Using network processors in DSL residential gateway design

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Abstract

Digital Subscriber Line (DSL) is a modern technology that uses digital coding techniques to transform ordinary phone lines (also known as “twisted copper pairs”) into high-speed data transfer lines. DSL offers an always-on dedicated connection that allows for simultaneous voice and data service. This paper focuses the discussion on the DSL end-to-end implementation and using a Network Processor in DSL Residential Gateway (Customer Premise Equipment) design, such as DSL router, bridge and IAD to help for faster DSL deployment. Designing a DSL Residential Gateway based on the Intel(r) Network Processor architecture as an example, will help the developer shorten their design cycle, because the platform embeds the DSL network processor chip, RTOS, IP protocol stack, RFC2364, RFC1483 and network drivers.

Introduction of DSL

DSL provides point-to-point connection between end user and telephone company Central Office (CO). At the home or office, customers have a DSL modem attached to their PC (either by internal PCI, external Ethernet, or external USB), which directly feeds to the CO. At the CO, data from multiple users is multiplexed via a Digital Subscriber Line Access Multiplexer (DSLAM) and passed asynchronously to a high-speed regional Wide Area Network (WAN). The access to this regional network is controlled at the CO Asynchronous Transfer Mode (ATM) Access Switch. Content providers, such as Internet Service Providers (ISPs) are connected to this regional broadband network via a high bandwidth transport mechanism. Figure 1 shows basic implementation between DSL CPE and CO.

There are a number of DSL technologies that have been developed to meet customer needs. The most common DSL technology is Asymmetric Digital Subscriber Line (ADSL), which delivers greater downstream bit-rate transmission than upstream. Conversely, Symmetric Digital Subscriber Line (SDSL) is deployed when customers, usually Small-Office/Home-Office (SOHO) users, telecommuters, or small businesses, need larger upstream bandwidth to upload files or perform video conferencing. As the voice application emerges, Voice over DSL (VoDSL) is getting popular lately. Figure 2 compares the various bandwidths for the DSL type.

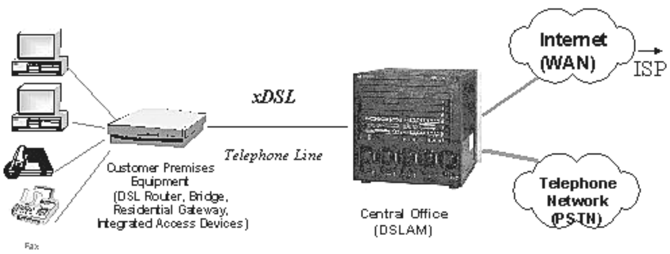


Figure 1. The Basic Implementation of DSL CPE and DSLAM

	Asymmetric DSL			Symmetric DSL		
Type	ADSL	G.Lite	VDSL	HDSL	HDSL2	SDSL
Maximum Upstream Speed	1 Mbps	512kbps	6.4 Mbps	784kbps/ 1.5 Mbps(T1)	2 Mbps	1.1 Mbps
Maximum Downstream Speed	8 Mbps	1.5 Mbps	52 Mbps	784kbps/ 1.5 Mbps(T1)	2 Mbps	1.1 Mbps
Maximum Distance	18 kft	25 kft	1 kft	12 kft	12 kft	12 kft
Cable pairs	1	1	1	2	1	1

Figure 2. DSL Bandwidth Comparison

DSL depends upon advanced digital signal processing and creative algorithms to squeeze so much information through twisted-pair telephone lines. To create multiple channels, DSL modems divide the available bandwidth of a telephone line in one of two ways: Frequency Division Multiplexing (FDM) or Echo Cancellation. FDM assigns one band for upstream data and another band for downstream data. The downstream path is then divided by time division multiplexing into one or more high speed channels and one or more low speed channels. The upstream path is also multiplexed into corresponding low speed channels. Echo Cancellation assigns the upstream band to overlap the downstream, and separates the two by means of local echo cancellation. With either technique, DSL splits off a 4 KHz region for POTS at the DC end of the band. Figure 3 showed the different modulation between FDM and Echo Cancellation.

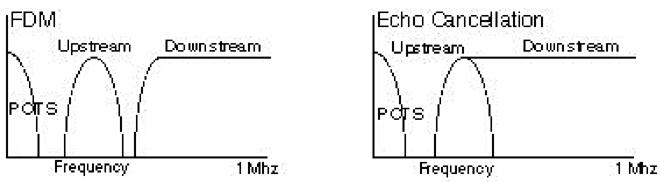


Figure 3. FDM and Echo Cancellation Comparison

DSL Technology

DSL is in effect an encoding technology over which may be deployed with higher layer encapsulations like ATM, protocols, and IP. The use of Layers (OSI reference model) is an easy way to map the DSL model that is currently deployed in the market today.

Within the DSL deployment, the Physical layer handles basic DSL encoding including the standards, data rates and compatibility with other technologies in the copper loop. Two popular encoding techniques used in DSL today are Discrete Multitone (DMT) and, Carrierless Amplitude and Phase (CAP). CAP and DMT are frequency domain techniques. However, CAP depends more on the time domain compared to the DMT which is capable of sending high bandwidth symbols across a wider spectrum for a short period of time (up to 1088 Kbaud), while DMT depends on many smaller bandwidth channels, sending longer duration symbols at a narrower frequency.

The Data Link Layer in an OSI model can be associated as an ATM encapsulation layer, where it encapsulates higher layer protocols in a packet transport over the encoding physical layer. ATM is selected as the encapsulation technique because most of the DSLAM and DSL modems deployed today rely on this technique, even in the Access network in an internet backbone. Closely associated with the ATM layer is the ATM Adaptation Layer (AAL) where data, voice and video traffic is adapted for transport in ATM cells.

There are various methods of transporting data, voice and video. Across such as RFC 1483 Ethernet MAC encapsulation over ATM , RFC 2364 PPP over ATM , Classical IP (RFC 1577), etc. RFC 1483 is mainly implemented in the DSL bridge design, while RFC 2364 is used for IP Routing (DSL Router) design today. PPP over Ethernet (over DSL) is getting popular today which places a small encapsulation header between the PPP header and the Ethernet MAC layer. RFC 1577 Classical IP model is not so popular in the market now. As for implementation today, we will focus more on IP at the Network Layer and TCP as a transport layer protocol.

Session and presentation are pretty much hidden from the end user, as their functions are normally within a given application. For an Application layer with which the user interacts, IP applications like FTP, DNS, TFTP, SNMP, SMTP, DHCP, etc., are commonly found in the DSL CPE software stack. Figure 4 shown the Internetworking Stacks.

