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Scaling Bandwidth And Services Using Channel Bonding

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WHITE PAPER

Competition for subscribers has never been fiercer, as telcos increasingly deploy higher-speed services aimed at stealing not only residential data subscribers, but also residential video subscribers, away from cable operators. DSL technologies are now able to provide beyond 50 Mbps of bandwidth, and fiber-to-the home initiatives offer even greater bandwidth potential for both video and data services. Cable operators need the capability to provide higher-bandwidth services so they can:

- Protect the installed base of high-speed data customers
- Deliver competitive, high-capacity commercial services to business customers
- Use video over IP to deliver subscriber-specific interactive video services to counter the large channel lineups provided by satellite operators.

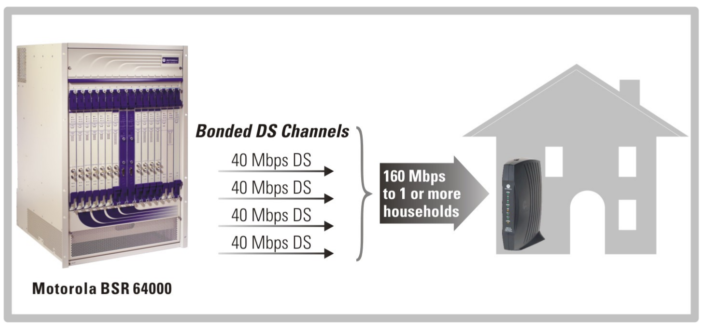
CableLabs®, through its member cable operators, established the DOCSIS® 3.0 Channel Bonding Initiative. The goal of this initiative is to develop a standardized approach to bond multiple physical channels into a single, virtual, high-bandwidth channel. This is achieved by inverse multiplexing multiple RF channels to create a single logical channel.

Channel Bonding Overview

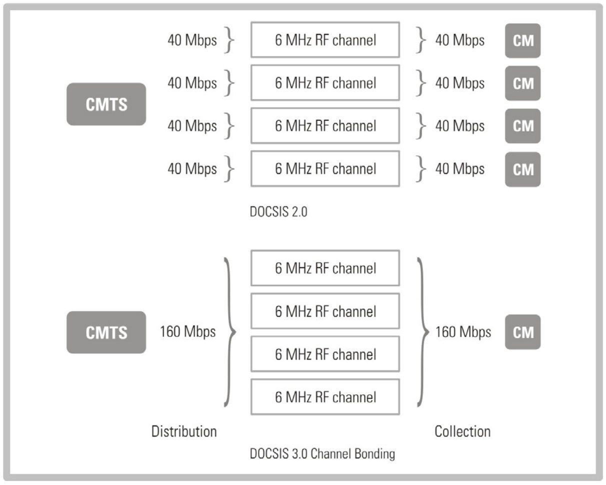
Approximately 40 Mbps of downstream bandwidth in a single 6 MHz- (or 8 MHz)-wide RF channel. Using existing DOCSIS specifications, multiple RF channels can be used to increase the total bandwidth available. However, with the current standards, a single cable modem can access only a single channel, and thus it cannot receive more than 40 Mbps.

In order to compete with DSL offerings, cable operators are looking for a mechanism to offer peak rates of much greater than 40 Mbps to individual customers. Channel bonding enables this by creating a single “logical channel” composed of multiple 6 MHz channels. Three things are needed for this to take place:

1. A Cable Modem Termination System (CMTS), receiving a stream of packets from a high-speed network interface such as Gigabit Ethernet, needs to transmit these packets in parallel over multiple 40 Mbps RF channels to a cable modem.
2. The cable modem needs to be able to receive data from multiple 6 MHz channels in parallel. It needs the ability to re-order the data packets to reflect the order in which they were received by the CMTS (i.e. before they were transmitted over the multiple RF channels in parallel).
3. A standard to define the CMTS-to-cable modem interface is needed to enable the parallel transmission and reordering to recreate the original serial packet stream.



This provides a perspective on downstream channel bonding, but this approach applies equally in the upstream direction. However, in upstream channel bonding, the cable modem provides the distribution function and the CMTS provides the collection function.



CableLabs is establishing specifications that will be included within DOCSIS 3.0 so operators can bond together multiple RF channels to create these high-bandwidth channels. Channel bonding will allow operators to deliver increased bandwidth to a given cable modem by transmitting DOCSIS frames across multiple RF channels, in parallel.

