Full Duplex DOCSIS Technology over HFC Networks

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Abstract

DOCSIS 3.1 technology provides a significant increase in network capacity supporting 10 Gbps downstream capacity and 1 Gbps upstream capacity. To support Gbps symmetric services over the HFC plant, increasing the upstream capacity is required. Full Duplex Communication using DOCSIS 3.1 technology provides the ability to increase the upstream capacity without sacrificing downstream capacity. In this paper, we provide an overview of how full duplex communications using DOCSIS technology can be implemented over the HFC network and the potential capacity gains it can deliver.

INTRODUCTION

Wired and wireless technologies use either frequency division duplexing (FDD) or time division duplexing (TDD) to enable bidirectional communications.

In FDD, the available spectrum is divided between the upstream (US) and downstream (DS) channels (uplink and downlink channels in wireless) without overlap between the channels to prevent interference as shown in Figure 1.

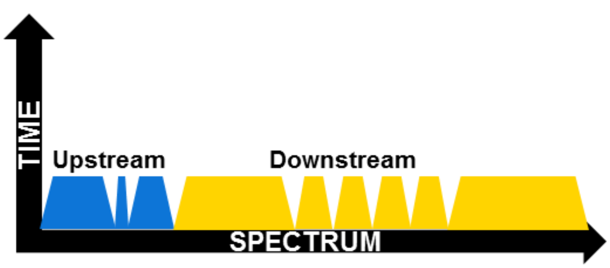

Figure 1: Frequency Division Duplexing

The spectrum split between US and DS channels is the main factor deciding the ratio between US and DS capacities. Thus increasing the US capacity will decrease the DS capacity, and increasing the DS capacity will decrease the US capacity.

In TDD, the same spectrum is used for both channels, but shared in time to avoid interference as shown in Figure 2. The amount of time allocated to each channel is the main deciding factor between US and DS capacities. Similar to FDD increasing a channel's capacity will decrease the other channel's capacity.

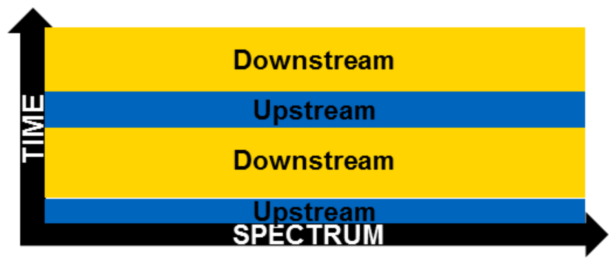

Figure 2: Time Division Duplexing

DOCSIS technologies operate using FDD; with the US channels typically residing in the 5-42 MHz, 5-65 MHz or 5-85 MHz bands while the DS channels share the upper frequency bands (up to 1 GHz) with the video channels [1].

Increasing a DOCSIS network capacity can be achieved by either increasing spectral efficiency; for example by upgrading from DOCSIS 3.0 technology to DOCSIS 3.1 technology, or by increasing allocated spectrum. In a spectrum limited network (upper band edge cannot be extended), increasing the US capacity will reduce the DS capacity

FULL DUPLEX COMMUNICATION

As discussed in the previous section, the goal from using TDD or FDD is to prevent interference between US and DS channels by preventing overlap. Recent developments wireless R&D have shown that advanced interference cancellation techniques make full duplex (FDX) communication possible [2].

In full duplex (FDX) communications, the system supports concurrent transmissions on the US and DS on the same frequencies. Interference between the US and DS transmissions is cancelled out at the receiver using interference cancellation techniques.

Interference cancellation at the receiver is required to cancel out self interference. The transmit signal which is at a high power relative to the received signal interferes with the low power received signal due to the limited isolation levels between the transmit and receive ports as shown in Figure 3. Ideally, the combining circuit would comprise of a circulator with infinite port to port isolation which would prevent any cross coupling between the transmit port and the receive port.

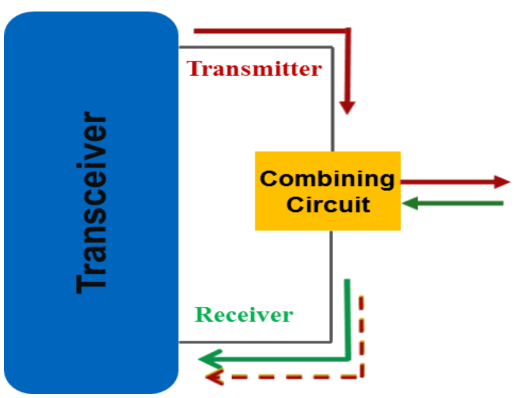

Figure 3: Self Interference in Full Duplex

Self interference cancellation at the receiver can be performed in the RF domain, digital domain or a combination of both [3].