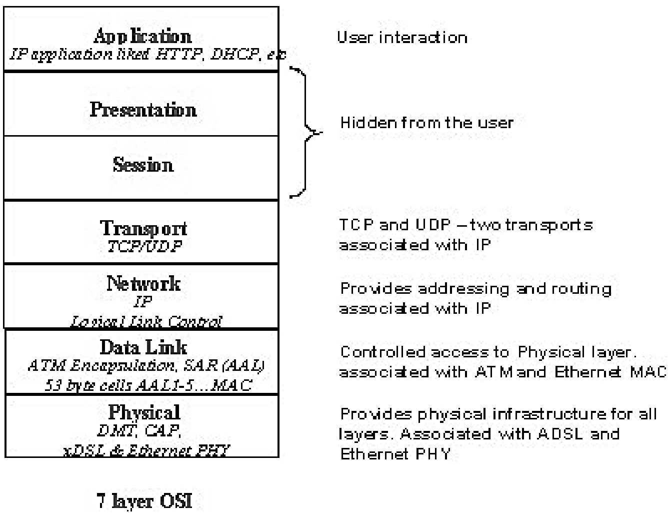


Figure 4. Layering Model

Definition of Residential Gateway

Multiple PCs at home is more common today. By 2002, Jupiter Communications predicts there will be 15.3 million home networks. The trend toward home networking is fueled by the increasing needs of homes with multiple PCs and other electronic devices. In 1999, 60% of new PC purchases were made by families that currently had at least one computer at home (Dataquest).

- Can all my computers access the DSL connection at the same time?
- Do I need to get several DSL lines in the home?
- Is there some way to utilize the home network so everyone can access the same DSL connection?

There is if you have a Residential Gateway (RG). This device seamlessly connects a home network to a broadband network, allowing the benefit of high-speed connection to be simultaneously enjoyed by all networked devices at home.

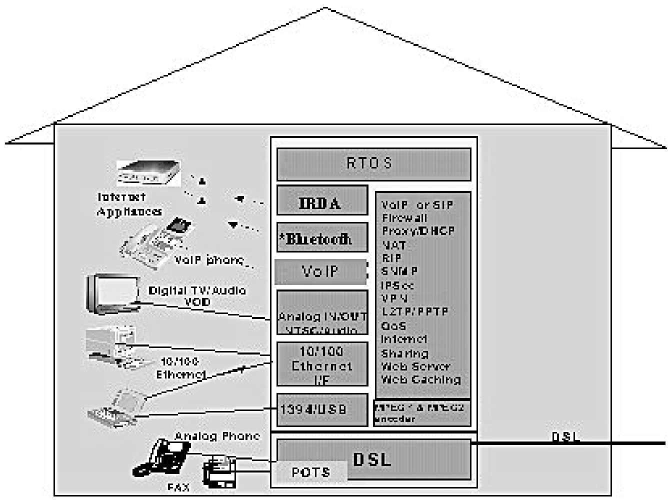
The CPE for residential and small business segments may range from being a residential gateway (RG) to an IAD. A residential gateway supports high-speed Internet access, as little as one voice line, and a mandatory lifeline support. In addition. the RG needs to support some form of home networking such as Ethernet, HPNA (home phone networking alliance) and wireless. The Internet access is ADSL as it is lower in cost and it inherently provides lifeline support.

An IAD may serve a small office, supporting up to four or eight voice lines and a high-speed Internet connection. Voice compression is optional, but does not provide any significant gains when using a broadband DSL access line. DSL service can be either asymmetric (ADSL) or symmetric (e.g., HDSL2 or G.SHDSL).

This paper will define Residential Gateways to two categories: Data only — DSL broadband Residential Gateway and Data + Voice — Multi-service Intelligent Residential Gateway

DSL Broadband Residential Gateways are primarily broadband data gateways only. They were built with one specific home networking technology (supporting HomePNA, Ethernet, USB, or wireless) and connect to broadband WAN access through DSL technology. Multiple PCs in the home can share one broadband network connection at the same time. Minimum security and management features like SNMP, OAM, IPSec are needed. DSL Router and Bridge are the typical design for this category.

Multi-Service Intelligent Residential Gateways support multiple home networking technologies, deliver telephony



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**Other brands and names are properly of their respective owners.*

Figure 5. Residential Gateway Software Features and Interfaces

(voice) features, video conferencing and support entertainment services in the form of streaming video and audio and interactive besides to high-speed Internet access. Higher security features liked Firewall, MPLS, IPSec will be supported to make sure that security is taking care of. Figure 5 showed the software features and Residential Gateway requirements.

Architecture and Design of DSL Residential Gateway

DSL Network Processor

Off-the-shelf communication processors with on-chip central processing units have been used in the past. This approach gained wide acceptance in the industry because of its relatively high integration of RISC processors and the protocol-intensive communication interfaces. However, recently the fast introduction of broadband services, requiring much faster equipment designs, have rendered this approach too slow for many to use. In addition, these increased performance requirements have rendered this approach too limited, due to the increased WAN bandwidth and the need to perform higher-layer-protocol processing.

Many networking equipment designers have taken the application-specific-integrated-circuit (ASIC) approach for some of their designs. The disadvantage of this approach is that it requires consistent high volume orders to achieve the required cost target. Not to mention ASIC long lead-time (typically 18 months) is unacceptably lengthy for CPE product introductions. Therefore, the network processor is gaining the momentum and becoming the choice of the designer to replace the generic RISC processor or ASIC design, because of its high integration of network processing capability, flexibility, providing industry standards based interfaces to Ethernet and DSL MAC/PHY and, lower cost.

The Service-Specific Concept

The service-specific concept extends the evolution of network processors a major step forward, to focus on CPE designs. By optimizing network processors for specific WAN services, these platforms become integrated silicon-and-software foundations for modems, bridges, routers, Intelligent residential gateways and integrated access devices. Integrated with the underlying hardware are the operating system, complete service-specific networking protocol stacks and an open Application Programming Interface (API). The result is a specialized network processor targeted at a specific WAN service, such as broadband Internet access over asymmetric DSL (ADSL), SDSL and voice over DSL (VoDSL).

DSL network processor platform consists of the following components:

- DSL network processor - highly integrated communication processor with on-chip RISC engine, Ethernet MAC, Voice function and DSL function dedicated network processor engine. The DSL network processor needs to be a PHY neutral processor, which provides the flexibility for the designer to choose the DSL chipset, Ethernet PHY and SLIC/CODEC for their design. This is important to avoid the interoperability issues and provide the flexibility for local complaint issues, for example: Japan will only support G.992.2 Annex C compliant CPE in ADSL deployment.
- DSL network processor OS - industry standards based RTOS kernel with preemption and multitasking capabilities, generic TCP/IP stacks and targeted drivers.
- DSL network processor stacks - industry standards based ATM encapsulation and signaling stack, plus a PPP stack, which includes IP control protocol (IPCP) and challenge handshake authentication protocol (CHAP). Application programming interfaces (APIs) need to be included for this layer, so the designer can optimize code and add higher-level value by adding higher layer IP applications such as DHCP, NAT, SNMP, DN, etc. Figure 6 depicts the internal details of these three major components and the link of each layer.

The Intel® DSL Network Processor as an example has the standard interface (MII) to connect to Ethernet PHY chip for the Ethernet LAN side. On the DSL side, a different type of DSL chipset can be used through the UTOPIA interface or the High Speed Serial interface to provide the DSL broadband access. On the voice side, it provides Gateway Circuit Interface (GCI) for SLIC/CODEC connection.