The standards are being developed to support both upstream and downstream channel bonding so that operators can logically bond together RF channels and then multiplex packet transmissions over those channels. Channel bonding is initially focused on supporting high-speed data services but can also be used to deliver video over IP. The specification allows operators to bond at least four channels, but vendor-specific implementations could support the bonding of even more channels. Although channel bonding could eventually deliver up to a Gigabit per second, in early implementations operators are likely to achieve up to about 160 Mbps downstream by bonding together four 40 Mbps channels.

Channel bonding enables increased throughput between a cable modem and a CMTS by sending packets on multiple streams at the same time. It uses a flexible, packet-based algorithm for combining the capacity of multiple upstream or downstream channels to achieve the equivalent through put of a wideband channel. This offers two major benefits because it allows operators to:

- Deliver higher-bandwidth peaks to a given subscriber
- Gain major increases in networking efficiency, since statistical multiplexing is more effective with wider channels.

Essentially, each DOCSIS packet is provided with an identification header before it is sent down one of the designated RF channels between the CMTS and the modem. The process allows the receiver to review the sequence numbers and recombine the packets in the right order to logically bond channels between the distribution hub and subscribers. The implementation of channel bonding will take advantage of the evolution of CMTS architectures and new modem silicon capable of powering an RF tuner that can accept multiple data channels. Each cable modem will still appear as a single entity to the CMTS but the DOCSIS MAC protocol will be modified so that it can synchronize the multiple streams.

Channel bonding will be configured at the CMTS. During the modem registration process in DOCSIS 2.0, the cable modem indicates its capabilities and the services for which it is subscribed. In DOCSIS 3.0, this negotiation will be extended to include support for channel bonding so that the cable modem can request that the CMTS bond a number of channels to create the required high-capacity upstream and downstream traffic flows. When completed, the standard will allow operators to logically bond together upstream or downstream RF channels and multiplex packet transmission over those RF channels.

Spreading Data Over Multiple Channels

A key feature of DOCSIS is the concept of service flows and packet classifiers. A packet classifier is a set of rules that are used to segregate a specific set of packets (such as those between the two endpoints of a Voice-over-IP (VoIP) phone call or other application) into a service flow. The service flow is the DOCSIS entity to which a specific Quality of Service (QoS) is applied.

The term Single Link Service Flows (SLSF) is used to refer to the existing DOCSIS service flows. SLSFs are restricted to a single RF channel. This concept of service flows has been extended to support channel bonding by introducing the concept of the Multi-Link Service Flow (MLSF). As the name suggests, an MLSF is a service flow that can be transmitted over multiple RF channels (links) in a bonding group.

A bonding group can be defined as a set of upstream or downstream channels bonded together to permit high-capacity forwarding of a sequence of packets. An MLSF can therefore have a data rate which is greater than the individual RF channel rates.

The DOCSIS channel bonding mechanism is based on classifying packets into a high-throughput Multi-Link Service Flow (MLSF), which bonds together multiple RF channels. Each MLSF is mapped to multiple SLSFs (one per RF channel in the bonding group). Non-bonded traffic can continue to operate over SLSFs as in current operation. But traffic loads must be balanced between MLSFs and SLSFs in the same way that they are currently balanced between service flows with DOCSIS 2.0.

Downstream channel bonding is performed for subscriber traffic only. These packets are classified into a high-throughput MLSF that provides the appropriate QoS and will distribute the traffic across the SLSFs for the RF channels that comprise the bonding group. Channel bonding adds a sequence number in a bonding extended header of the packets prior to distributing them for simultaneous forwarding on multiple downstream channels. This header is used to reorder the packets upon reception.

The CMTS will transmit DOCSIS MAC management messages as non-bonded packets on a single downstream channel. It will transmit all downstream packets (bonded and non-bonded) with the same DOCSIS Program Identifier (PID) used currently. This enables multiplexing of DOCSIS and non-DOCSIS traffic (e.g. video) on a single RF channel at the MPEG layer, just as is done with existing DOCSIS implementations.

The CMTS forwarding function delivers packets to a MAC-layer interface for forwarding downstream. The DOCSIS forwarder classifies the packets either directly into an individual SLSF or into an MLSF.