FULL DUPLEX DOCSIS NETWORKS

Current DOCSIS networks have a limited amount of bandwidth available for US channels. FDX communication over the HFC network can provide additional bandwidth for US channels, while maintaining the available bandwidth for DS channels.

To implement FDX communications over the DOCSIS network, several things need to be considered; such as: Backward compatibility with previous DOCSIS generations, performance, scalability, and device complexity.

Backward compatibility: For a FDX device to be backward compatible with other DOCSIS devices, devices need to be able to coexist on the same network while achieving the target KPIs. Operating spectrum can be either shared spectrum or dedicated spectrum; for efficiency, shared spectrum is preferred but device complexity is another factor to be considered when looking at spectrum sharing. For example, in DOCSIS 3.1, the US spectrum can be shared between SC-QAM and OFDMA channels using Time and Frequency Division Multiplexing (TaFDM), while on the DS, SC-QAMs and OFDM channels operate in dedicated spectrum.

Performance: Symmetric services is a growing trend in broadband networks, especially in FTTH deployments. With 1 Gbps DS tiers being offered on current DOCSIS networks 1 Gbps US tiers is a reasonable initial performance target to be able to deliver 1 Gbps symmetrisc services, keeping in mind that the technology needs to be able to scale to higher tiers as needed.

Scalability: Technology transition within a network is closely managed to minimize any impact to current customers. Solutions that can be deployed in a gradual manner based on network capacity demands help facilitate technology transitions and lower the associated cost of such transitions. Solutions need to be able to scale efficiently based on the number of users and service requirements while at the same time maintaining backward compatibility. This enables an operator to introduce new technologies gradually without the need to do a complete network upgrade ,replacing devices at all customer premises in addition to service interruption.

Device Complexity: Managing device complexity is critical to managing technology deployment costs. With current HFC network architecture, where the CMTS is a common resource shared across many users, minimizing CM complexity in exchange for driving additional (reasonable) functionality into the CMTS might be a viable approach.

Based on the above, CableLabs has proposed a DOCSIS 3.1 technology based FDX solution as a means to improve US network capacity.

Proposed FDX Architecture:

Based on the previously discussed requirements, CableLabs has proposed a FDX DOCSIS technology based solution. In the proposed solution, the CMTS operates in FDX mode on the DOCSIS channels while at any point in time, a CM is either transmitting or receiving on a certain channel with the option that it might be able to concurrently transmit and receive on different channels as shown in fig.

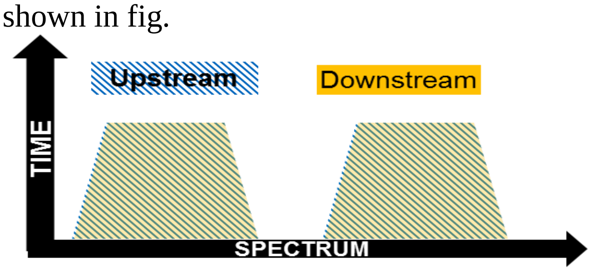

Figure 4a: FDX Channels as seen by CMTS

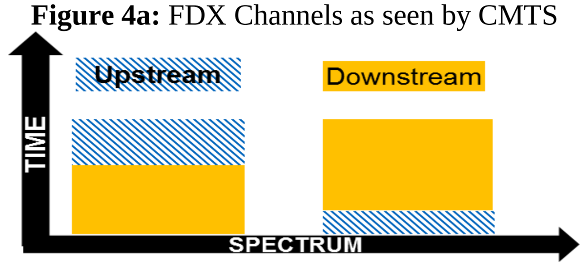

Figure 4b: FDX Channels as seen by CM

This approach allows the interference cancellation to be implemented only at the CMTS and thus minimizing CM complexity. The performance of the interference cancellation at the CMTS impacts directly the achievable US capacity, while the DS transmit power and interference patterns impact the achievable DS capacity.

Coexistence with legacy DOCSIS devices also needs to be addressed especially if sharing the DS spectrum is desired. Legacy devices continuously listen to the DS channels from the CMTS. US transmissions from a nearby device operating in FDX mode can potentially interfere with the DS signal being received by a nearby CM.