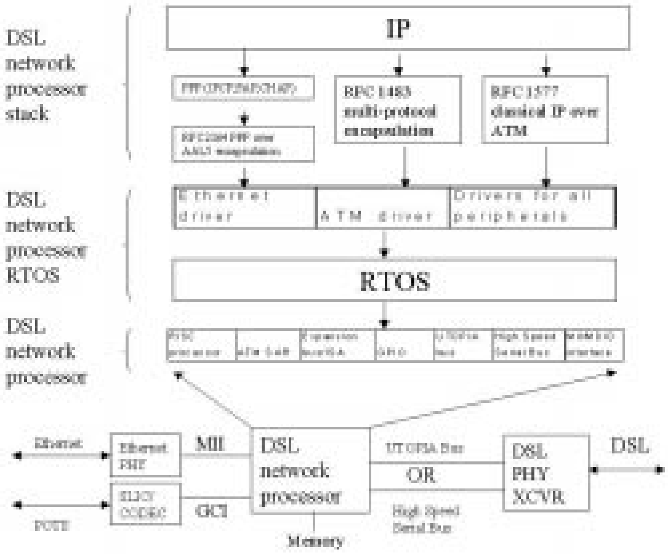

Figure 6. Software Architecture of Intel DSL Network Processor in Residential Gateway Design

Bridging

Bridging is one of the methods of interconnecting two or more internetworking devices, and relies on Link Layer addressing for communications. Translated to the ATM domain, RFC 1483 outlines a method by which multiprotocol traffic may be bridged across the ATM (and therefore ADSL) local loop between a host and a LAN switch.

ATM is a cell-based transfer mode that requires variable length user information to be segmented/reassembled to/from fixed length cells. The RFC1483 compliant protocol, stacks encapsulate connectionless network interconnect traffic and, routed and bridged Protocol Data Units (PDUs) over an ATM network. The PDUs are carried in the Payload field of Common Part Convergence Sublayer (CPCS) PDU of ATM Adaptation Layer type 5. For Bridging mode, The Common Protocol Data Unit (PDU) Header and Trailer are conveyed to allow pipelining at the outgoing bridge to a subnetwork.

The data from a PC, encapsulated into IP packet in an Ethernet frame can be forwarded to a DSL Bridge through the Ethernet. At the DSL Bridge, the data will go through the SAR process as described above and then transmitted across the DSL loop. The Intel® IXP220 Network Processor supports data-only applications. Figure 7 showed the protocol architecture of a DSL Bridge.

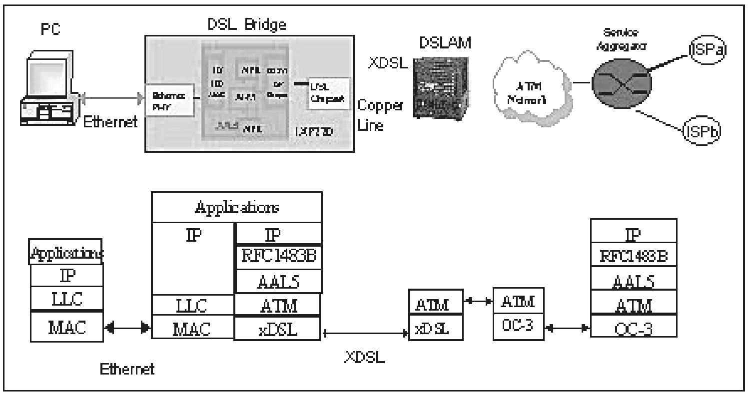

Figure 7. Architecture design for DSL Bridge using network processor

Note:
NPE – Network Processor Engine
HSS – High Speed Serial Bus

AAL5 CPCS-PDU

The data field contains the user information. The PAD field pads the CPCS-PDU to fit exactly into the ATM cells, such that the last 48 byte cell payload created by the SAR sublayer will have the CPCS-PDU Trailer right justified in the cell. The Trailer consists of CPCS-UU, CPI, Length and CRC fields. The CPCS-UU (User-to-User indication) field is used to transparently transfer CPCS user-to-user information. The field has no function under the multiprotocol ATM encapsulation and can be set to any value. The CPI (Common Part Indicator) field aligns the CPCS-PDU trailer to 64 bits. The Length field indicates the length, in bytes (octets), of the data (Payload) field. The maximum value for the Length field is 65535 octets. The CRC field protects the entire CPCS-PDU except the CRC field itself.

LLC Encapsulation is needed, when several protocols are carried over same VC (Virtual Circuit). In order to allow the receiver to properly process incoming AAL5 CPCS-PDU, the Payload Field must contain information necessary to identify the protocol of the bridged PDU. In LLC Encapsulation this information is encoded in an LLC header placed in front of the carried PDU. Figure 8 depicts various layers involved when adapting user application data into AAL5 and then onto DSL physical media.

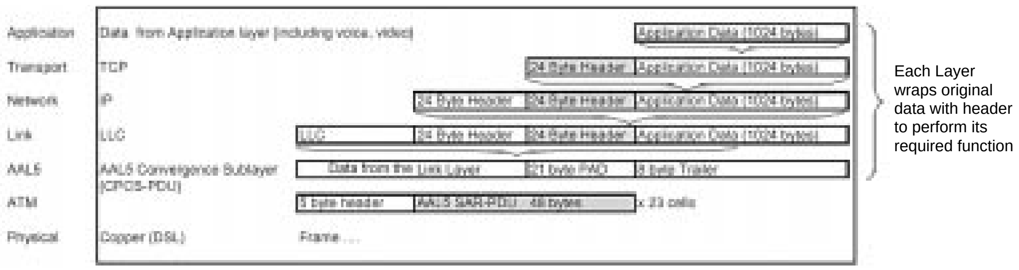

Figure 8. Adaptation Layer

IP Routing

Once ATM layer connectivity is established between the customer premises and the service provider network, the session setup and release phases at the link level and the network level can be established using PPP. PPP packets are carried over the ATM using AAL5, based on LLC (Logical Link Control) multiplexing (i.e., each VC carries only one PPP session information with no multiplexing with other protocols in parallel with PPP). The mapping of PPP over AAL5 uses LLC encapsulation - the delineation and checksum components that typically come with PPP in an HDLC-like framing are not needed when using AAL5. Please refer to the previous section (AAL5 CPCS-PDU) for the details of the generating the ATM cell using AAL5 based on the LLC. Figure 9 showed the architecture design for DSL IP Router using network processor.

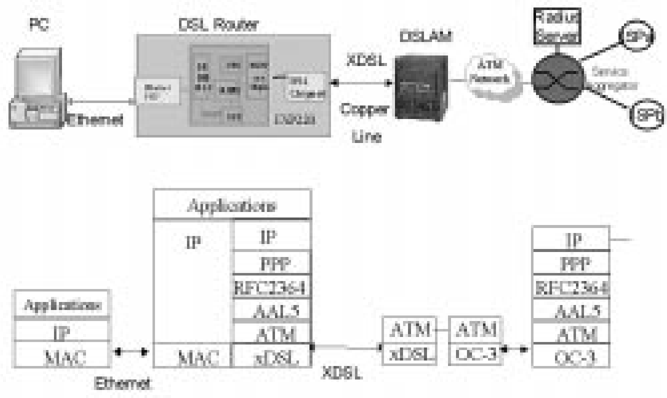

Figure 9. Architecture design for DSL IP Router using network processor

Multi-Service Intelligent Residential Gateway

The voice and data convergence revolution has started recently. Besides the data function liked Routing and Bridging as discussed in previous section, the other key feature of the Multi-Service Intelligent Residential Gateway is the voice support. Multi-Service Intelligent Residential Gateway supporting analog and digital voice interface should have provisions to interface to a PCM highway, such as H.100 bus. An Intel® Service-SpecificTM Network Processor, such as IXP225, provides these interfaces and also supports higher-layer voice-specific stacks such as H.323.

