

METHOD AND SYSTEMS FOR OPTIMIZING ADSL CONNECTIONS IN DSL ACCESS MULTIPLEXOR

Field of the Invention

The present invention relates to Digital Subscriber Line
5 Access Multiplexor (DSLAM) and more specifically to a method
and systems for optimizing Asymmetric Digital Subscriber Line
(ADSL) connections in DSLAM, based on a flexible digital
signal processor and network processor architecture.

Background of the Invention

10 Asymmetric Digital Subscriber Line (ADSL) technology
provides simultaneous transport capabilities, e.g. Internet
high-speed access, voice and fax, over a single existing
copper telephone line at low cost. ADSL exploits bandwidth
capacity that is not used by traditional voice service on
15 copper telephone line according to one of the several existing
protocols, e.g. G.dmt and G.lite protocols standardized at the
IUT-T as G.992.1 and G.992.2 respectively. G.dmt provides
maximum downstream (core network to customer) speeds of up to
8 megabits per second (Mbps) and upstream speeds of up to 640
20 kilobits per second (Kbps) while G.lite provides maximum
downstream speeds of up to 1.5 Mbps and upstream speeds of up
to 512 Kbps. Downstream transmission bandwidth is about 1 MHz
for G.dmt and 500 KHz for G.lite.

As illustrated on Figure 1, ADSL architecture 100
25 comprises at least one DSL Access Multiplexor (DSLAM) 105-1
and several remote ADSL units (110-1, 110-i and 110-n) all
integrating a splitter to handle simultaneous transport of

voice and data. Remote ADSL units and DSLAM are connected through the local loop telephone twisted-pairs. Several communication devices can be simultaneously connected to a single ADSL unit, e.g. phone 115-1 and computer 120-1 are both
5 connected to ADSL unit 110-1. DSLAMs comprise connections to Plain Old Telephone Service (POTS) switch 125 and carrier aggregation services device 130 that are linked to core network, e.g. public switched telephone network and Internet.

Market studies show that the number of subscribers for
10 digital subscriber line subscriber service around the world increases dramatically each year. As a consequence, the greatest challenge to DSL Access Multiplexor designers is how to integrate more and more DSL channels within a DSLAM box given tight constraints on power consumption for the box.

15 The three main contributors to power consumption and cost in a DSLAM box are the line drivers and line receivers, the analog front-ends including the A/D and D/A converters, and the digital signal processing components that perform the necessary transceiver signal processing functions.

20 The line driver is the single biggest contributor to the power consumption typically requiring 750 mW to 900 mW of power for a full-rate G.dmt ADSL signal transmitted from the DSLAM to a remote ADSL unit.

The single biggest contributor to expense is the digital
25 signal processing unit which typically supports 8 to 16 G.dmt ports in 0.18 micron, e.g. IBM SA-27E technology, and 16 to 32 G.dmt ports in 0.13 micron, e.g. IBM Cu-11 technology. The range is largely based on tradeoffs between hard-wired versus programmable DSP-based software solutions. The latter allows
30 flexibility, but usually leads to a less dense (square millimeter of silicon) implementation.

Compared with G.dmt, G.lite lowers system costs per port because it requires about half the complexity of G.dmt from a digital signal processing perspective. G.lite also lowers the power consumption in the line driver approximately by half because it only utilizes half the downstream transmission bandwidth.

Figure 2 illustrates the standard architecture of a DSLAM card 200 comprising 12 ADSL ports supporting the G.dmt protocol. For sake of clarity, data, address, control and power busses are not represented. Each ADSL link is connected to the DSLAM card through a line driver / line receiver for full-rate ADSL, referred to as 205-1 to 205-12, and an Analog Front End (AFE) interface, referred to as 210-1 to 210-12, that comprises A/D and D/A converters. A Fast Fourier Transform unit (FFT) and a block-based correction code unit using Reed Solomon encoding and decoding (RS) are associated to each DSLAM port, e.g. FFT unit 215-1 and RS unit 220-1 are associated to port one. It is to be noticed that one single FFT unit and RS unit may be associated to several ports. Then, a DSP unit 225, associated to memory 230, performs the remaining transceiver signal processing functions and outputs ATM cells or bit streams in STM mode for all DSLAM ports. DSLAM card 200 further comprises a voice interface 235 that is connected to a standard POTS switch and an Utopia interface 240 that transmits its data traffic to or receives data traffic from a carrier aggregation unit, e.g. an ATM switch. Furthermore, DSLAM cards are generally linked to an external Network Processor (NP) that controls data traffic. POTS switch, ATM switch and Network Processor are not represented for sake of clarity.