Interference from a FDX device's US transmission to the DS signal being received by another device is dependent on the level of RF isolation between both devices. US transmissions from FDX devices will impact nearby devices with low inter-device RF isolation. Based on experimental measurements conducted by CableLabs, devices operating on the same tap as a transmitting device will observe high levels of interference and thus severely impairing their ability to receive the DS signal, while devices connected to different taps will either not be impacted by the US transmissions, or observe reduced levels of DS SNR that will require them to temporarily operate using a lower modulation order.

To minimize the probability of impairing a device's DS reception; the CMTS would need to manage device to device interference. One possible approach to achieving this is to identiy the interference group (CMs that will observe interference due to transmissions from a FDX device) associated with the FDX devices, and based on the interference group, the CMTS could align scheduling such that a devices in the interference group are not scheduled to receive data (tor more optimally operate at a lower modulation order if possible) while FDX device is scheduled for an US transmission.

Measuring the device to device isolation to identify interference groups can be achieved by channel sounding; where CMs measure the received power due to FDX device's transmission, and then report the recived power to the CMTS.

PERFORMANCE

The potential capacity achieved by using FDX DOCSIS communications on the HFC network is dependent on the HFC network RF characteristics, CM and CMTS capabilities and the performance of the self interference cancellation at the CMTS.

We use the DOCSIS 3.1 specifications as a baseline for the CM and CMTS capabilities, and the measured RF characteristics of a passive HFC network shown in Figure 5 with the assumptions listed in Table 1.

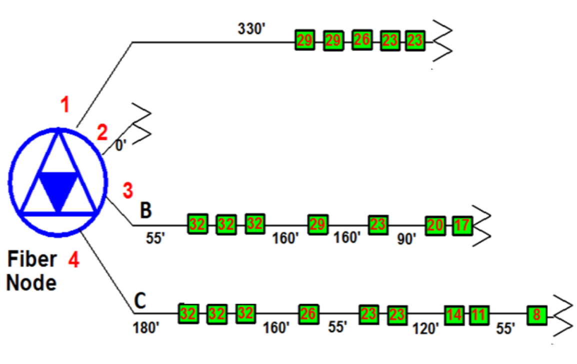

Figure 5: Passive HFC Network

Parameter	Value
CMTS Launch Power	41 dBmV / 6 MHz
Target US Signal Receive Power	0 dBmV / 6 MHz
Maximum CM Tx Power	65 dBmV
DOCSIS Channel Width	192 MHz
Drop Cable + Splitter Loss	4.5 dB
System Efficiency	80%

Table 1: HFC Network Assumptions

Assuming the parameters given in Table 1, we analyze the achievable US and DS capacity as a function of interference cancellation capabilities at the CMTS as shown in Figure 6. It is assumed here that the CMTS scheduler allows CMs within the interference group to receive at a lower modulation order in the presence of a nearby US transmission.

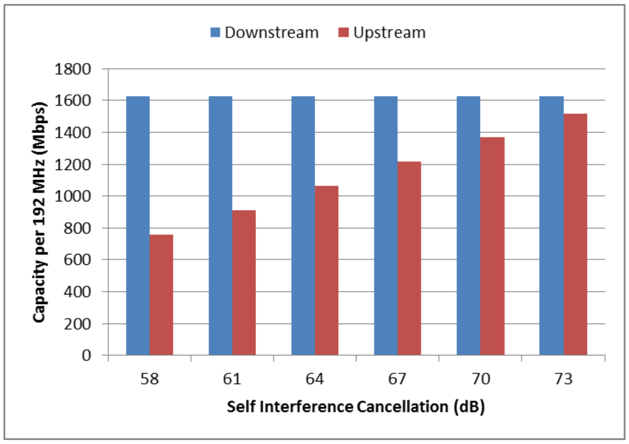

Figure 6: US and DS Capacities for FDX DOCSIS System

Due to the interference of US transmissions with the DS channel, there is a 11% reduction in DS capacity in comparison to a DOCSIS 3.1 system operating under the same assumptions but with no interference.

Further enhancements in US and DS capacities are possible by jointly optimizing the US transmit power, DS transmit power with respect to the self interference cancellation capabilities. Additionally, the DS capacity can be further optimized by scheduling DS traffic to devices part of an interference group when no other device in the group is transmitting, thus reducing the need to use lower modulation orders and thus improve DS capacity.

SUMMARY

FDX DOCSIS communications over the HFC network holds potential to significantly increasing upsteam capacities and enabling

Gbps summetric services over the HFC plant. The proposed FDX DOCSIS solution leverages DOCSIS 3.1 technology, the RF characteristics of the HFC plant, self interference cancellation at the CMTS and intelligent scheduling.

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