Analog voice requires the use of a subscriber line IC (SLIC) and a codec for conversion to a pulse code modulation (PCM); encoded 64-kbps stream, using 8-kHz sampling frequency and, 8-bit sample size. This voice support occupies a single digital signal level 0 (DS0) time slot. The encoding process is known as the ITU G.711 digital encoding standard.

New digital encoding schemes rely on the DSP technology to provide the voice compression below 64kbps. For example, ITU G.729A, where the compress voice channel requires only 8kbps. When such a compressed voice is packetized in IP packets, the resulting voice bit stream can be up to 30 kbps, because VoIP uses an 8-byte IP header followed by a 20 byte user datagram protocol (UDP) header. It is then followed by a 12 byte real- time protocol (RTP) header.

Voice over cells use ATM transport, where the digitized voice is encapsulated in cells using AAL1 or AAL2. The voice travels over the ATM switch-based network. With VoIP, digitized voice is packetized in IP packets and is transport over a router-based network.

Besides that, security features liked IPSec, Firewall and VPN are also needed to make sure that the network is secured. Other features of Intelligent Residential Gateway can be referred to the Figure 5.Figure 10 shows the end-to-end architecture for the Intelligent Residential Gateway using Intel IXP225 which supports Data and Voice applications.

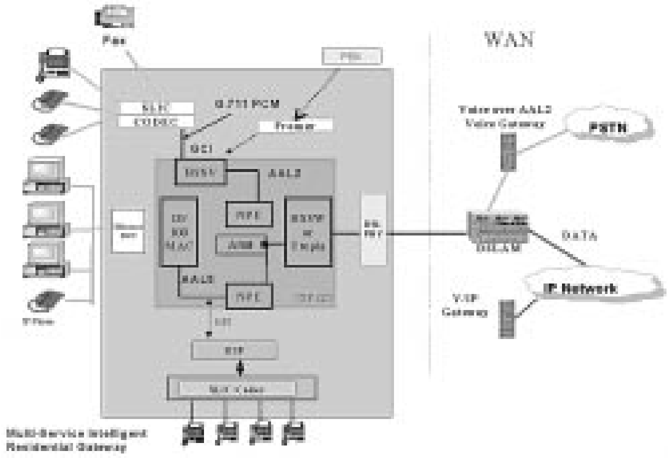

Figure 10. Architecture for Intelligent Residential Gateway Using Intel® Network Processor

Summary

A new concept, addressing specific WAN services (the service-specific network processor) has been introduced. These are integrated hardware and software platforms that implement all of the needs for specific WAN services such as DSL. This concept extends the power of the Intel(r) Internet Exchange Architecture, providing a powerful tool to OEMs developing customer premises equipment, including Residential Gateway and Integrated Access Devices (IADs) addressing the growing needs of voice and data convergence. The Intel IXP225 for example is a service-specific network processor optimized to address the converged network challenge.

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3. Gross, G.et al., RFC 2364:PPP over AAL5, July 1998.
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5. David Ginsburg, “Implementing ADSL”, Addison-Wesley July 1999.
6. URL to Intel® Internet Exchange Architecture (IXA) http://developer.intel.com/design/IXA/index.htm
7. URL to Intel IXP220/IXP225 information, http://developer.intel.com/design/network/products/npfamily/IXP22x.htm

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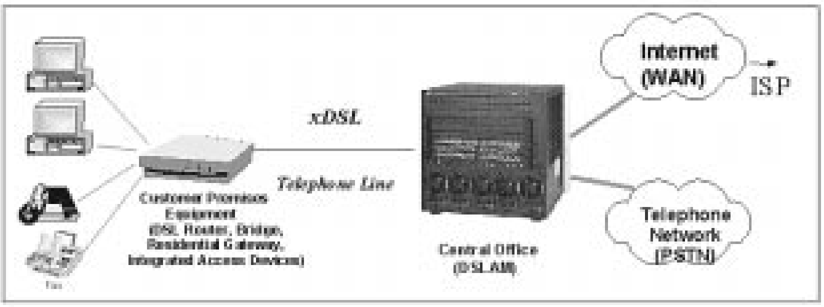
Agenda

- DSL Technology basics
- Definition of Residential Gateway
- The service specific Network Processor concept
- DSL Router, Bridge and Residential Gateway Protocol Stack
- Intel Service Specific™ DSL Network Processor
- Summary

DSL Technology Basics

The basic implementation of DSL CPE and DSLAM



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DSL Bandwidth Comparison

Modulation Techniques

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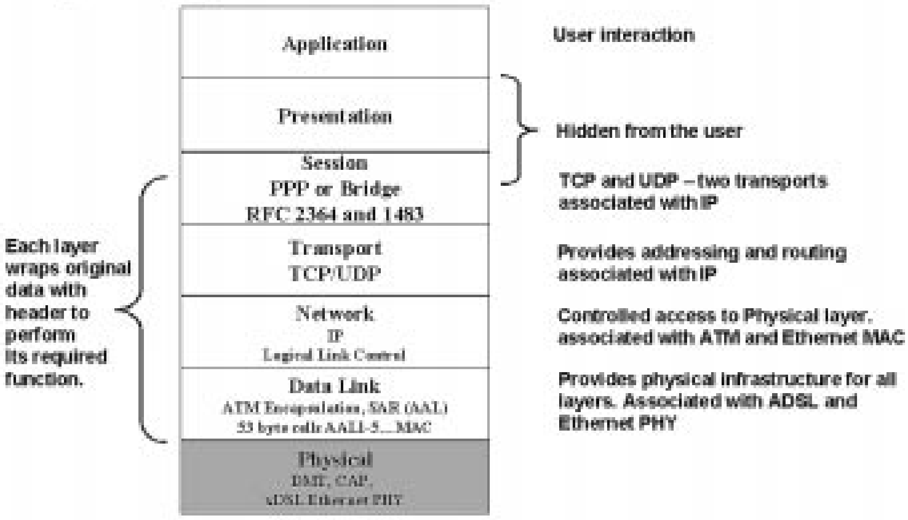
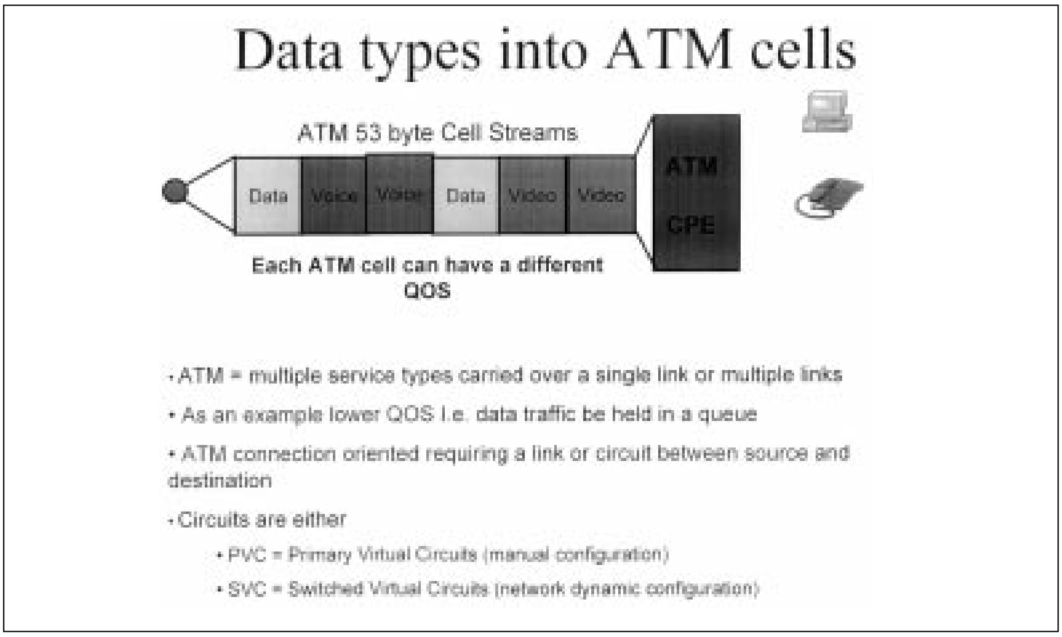
– Echo Cancellation assigns the upstream band to over-lap the downstream, and separates the two by means of local echo cancellation, a technique well know in V.32 and V.34 modems.