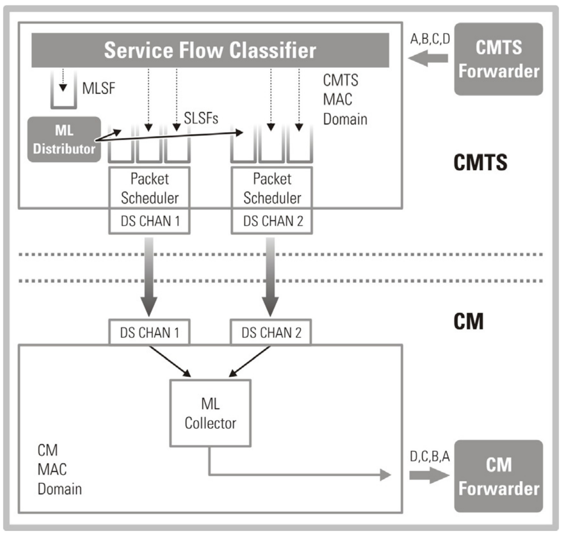
A given bonding group may have several MLSFs, and both MLSFs and SLSFs share the same service flow ID numbering space within the MAC Domain. All cable modems—including DOCSIS 3.0 cable modems intended primarily for bonded operations—define a non-bonded downstream SLSF that serves as the primary downstream service flow for that cable modem.

The DOCSIS forwarder implements a multi-link distributor function for each downstream bonding group. The multilink distributor is responsible for scheduling packets from multiple MLSFs onto the channel group. Once a particular MLSF packet is scheduled for forwarding on the channel group, the multilink distributor sends the packet to one of the SLSFs for the bonding group.

For each downstream channel, the packet scheduler schedules the packets for all of the SLSFs assigned to that channel. This includes the non-bonded SLSFs as well as the bonded SLSFs that contain bonded packets. The interaction between an MLSF distributor and the set of packet schedulers will be specific to each vendor's CMTS implementation.

Cable Modem Downstream Channel Bonding Operation

The cable modem will implement a multi-link "collector function" which stores bonded packets that are received out-of-order. It will deliver downstream packets of any given bonding group in the order of the sequence number of the packets within that bonding group. In one example, the sequence of four packets (A, B, C and D) is delivered to a single MLSF, and then distributed to two SLSFs for forwarding downstream. (See Figure 2)



The cable modem collects the packets, A, B, C and D, and forwards them in packet sequence order as signaled in the header of the bonded packet. The cable modem will need to rapidly detect a lost bonded packet on a bonded downstream channel when it receives a subsequent, higher-sequence bonded packet on that channel, and the cable modem will assume that a bonded sequence numbered packet is lost, if it is not received within a specified number of milliseconds of a subsequent sequence number.

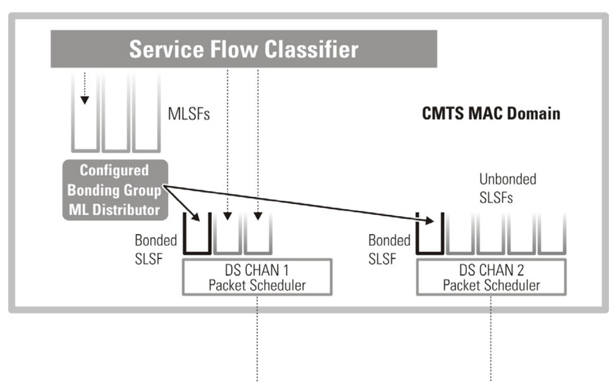
Packets must be forwarded from the cable modem in the correct order. If a packet is lost on a particular channel, this will cause packets with higher sequence numbers to be held in cable modem memory until the cable modem can determine that the packet is lost rather than misordered. Thus it is an important requirement of downstream channel bonding operation that the maximum interval for out-of-order packets to be emitted is limited. This puts an upper limit on the amount of reassembly memory required in the cable modem and also limits the forwarding delay of packets received on the other channels.

Configured Downstream Channel Bonding Groups

CMTS platforms will support vendor-specific configurations of configured downstream channel bonding groups with the following attributes:

- Bonding group identifier
- Bonding channel set, i.e. a list of downstream channel IDs

The bonding group ID and downstream channel ID will be unique within a given MAC Domain. The simplest mechanism for configuring downstream channel bonding is to assign an MLSF directly to a configured bonding group. In order to facilitate cable modem configuration files that may be used independently of the particular DOCSIS MAC Domain in which a cable modem registers, operators will be able to configure bonding groups with similar purposes to the same bonding group ID within each MAC Domain. The cable modem and the CMTS will support at least four channels per downstream bonding group. A cable modem will need to support at least one downstream bonding group, i.e. 1 MLSF. (See Figure 3).



