Flexibility dictates the need for programmable architecture that can facilitate quick and easy software upgrades to address new features, interoperability issues, performance, and evolving standards.

For broadband technologies, high performance digital signal processors (DSPs) are required to implement the various signal processing algorithms necessary to perform functions such as modulation, voice compression, and video processing. The industry has moved beyond general purpose DSPs to specialized silicon/software solutions optimized for a particular vertical application. These solutions include:

- Digital signal processor (DSPs) cores
- RISC processor cores
- Networking interfaces including Ethernet, Utopia, PCI, USB, 1394, etc.
- Software with well defined application programming interfaces (APIs) including signal processing algorithms, protocol stacks, device drivers, real-time operating system ports, network management, and application software
- High-performance analog components, including data converter and amplifiers
- Power management solutions, including power supply control and battery management
- Digital modem technologies for broadband communications
- Radio frequency wireless technologies for wireless devices
- Voice over Packet (VoP) technologies including voice compression, echo cancellation, tone processing, dial modem, Group 3 facsimile, and telephony signaling
- Networking technologies including routing, switching, filtering, encryption and Quality of Service (QoS)

These solutions must be very low power to allow battery or line powered operation for end-point devices or to scale in an infrastructure environment where equipment is limited by power consumption and heat dissipation.

Cost is always a concern. Customers want semiconductor providers to provide them with the lowest cost solution. This is for the entire customer’s solution, not just the semiconductor manufacturer’s portion. Thus, the semiconductor manufacturer must understand the total build of materials (BOM) cost of the equipment and work at reducing the total BOM. This includes integrating more functionality into the silicon solution and eliminating the need for “glue” logic. It also includes reducing manufacturing costs by making the solution easy to build by minimizing the number of printed circuit board layers, making the chip package easy to mount and signals easy to route on the printed circuit board. There is a constant need for cost reduction for mass-market deployment. Customers want to know that the semiconductor’s roadmap will offer significant cost reduction for subsequent customer refreshes of the product. Key to facilitating continued cost reduction is having high-volume manufacturing facilities with leading edge process technologies coupled with strong system integration capabilities.

To speed customer time to market, semiconductor manufacturers must offer the customers hardware reference platforms integrated with software and fully system tested for conformance to industry standards, interoperability with other vendors, and product hardened under real world conditions.

The following subsections look at how building blocks are put together to deliver broadband solutions for infrastructure equipment, premise access gateway equipment, and broadband end-point devices.
Infrastructure Equipment

As shown in Figure 5, broadband infrastructure gateway equipment is responsible for interconnecting broadband access services to the optical core network infrastructure. For multi-services gateways, multi-core DSP platforms facilitate the ability to support multiple broadband access technologies as well as traditional voice-grade services. Communications processors containing high-speed processing engines and networking interfaces perform protocol processing and network management functions. High-speed aggregation logic is required for performing packet processing while providing QoS functions.

![Figure 5: Broadband Infrastructure Gateway](image)

Infrastructure gateway equipment providing broadband access is driven by the need to support a large number of end-user connections in a concentrated area (central office or remote terminal unit in the neighborhood) while being constrained on the total power (heat) dissipation.

Texas Instruments has developed the concept of solution density to help service providers and original equipment manufacturers more clearly understand the technical requirements for implementing high-density products. From a system engineering perspective, a solution must be evaluated on how the combination of system elements delivers a complete solution with lowest power and smallest area without compromising quality and features. Solution density refers to the optimization of the overall system architecture, taking into account the following critical elements:

- Power of the solution expressed in milli-Watts (mW) per end-user channel
- Density of the solution expressed in end-user channels per square inch
- Cost of the solution including silicon, hardware, software and any intellectual property license fees
• System partitioning including packet aggregation and routing
• Software features that define the functionality of the product
• Network management capabilities to address high availability and accountability

In order to engineer an optimal solution, cost, power and area must be evaluated on a total system basis and must be a function of the features and capabilities supported. For example the designer must consider the need for external logic, e.g., external memory, aggregation logic, layout/routing issues, etc. In many systems, power (heat dissipation) is the key-driving factor especially for high-density solutions. That is, most solutions run out of power in the rack before they run out of board area. Proper functional partitioning is also essential to avoid processing and/or bandwidth bottlenecks in the overall system when scaling to support very large numbers of end-user ports.