It is to be noticed that the architecture for handling the G.lite protocol is similar and, as mentioned above, requires about half the complexity of G.dmt from a digital signal processing perspective. Furthermore, since the FFT size of the G.lite protocol is half that of the one of the G.dmt

protocol in the transmit direction, the FFT function may be performed in roughly half the time as compared with G.dmt.

Although commercial DSLAM products have been delivered based strictly on G.lite at about half the system cost and
5 double the density per fixed power budget when compared to G.dmt, G.lite is only capable of achieving a maximum speed of 1.5Mbps downstream.

Today's market offerings consist in DSLAM cards implementing either the G.dmt or the G.lite protocols. G.lite DSLAM
10 cards comprise twice the port density of G.dmt DSLAM cards. For example, there exist DSLAM line cards with up to 64 G.dmt ports and DSLAM line cards with up to 128 G.lite ports. However, single DSLAM cards allowing 128 users with G.dmt speeds do not exist. Furthermore, such DSLAM card solutions
15 based on current DSLAM methods and technologies would increase power consumption and cost per port accordingly.

Summary of the Invention

It is a broad object of the invention to remedy the shortcomings of the prior art as described here above.

20 It is another object of the invention to provide a method and systems for optimizing Asymmetric Digital Subscriber Line connection in Digital Subscriber Line Access Multiplexor.

It is still another object of the invention to provide a method and systems to determine connection protocol of each
25 port of a Digital Subscriber Line Access Multiplexor (DSLAM) according to the number of active subscribers coming into the DSLAM at any given instant.

It is still another object of the invention to provide a method and systems to reduce required digital signal

processing resource of Digital Subscriber Line Access Multiplexor.

It is still another object of the invention to provide a method and system to reduce the physical area required to
5 implement a Digital Subscriber Line Access Multiplexor.

It is a further object of the invention to provide a method and system to reduce power consumption of Digital Subscriber Line Access Multiplexor.

The accomplishment of these and other related objects is
10 achieved by a DSL access multiplexor system for optimizing DSL connections comprising :

- i DSL links ;
- flexible and programmable means adapted for handling i DSL links according to a first DSL protocol or j DSL links
15 according to a second DSL protocol, i being greater than j, said first DSL protocol requiring less processing power than said second DSL protocol ; and,
- control means adapted for setting said flexible and programmable means into a first mode handling i DSL links
20 according to said first DSL protocol or into a second mode handling j DSL links according to said second DSL protocol ;

and by a method for optimizing DSL connections in a DSL access multiplexor being adapted to handle at least two DSL protocols wherein a first DSL protocol requires less process-
25 ing power than the second DSL protocol, said DSL access multiplexor comprising up to i DSL links based on said first DSL protocol and up to j DSL links based on said second DSL protocol, i being greater than j, said DSL access multiplexor further comprising at least one flexible and programmable
30 means, said at least one flexible and programmable means being

adapted to handle one of said first and second DSL protocol at a time, said method comprising the steps of:

- looking for new DSL connection request ;
- if a new DSL connection is required and at least one link based on said second DSL protocol is available, setting said requested connection based on said second DSL protocol ;
- else if a new DSL connection is required and at least one link based on said first DSL protocol is available, setting said requested connection based on said first DSL protocol ;
- else if a new DSL connection is required and at least k connections based on said second DSL protocol are already established, k being the minimum integer value allowing to swap k connections according to said second DSL protocol to at least k+1 connections according to said first DSL protocol :
 - determining said k connections based on said second DSL protocol according to first predetermined criteria ;
 - swapping said k connections based on said second DSL protocol to k connections based on said first DSL protocol ;
- and,
- setting said requested connection based on said first DSL protocol.

Further advantages of the present invention will become apparent to the ones skilled in the art upon examination of the drawings and detailed description. It is intended that any additional advantages be incorporated herein.