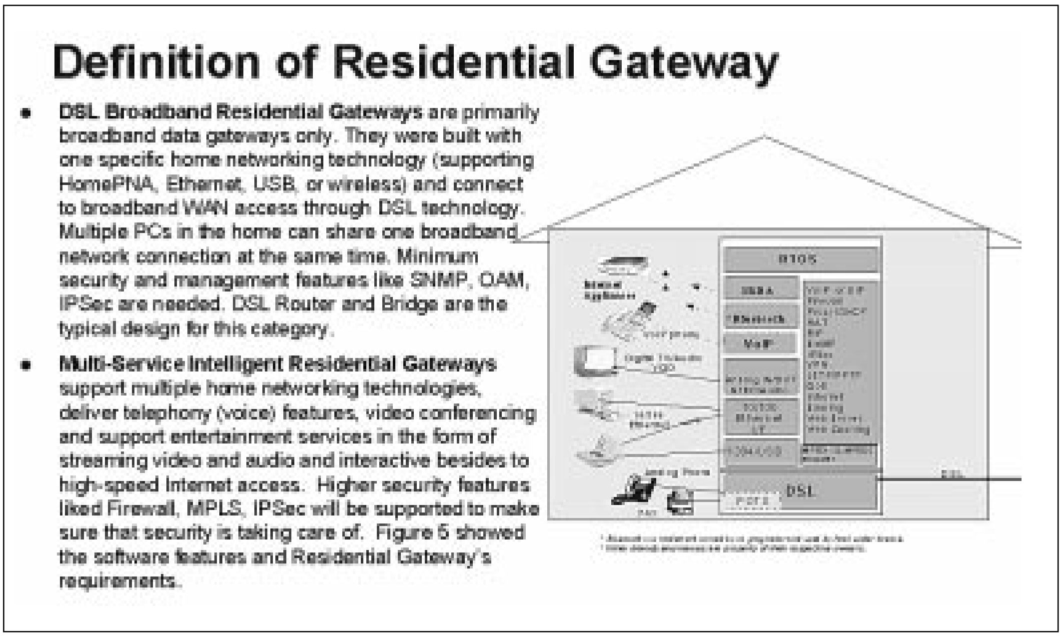
Layering protocol



ATM Adaptation layers

ATM Adaptation layer	*Characteristics*	*Quality Of Service*
AAL1	Best suited for replacement of leased circuits,i.e. 64Kbps. Timing recovery from cell header. Circuit emulation.	CBR = Constant Bit Rate traffic – Most stringent
AAL2	Reduces segmentation time...good for low data rate voice circuits	VBR = Variable bit rate sources
AAL5	Best suited for bursty data traffic...with no timing recovery from incoming cell header.	UBR = Unspecified bit rate. Network provides minimal QOS guarantees UBRw = UBR weighted... data handled difference due to Diff Serv marking (IP TOS) GFR = Guaranteed Frame Rate. Network makes a guarantee of minimum frame rate ABR = Available Bit Rate. Flow control is maintained from ATM CPE to other ATM switches


Data types into ATM cells
ATM 53 byte Cell Streams
Data
Voice
Voice
Data
Video
Video
ATM
CPE
Each ATM cell can have a different QOS
• ATM = multiple service types carried over a single link or multiple links
• As an example lower QOS i.e. data traffic be held in a queue
• ATM connection oriented requiring a link or circuit between source and destination
• Circuits are either
• PVC = Primary Virtual Circuits (manual configuration)
• SVC = Switched Virtual Circuits (network dynamic configuration)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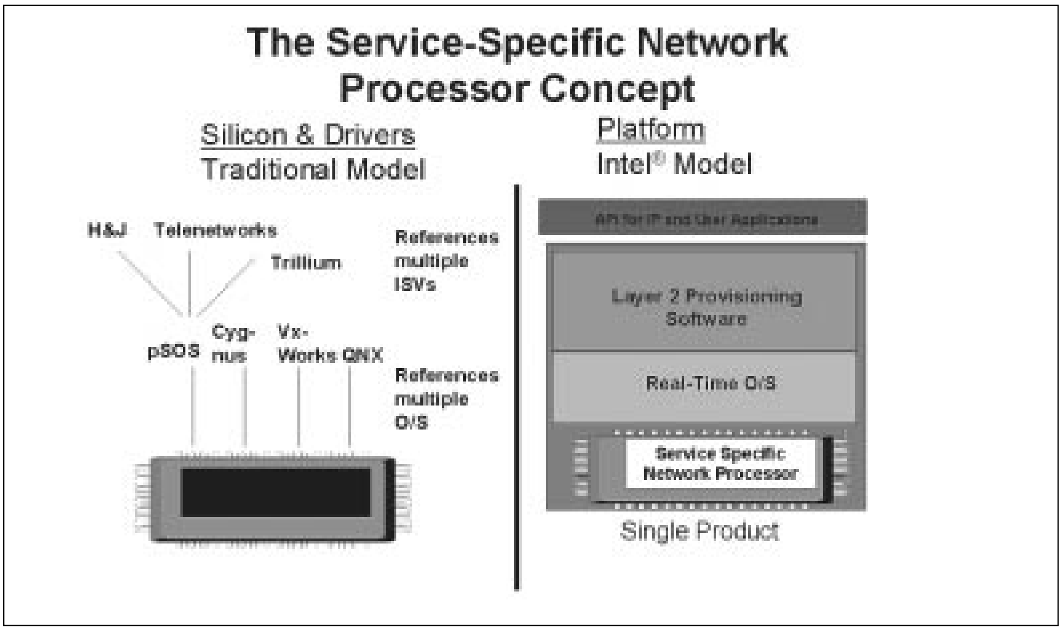
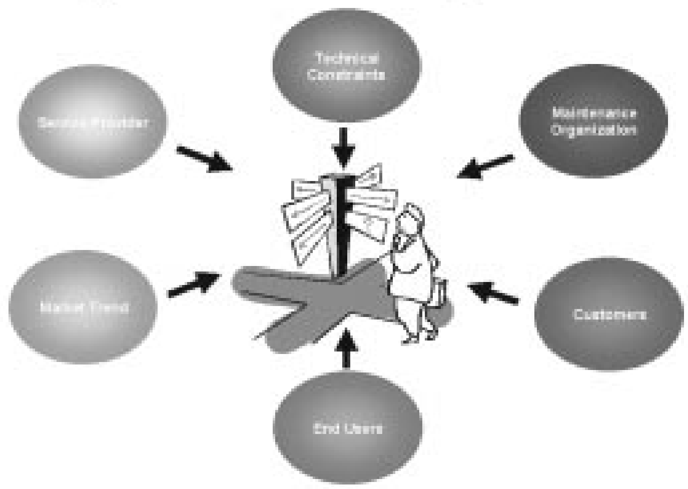
RTOS
VoIP
DSL
DSL