In this example, the CMTS implements a single configured bonding group. All MLSFs configured in the cable modem configuration file of the DOCSIS 3.0 cable modems in the MAC Domains are assigned to the multi-link distributor for that bonding group. The multi-link distributor schedules packets from the MLSFs assigned to its bonding group. When a packet is scheduled, it is distributed to a single “bonded" SLSF for that bonding group on a particular channel.

Downstream QoS

The CMTS or Modular-CMTS (M-CMTS) needs to maintain the DOCSIS QoS for an MLSF when considering the aggregate service provided to the MLSF by the set of bonded channels. The CMTS needs the ability to restrict any MLSFs that cannot meet its QoS requirements, and it needs to maintain the QoS requirements of every SLSF to which the MLSF is distributed.

The scheduling of downstream bonded packets from an MLSF to its set of SLSFs is CMTS vendor dependent, but the final protocol when defined within DOCSIS 3.0 will set certain requirements, such as that the CMTS or M-CMTS will need to emit packets on the same channel in strictly non-decreasing sequence number order, and the CMTS will only be able to emit packets out-of-order by only a defined number of milliseconds.

Upstream Channel Bonding

The detailed specifications for upstream channel bonding are less well-developed than for downstream, but they will follow the same general principles. A bonded upstream channel will consist of a bonding of service flows across multiple upstream channels, with each flow uniquely identified by its service flow identifier and the associated upstream channel. The cable modem will need to range on all upstream channels that compose the bonded upstream channel and negotiate the upstream channel set with the CMTS.

Taking Advantage of Channel Bonding

Packet-based channel bonding will enable flows to remain almost the same as they are with DOCSIS 2.0, with packets entering a similar architecture as they do today. It enables the coexistence of DOCSIS 1.x, 2.0, and 3.0 cable modems across common network infrastructure, and it will not impose a new infrastructure design on cable operators.

Multi-channel cable modems can be created by extending existing DOCSIS chipsets available from multiple vendors. In the most likely scenario, modem silicon vendors will produce combined downstream and upstream channel bonding chip set solutions. Channel bonding products are expected to come to market in a relatively short timeframe, since some existing DOCSIS chipsets can be extended to support the emerging specification.

Operators will therefore be able to protect investments in existing infrastructure equipment. Channel bonding will be implemented on evolving chassis-based CMTS platforms, as well as on M-CMTS platforms, which can also be referred to as a “decoupled CMTS” because it separates the logical functions of a CMTS platform. There is naturally a tradeoff, since reliability and manageability can be better delivered using a chassis-based system. But the promise of increased flexibility and pay-as-you-go scalability constitute a major advantage of the M-CMTS architecture.

These channel bonding solutions will consist of the CMTS or M-CMTS, cable modems and other customer premises equipment. This approach leverages current silicon efficiently and will allow operators to rapidly capitalize on the opportunity to deliver higher-bandwidth data services via channel bonding. Silicon vendors as well as vendors of CMTS platforms and cable modems are working closely with CableLabs and operators to accelerate the availability of equipment to support channel bonding.

Motorola supports channel bonding and is aggressively developing products and solutions that allow cable operators to take advantage of the wideband capacity enabled by channel bonding. Motorola is developing both external edge QAMs as part of its M-CMTS solutions, and internal high density downstream QAMs for its chassis-based Broadband Services Router 64000 (BSR 64000) CMTS/edge router.

Both the M-CMTS and the chassis-based system will be based on the award winning BSR 64000. Existing BSR 64000s deployed on the network will be compatible with M-CMTS platforms so that operators can protect investments in existing assets while implementing channel bonding and deploying next-generation CMTS platforms based on modular or system-based architectures.

As cable operators strive to protect their installed base and deliver higher-speed data services, channel bonding is quickly becoming a critical technology. CableLabs is defining specifications for channel bonding within the DOCSIS 3.0 standard under development. Motorola actively participates in this standards-making process and is aggressively evolving the company's product line of cable modems and CMTS platforms to support the emerging channel bonding specifications as they are developed and finalized by CableLabs.

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