Brief Description of the Drawings

Figure 1 illustrates the architecture used to provide ADSL

technology.

Figure 2 depicts a simplified scheme of a standard DSLAM card.

Figure 3 shows a DSLAM system logic architecture according to the invention

Figure 4 illustrates an example of DSLAM system chip implementation according to the invention.

Detailed Description of the Preferred Embodiment

The invention takes benefits of both G.dmt and G.lite and is related to a flexible method based on DSLAM utilization and
5 DSLAM architecture that incorporate a programmable Digital Signal Processor (DSP) and a Network Processor (NP). This flexible method takes advantage of the statistical nature of the number of active connections into a DSLAM at any given instant. This is achieved by providing a means to support full
10 G.dmt rates for any of the attached users as long as half, or less than half, the users are actively moving data through the DSLAM, but by only using half the digital signal processing hardware and half the power consumption for the line drivers. The invention allows one to double the number of ADSL ports
15 available over a conventional scheme given about 20% more power budget, depending on the power consumed by the analog front-end A/D and D/A converter hardware and the cost of the Network Processor hardware. Since the invention is based on the ITU-T G.dmt and G.lite standards, it works with existing
20 G.dmt and G.lite unit that are already installed at customer premises.

When the utilization is under 50% with only half the subscribers or less active on their respective connections, all those users experience the maximum G.dmt rates possible on
25 their wire. However, when utilization exceeds 50%, gradually

active subscribers start to experience G.lite rates based on either a fixed policy or one that is based on a tiered tariff structure, until ultimately, when the utilization reaches 100%, all subscribers are forced to a maximum rate allowed by G.lite. Only as utilization drops, will active subscribers be brought back to their G.dmt maximum transmission rates. Once the utilization drops below 50% again, then all active subscribers will be able to utilize G.dmt's maximum transmission rates.

For sake of illustration, the following description is based on a DSLAM chip comprising 48 ports, i.e. up to 24 G.dmt ports and up to 48 G.lite ports depending upon DSLAM utilization, using IBM Cu-11 technology and an IBM high-performance DSP technology.

In order to optimize the digital signal processing hardware, programmable DSP resources are used. Since G.lite typically takes a bit more than 50% of the DSP processing capability of G.dmt, the DSP processing capability of two G.lite ports is adequate to realize one G.dmt port. As a consequence the use of the same programmable DSP resource allows the realization of two G.lite ports or one G.dmt port.

To handle the full G.dmt access capability, the DSLAM system according to the invention must include a full-rate line driver and receiver for all ports on the DSLAM card, i.e. 48 ports in this description example. Likewise, the DSLAM system must include a full-rate analog front-end with A/D and D/A converters capable of realizing G.dmt for all ports, i.e. 48 ports in this example.

To manage detection of various packet streams and perform flexible control of DSP function mode (G.dmt or G.lite) based on the current utilization in the DSLAM and detection of active subscribers based on active packet flow, the DSLAM

system must include a Network Processor (NP) capability. Furthermore, the NP must be capable of detecting active voice call setups so that those individual users can be forced back to G.lite before the call setup is completed, and then to
5 detect voice call hang-ups so that the same user can increase speed back to G.dmt.

The DSLAM system according to the invention must also comprised a fast means to switch back to G.lite when voice calls are being setup using G.dmt so as not to delay the voice
10 call. This can be accomplished using the G.lite fast retrain once a G.lite connection has been established in a prior session. "Escape from handshake to fast retrain" procedure is detailed in G.992.2 standard. The total time for this is 3 seconds, one second for G.hs (G.994.1 standard) escape to
15 G.lite fast retrain, and 2 seconds for a fast retrain back to showtime. Assuming outbound or inbound calls are detected immediately, this 3 seconds can be overlapped with the voice call setup. For outbound phone calls, while the network setup for the voice call is taking place, the 3 seconds of retrain-
20 ing time can take place, and only then, will the completion of the outbound call take place, or in the case of inbound calls, the caller to the Voice over ADSL user will simply experience 3 more seconds of delay before the phone begins to ring.