The Service-Specific Network Processor Concept
Silicon & Drivers
Traditional Model
Platform
Intel® Model
H&J
Telenetworks
Trillium
References multiple ISVs
pSOS
Cyg-nus
Vx-Works
QNX
References multiple O/S
API for IP and User Applications
Layer 2 Provisioning Software
Real-Time O/S
Service Specific Network Processor
Single Product

Driving forces to Service Specific Platform



DSL Network Processor

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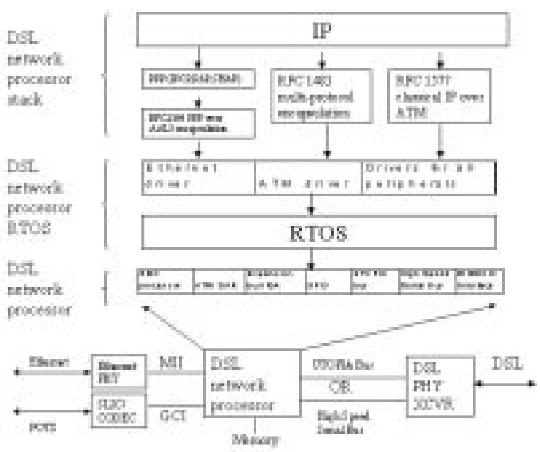
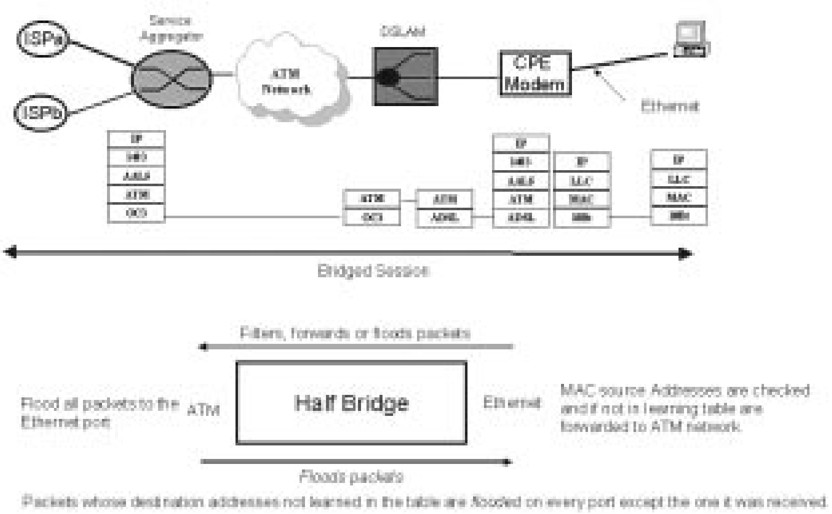
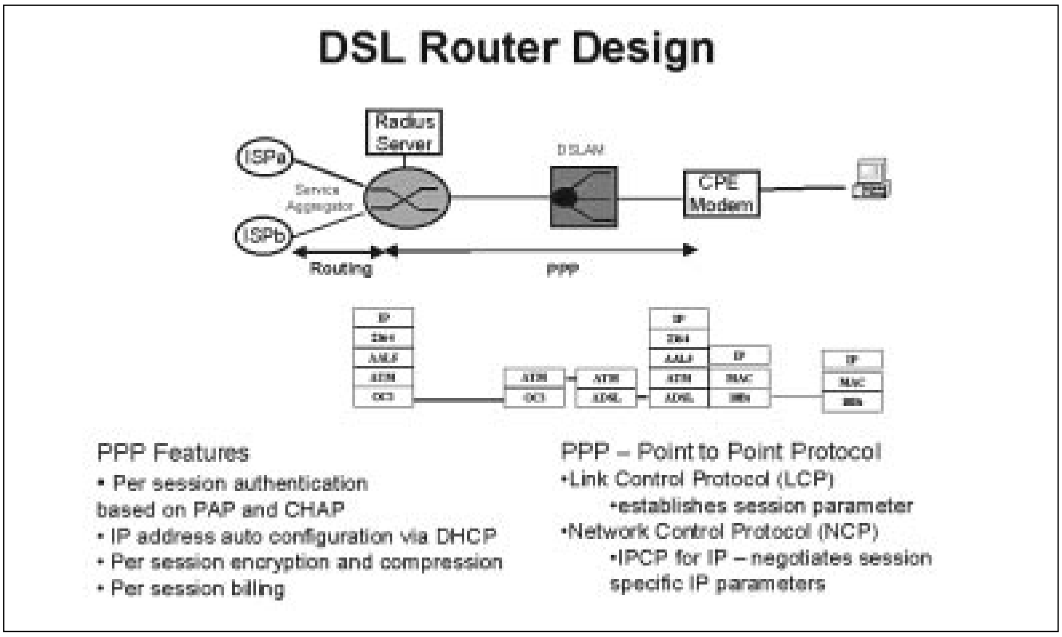
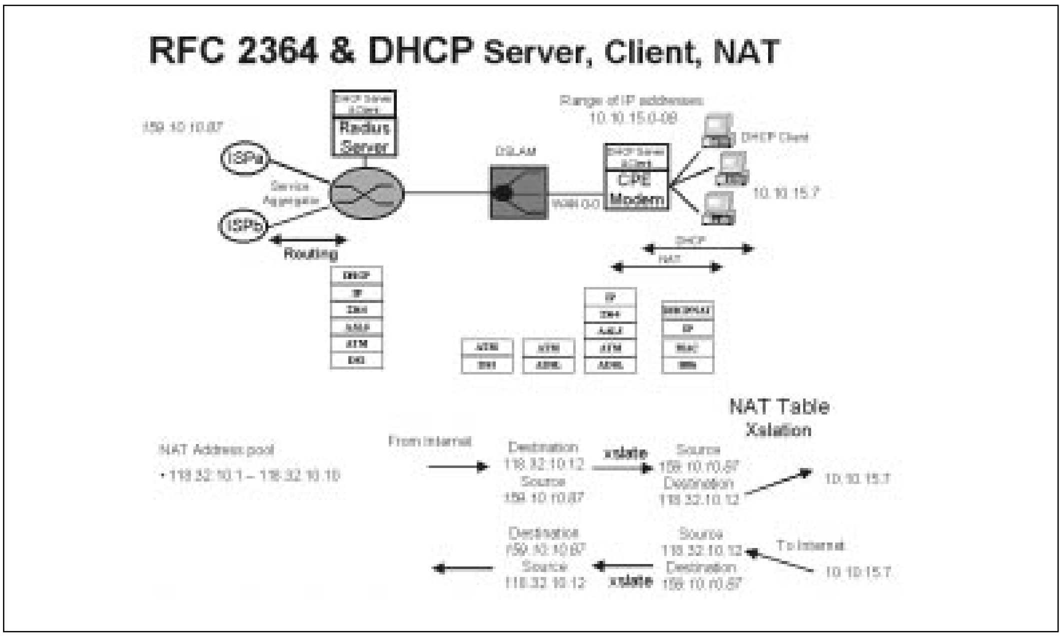
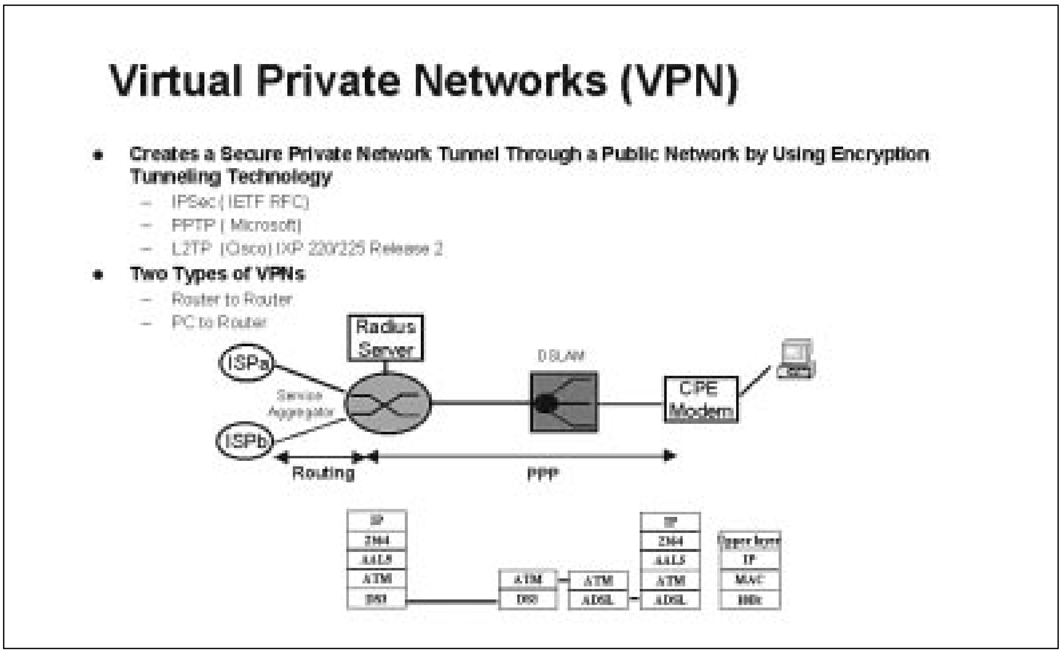