**Premise Access Gateway Equipment**

As shown in Figure 6, premise access gateway equipment is responsible for terminating a broadband access pipe from a service provider and making that pipe available to the home or office home network. Communications processors containing high-speed processing engines and networking interfaces perform protocol processing such as bridging, routing, packet filtering and firewall operation. Typically, a premise access gateway provides connection to a single broadband access medium, e.g., cable or DSL or fixed broadband wireless but may support multiple LAN interfaces such as wired Ethernet, wireless Ethernet and Bluetooth. VoP technologies are required for derived voice services.

![Figure 6: Broadband Premise Access Gateway](image-url)
Broadband End-Points

As shown in Figure 7, broadband end-point devices come in many forms such as PDAs, digital cameras, MP3 players, digital television, and IP Phones. DSPs perform multimedia processing such as MP3 audio, MPEG4 and JPEG imaging. High quality analog components are essential for performing analog to digital (A/D) and digital to analog (A/D) processing. These consumer devices must be extremely low cost. Devices that are portable handheld devices must be very low power to ensure long battery life. Also, devices that are line powered, e.g., from the infrastructure, Ethernet, or USB interface, must adhere to the power constraints of that interface. Thus, low-power devices coupled with power management technologies are essential.

Figure 7: Broadband End Points
TI Broadband Solutions

Texas Instruments is uniquely qualified by possessing all of the necessary technologies and system expertise to provide original equipment manufacturers with complete and innovative solutions. As shown in Figure 8, TI offers the following broadband and home networking solutions:

- **ADSL**: Infrastructure, residential gateway, and CPE (PC and embedded)
- **Cable**: Infrastructure (CMTS) and CPE (Cable Modem)
- **Universal port remote access server (RAS) for POTS services**: Dial modem (V.90, V.92, V.34…), Group 3 facsimile (fax) and Voice over Packet (VoP)
- **Voice Over Packet solutions**: Infrastructure (high density), CPE (integrated access device), and end-point (IP phone)
- **Home networking**: Ethernet, 802.11a/b/g wireless Ethernet, Bluetooth
- **Internet digital audio and video**: MP3, MPEG4, and others

![Figure 8: TI Broadband Solution Landscape](image)
Only TI provides all the building blocks for the end-to-end solution. Because TI plays in every element of the system from the end-point to the infrastructure, TI understands how and where to best deal with end-to-end issues such as security, quality of service, network management and remote troubleshooting capabilities.

DSP and analog drive big-volume markets such as digital wireless phones and broadband networking gear. TI is leveraging its strength in these markets to penetrate intriguing new product categories such as Internet audio, voice-over-packet, digital still cameras, bio-medical devices, e-mail terminals, web terminals, Internet-accessible TVs, screen phones and other handheld information appliances and more. International Data Corp. early this year predicted worldwide market for non-PC information appliances will grow from 11 million units shipped in 1999 - worth $2.4 billion - to ~90 million units shipped in 2004 worth almost $18 billion. While there will be great diversity among these products, most will have critical characteristics in common: ease of use, portability and highly personal. Many of these products will be linked via always-on broadband connections.

**TI Powered Broadband End-Points**

**Features**
- Easy to use
- Personal
- Connected
- Always on
- Programmable

**Broadband Products**

*Figure 9: TI Powered Broadband End-Points*
TI broadband solutions leverage the overall strengths of TI in delivering highly innovative and integrated solutions:

- Leader in programmable DSP platforms—best in cost, power, and performance
- Leader in analog—power, signal conditioning, and mixed signal
- System, software, and analog integration capabilities—best system level solution
- World class software tools and DSP value network—open systems reduces customer’s time to market and development costs
- Silicon/SLI/ASIC technology—customized system solutions
- World class production facilities—support large volume production and rapid ramp up
- Intellectual property (patents) —innovation, ability to offer indemnification

**TI Ingredients for Broadband Solutions**

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**Summary**

Texas Instruments is uniquely qualified by possessing all of the necessary technologies and system expertise to provide original equipment manufacturers with complete and innovative solutions from the infrastructure equipment to the end-point devices. For more information see the broadband solutions section at [www.ti.com/sc/broadband](http://www.ti.com/sc/broadband).
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