If one accepted a voice call over a full rate G.dmt
25 connection, the line might be forced back down to G.lite later due to an increase in users' activity connected to the DSLAM, resulting in a noticeable drop-out in the middle of the voice call. This solution makes the assumption that the user would prefer the lower data rate in order to avoid the potential
30 interruption in the middle of the voice call. If service level agreements were defined such that a given user was always to receive G.dmt service, then voice calls could continue without backing off to G.lite first. Also, a customer might decide they don't mind a 3 second drop-out in the middle of a

conversation such that they can keep G.dmt rates when utilization is low going into the DSLAM.

In this example of DSLAM card comprising 48 ports, all users have access to G.dmt data rates of up to 8Mbps downstream as long as only 24 or less are actively using their ADSL connections. Activity is monitored by a Network Processor running in the DSLAM environment that monitors packet requests to the network. A given user is defined to be inactive if there are no packet requests being sent or received for a predetermined time, e.g. 5 minutes.

When the 25th user becomes active, one of the current 24 active users will be forced back to G.lite operation and the 25th user will only be allowed to make a G.lite connection, with maximum speeds of 1.5Mbps. As subsequent users become active, they will be brought on line with a G.lite connection, and take back one of the current users from G.dmt to G.lite until all 48 lines have active users, but all operating with G.lite.

Once the utilization drops back below 100%, users can be bumped back up to G.dmt. Because G.dmt takes 8-10 seconds to establish a connection, the speed at which the system decides to increase a user back to G.dmt should be modest. In addition, if a user has at least one Voice over DSL connection active, that user will remain at G.lite speeds until they hang up all their Voice over DSL connections. Again, a 5 minute duration is an example duration over which the system would wait before it bumps a user back up to G.dmt speeds. Other duration could be defined.

The choice of which users are either bumped up to G.dmt (as utilization drops back from 100%) or dropped back from G.dmt (as utilization approaches 100%) is complex and may be

based on tiered service rates or other factors. This choice mechanism of choice is beyond the scope of the invention.

Once a user makes a request for a Voice over DSL connection, or receives a Voice over DSL phone call, the transceiver must be backed off to G.lite if it already had not been operating in G.lite mode. The very first time this is done, there will be significant latency introduced. After the first time, this latency will be a maximum of 3 seconds because of the fast retrain capability of G.lite. To avoid noticeable drop-outs in the middle of the voice calls, all users are preferably starting out with G.lite until the fast retrain parameters are established, and then the system bumps those users up to G.dmt when the overall system utilization allows it.

It is to be noticed that the support for voice over DSL and actions taken is a service level definition issue. If the operator could guarantee full G.dmt, then he could offer this to some customers even while running voice over DSL. This might be provisioned by not attaching as many lines to a given DSLAM line card, e.g. 40 lines instead of 48 so that 4 users always could be assured of G.dmt rates. Various service level features are possible. Smaller number of users with different service level agreements can also be afforded by the invention.

It should also be noted that depending on the eventual specification in the ITU-T for Very high bit rate DSL (VDSL), it may be possible to extend this invention to a platform capable of supporting n ports of VDSL, $k \cdot n$ ports of G.dmt, and $2 \cdot k \cdot n$ ports of G.lite. Again, the requirements would mean that VDSL also runs on a highly flexible DSP platform capable of reconfiguration and that the cost for the analog front-end or line driver technology for VDSL is not significantly higher than that of G.dmt. If the costs remain considerably higher

for VDSL than for G.dmt then the costs of such a flexible DSLAM card may outweigh the benefits of being able to pack more lines onto a card.

Figure 3 shows logic architecture 300 of a DSLAM card comprising 48 ports, according to the invention. Each of the 48 ports includes a full-rate (G.dmt) line driver and receiver (driv./receiv.) and a full-rate analog front-end (AFE) with A/D and D/A converters. AFEs are connected to a memory block that could be shared or not. A Network Processor (NP) core is linked to each ADSL port's I/O port, e.g. Utopia, so as to analyze data stream and determine the protocol to be used in each DSP, G.dmt or G.lite. As mentioned above, each DSP core coupled with a Reed Solomon core (RS) and Fast Fourier Transform (FFT) through OPB bus handles several ports. In the implementation example, each DSP core is able to support four ports, i.e. two G.dmt ports, four G.lite ports or one G.dmt port and two G.lite ports. Thus, 12 DSP cores are implemented in the illustrated DSLAM system. DSPs receive instruction from NP according to the current number of active subscribers coming into DSLAM system 300 so as to be configured either in G.dmt or G.lite mode. DSP, RS and FFT cores receive data from NP. NP is also connected to Utopia and voice interfaces and a memory that could be external to save room in the system. In this example, DSLAM System 300 further comprise a PLB/OPB bridge and two DSPs, one per 24 ports (or 12 G.dmt ports), which executes the startup state machinery. These DSPs are linked to memories that contain startup code and data.