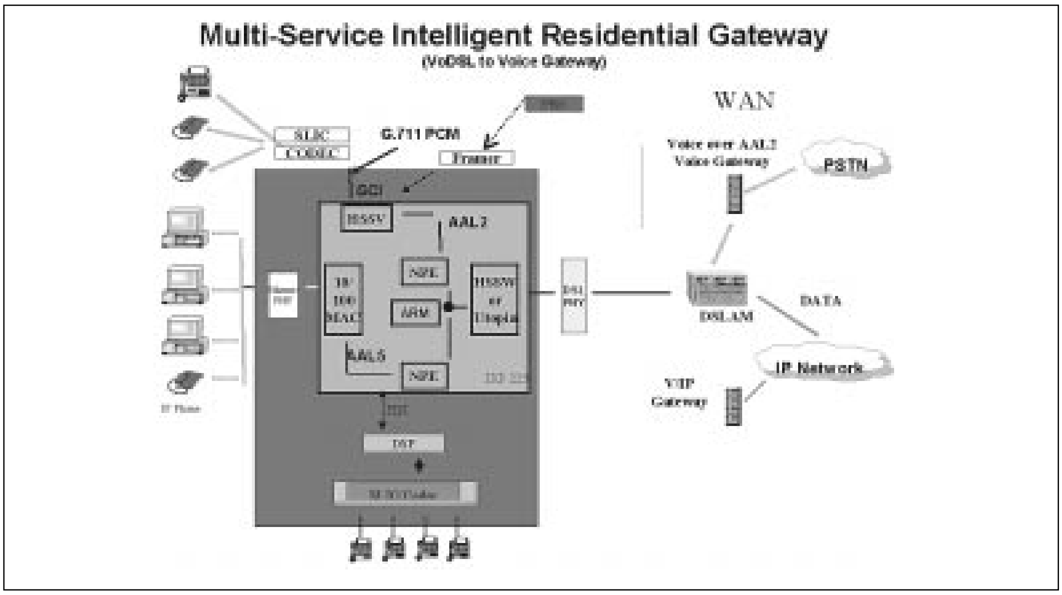
DSL Bridge Design



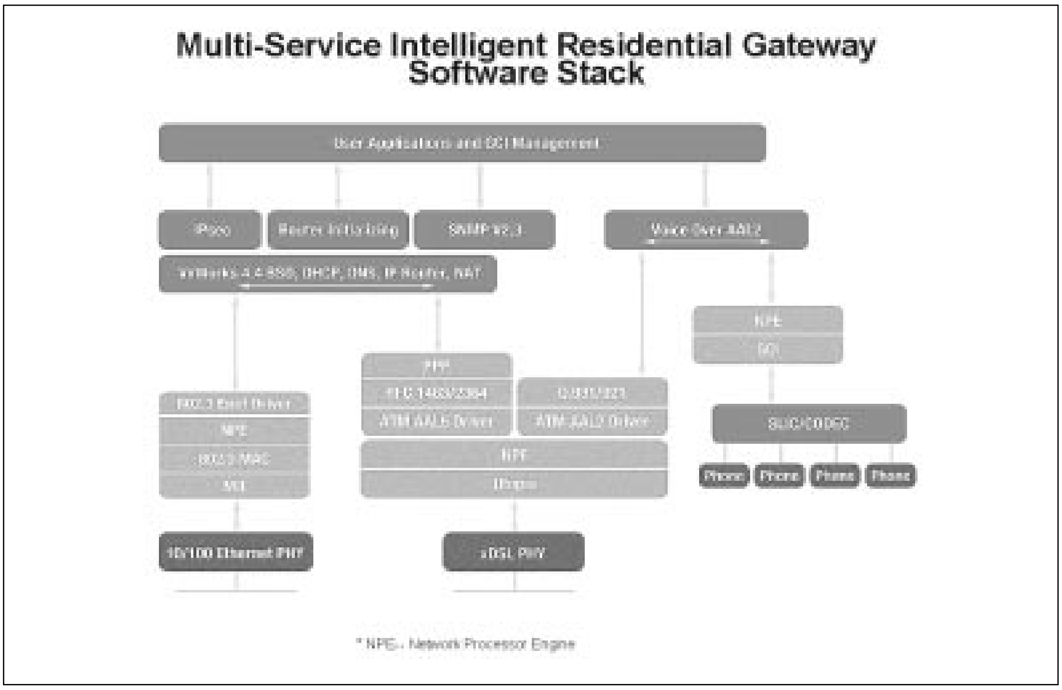

DSL Router Design
Radius Server
ISPa
ISPb
Service Aggregator
DSLAM
CPE Modem
Routing
PPP
PPP Features
• Per session authentication based on PAP and CHAP
• IP address auto configuration via DHCP
• Per session encryption and compression
• Per session billing
PPP – Point to Point Protocol
•Link Control Protocol (LCP)
•establishes session parameter
•Network Control Protocol (NCP)
•IPCP for IP – negotiates session specific IP parameters


RFC 2364 & DHCP Server, Client, NAT
Radius Server
ISPa
ISPb
Routing
DSLAM
CPE Modem
Range of IP addresses
10.10.15.0-08
DHCP Client
10.10.15.7
DHCP
NAT
NAT Table
Xslation
NAT Address pool
• 118.32.10.1 – 118.32.10.10
From Internet
Destination
118.32.10.12
Source
159.10.10.87
xslate
Source
159.10.10.87
Destination
118.32.10.12
10.10.15.7
Destination
159.10.10.87
Source
118.32.10.12
xslate
Source
118.32.10.12
Destination
159.10.10.87
To Internet
10.10.15.7

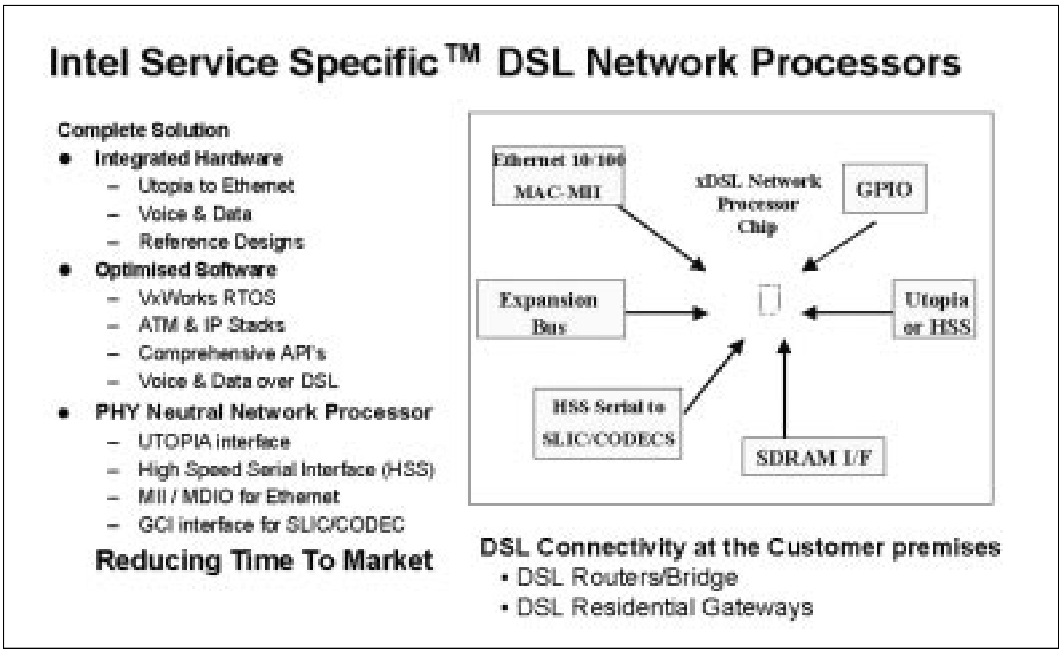

Virtual Private Networks (VPN)
• Creates a Secure Private Network Tunnel Through a Public Network by Using Encryption Tunneling Technology
– IPSec (IETF RFC)
– PPTP (Microsoft)
– L2TP (Cisco) IXP 220/225 Release 2
• Two Types of VPNs
– Router to Router
– PC to Router
Radius Server
ISPa
ISPb
Service Aggregator
DSLAM
CPE Modem
Routing
PPP



Multi-Service Intelligent Residential Gateway
(VoDSL to Voice Gateway)
WAN
SLIC
CODEC
G.711 PCM
Framer
GCI
HSSV
AAL2
NPE
ARM
AAL5
NPE
Voice over AAL2
Voice Gateway
PSTN
DSLAM
DATA
IP Network
VoIP
Gateway



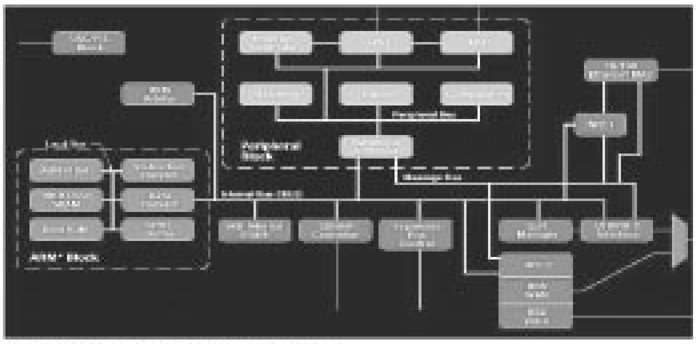
Multi-Service Intelligent Residential Gateway
Software Stack
Phone
Phone
Phone
Phone
10/100 Ethernet PHY
xDSL PHY
* NPE - Network Processor Engine



Intel Service Specific™ DSL Network Processors
Complete Solution
• Integrated Hardware
– Utopia to Ethernet
– Voice & Data
– Reference Designs
• Optimised Software
– VxWorks RTOS
– ATM & IP Stacks
– Comprehensive API's
– Voice & Data over DSL
• PHY Neutral Network Processor
– UTOPIA interface
– High Speed Serial Interface (HSS)
– MII / MDIO for Ethernet
– GCI interface for SLIC/CODEC
Reducing Time To Market
Ethernet 10/100
MAC-MII
xDSL Network
Processor
Chip
GPIO
Expansion
Bus
Utopia
or HSS
HSS Serial to
SLIC/CODECS
SDRAM I/F
DSL Connectivity at the Customer premises
• DSL Routers/Bridge
• DSL Residential Gateways

Intel Service-Specific™ DSL Network Processor

- *Highly Integrated Voice and Data Functions
  - *AAL2 voice processing
  - *Ethernet MAC
  - *Two high speed serial ports
  - *SDRAM controller
  - *Peripheral blocks
- * Distributed Processing Architecture
  - *ARM 7TDMI*
  - *Two Network Processor Engines
- * PHY Neutral WAN Port



*Other brands and names are property of their respective owners.

Other Useful Information

- **Intel Service-Specific™ DSL Network Processor**
  - http://developer.intel.com/design/network/products/npfamily/ixp220_225.htm
- **DSL Forum**
  - http://www.dslforum.org/
- **RFC Standard**
  - http://www.ietf.org/rfc
- **International Telecommunication Union (ITU)**
  - www.itu.int
- **ATM Specification**
  - http://www.atmforum.com/atmforum/specs/specs.html

Summary

- Residential Gateway is the new trend for DSL broadband application
- A new concept addressing specific DSL services—the service-specific network processor— has been introduced.
- The service specific Network Processor provides a time to market for OEMs in developing the customer premises equipment, including Residential Gateway and Integrated Access Devices (IADs) to address the growing needs of voice and data convergence