Depending upon used technology and data processing rate, the connection of ADSL link ports of DSLAM card to local loop include switching devices or Time Division Multiplexing (TDM) devices. Such devices are used to drive customer connections on adapted ADSL link ports. For example, if a new connection is requested when all resources are used and at least one connection is a G.dmt connection, e.g. all possible G.dmt

connections are used, one customer connected with a G.dmt connection will be swapped to a G.lite connection according to the criteria mentioned above. In such case, it is requested that the new connection shares the same hardware resource as
5 the connection swapped from G.dmt to G.lite and thus, to drive new requested G.lite connection accordingly. Using switching devices controlled by the network processor allow one to drive easily the connections on the right ports. On the other hand, the use of TDM devices reduces hardware requirements and may
10 be optimized according to DSLAM card architecture since several TDM devices may be used, e.g. one per set of ADSL link ports sharing same hardware resources.

As mentioned above, the description is based on a chip built in IBM's Cu-11 technology, i.e. 0.13 micron. A particular implementation is built using IBM's high-performance DSP
15 technology with the programmable DSP core running at 300MHz coupled with fast and flexible hardware blocks for performing the FFT (200MHz core) and Reed Solomon (100MHz core) functions, interconnected with a private OPB bus per programmable DSP core running at 100MHz. As such, a single core would
20 be capable of supporting 2 G.dmt or 4 G.lite ports in 13mm² of Cu-11. This would mean a 24 port chip would consume 156mm². Included in this 13mm² per dual ports is the overhead of having one controller DSP per 12 ports which executes the
25 startup state machinery and is connected to a large block of memory containing the startup code. In total, the chip would have 12 programmable DSP cores for the underlying signal processing, and 2 for the startup state machinery. In addition, a PPC 440 running at 300MHz would be the Network
30 Processor handling the packets on all 24 ports (or 48 when in G.lite mode of operation) or a net downstream of 192Mbps and 15.36Mbps upstream. This would enable a single chip per line card to be responsible for all the DSP and NP functions, and the NP would only need a single external SDRAM. This would
35 mitigate the cost overhead of including the PPC 440 core and

the required external SDRAM that it needs to perform the NP functions because there would be only one per DSLAM line card to support 24 G.dmt ports or 48 G.lite ports. The additional area for the PPC 440 in Cu-11 would be 14mm² or less leading to an overall chip area of 170mm² or 13mm plus the I/O ring of 1mm or a 14mm on a side chip. TDM devices, external or embedded on the DSLAM chip, may be used, e.g. each TDM device may handle four ADSL links. A diagram of this chip implementation is shown on Figure 4.

Naturally, in order to satisfy local and specific requirements, a person skilled in the art may apply to the solution described above many modifications and alterations all of which, however, are included within the scope of protection of the invention as defined by the following claims.

Claims:

1. A DSL access multiplexor system for optimizing DSL connections comprising :

- i DSL links ;

5 - flexible and programmable means adapted for handling i DSL links according to a first DSL protocol or j DSL links according to a second DSL protocol, i being greater than j, said first DSL protocol requiring less processing power than said second DSL protocol ; and,

10 - control means adapted for setting said flexible and programmable means into a first mode handling i DSL links according to said first DSL protocol or into a second mode handling j DSL links according to said second DSL protocol.

2. The system of claim 1 wherein said control means further
15 comprise analyzing means to determine the number of active connections and the current mode.

3. The system of claim 2 wherein said control means further
comprise first adjusting means adapted for handling a new
connection request such that if the current mode corresponds
20 to said first one and it exists at least one free link among
said set of i DSL links, the new connection is set to one of
said free links among said set of i DSL links, else if the
current mode corresponds to said second one and it exists at
least one free link among said set of j DSL links, the new
25 connection is set to one of said free links among said set of
j DSL links, else if the current mode corresponds to said
second one and all the j DSL links are used, the current mode
is changed from said second mode to said first mode, the j DSL
connections are transferred among the set of i DSL connections

and adapted to said first protocol, and the new connection is set to a free link among said set of i DSL links.

4. The system of either claim 2 or claim 3 wherein said control means are adapted for transferring automatically all active connections from said second DSL protocol to said first DSL protocol when a voice call setup is detected upon one of said active connections, according to predetermined conditions, if the current mode corresponds to said second one.

5. The system of anyone of claims 2 to 4 wherein said control means further comprise second adjusting means adapted for optimizing current connections when current mode corresponds to said first one and the number of active connections is less or equal to a predetermined threshold k such that the current mode is changed from said first mode to said second mode, the active DSL connections are transferred among the set of j DSL links and adapted to said second protocol.

6. The system of claim 5 wherein said threshold k is determined such that the processing power requested to handle k DSL connections based on said first protocol is equivalent as the one requested to handle j DSL connections based on said second protocol.

7. The system of either claim 5 or claim 6 wherein said second adjusting means further comprise voice call setup and hang-up detection means so that said connection optimization is inhibited as long as at least one voice call over a DSL connection has been setup and not hang-up.

8. The system of anyone of claims 1 to 7 wherein said flexible and programmable means comprise at least one flexible programmable digital signal processor.

9. A DSL access multiplexor system for optimizing DSL connections comprising several systems as described in anyone of claims 1 to 8.

10. The system of claim 9 wherein said control means comprise at least one network processor.

11. A DSL access multiplexor system for optimizing DSL connections as described in anyone of claims 1 to 10 that is implemented on a chip.

12. A method for optimizing DSL connections in a DSL access multiplexor being adapted to handle at least two DSL protocols wherein a first DSL protocol requires less processing power than the second DSL protocol, said DSL access multiplexor comprising up to i DSL links based on said first DSL protocol and up to j DSL links based on said second DSL protocol, i being greater than j, said DSL access multiplexor further comprising at least one flexible and programmable means, said at least one flexible and programmable means being adapted to handle one of said first and second DSL protocol at a time, said method comprising the steps of:

- looking for new DSL connection request ;
- if a new DSL connection is required and at least one link based on said second DSL protocol is available, setting said requested connection based on said second DSL protocol ;
- else if a new DSL connection is required and at least one link based on said first DSL protocol is available, setting said requested connection based on said first DSL protocol ;

- else if a new DSL connection is required and at least k connections based on said second DSL protocol are already established, k being the minimum integer value allowing to swap k connections according to said second DSL protocol to at least k+1 connections according to said first DSL protocol :

- determining said k connections based on said second DSL protocol according to first predetermined criteria ;

- swapping said k connections based on said second DSL protocol to k connections based on said first DSL protocol ;
and,

- setting said requested connection based on said first DSL protocol.

13. The method of claim 12 wherein new connections are established according to said first DSL protocol.

14. The method of either claim 12 or claim 13 further comprising the step of transferring automatically an active connection between said second DSL protocol to said first DSL protocol when a voice call setup is detected upon said active connection, according to predetermined conditions.

15. The method of anyone of claims 12 to 14 further comprising further comprising the steps of :

- looking for free links ;

- if it exists at least one free link based on said second DSL protocol and at least one active connection based on said first DSL protocol :

- determining at least one active connection based on said first DSL protocol according to second predetermined criteria ;

- swapping said at least one determined active connection based on said first DSL protocol to a connection based on said second DSL protocol.

- 5 **16.** The method of anyone of claims 12 or claim 15 further comprising the step of freeing DSL connections not used during a predetermined time.
- 17.** The method of anyone of claims 12 to 16 wherein said first or second predetermined criteria are based on the type of DSL connection or the subscription type of DSL connection.
- 10 **18.** The method of anyone of claims 1 to 17 wherein said first DSL protocol is G.lite protocol and said second DSL protocol is G.dmt protocol according to G.992.2 and G.992.1 standards.