WHITE PAPER

Cable
Connected Home

Multigigabit Speed and Symmetrical Data Service with Full Duplex DOCSIS* 3.1

Full Duplex DOCSIS 3.1 standard helps cable service operators evolve networks for next-generation access

Authors

Shaul Shulman
Senior System Architect
Intel Corporation

Brian Kurtz
Cable Architect
Intel Corporation

The fast-growing need for speed

The growing number and diversity of connected devices within the home and the desire for bandwidth-hungry online experiences, such as 4K video streaming and VR, are fueling exponential growth in the demand for faster home connectivity. Nielsen's Law of Internet Bandwidth states that users' data demands grow by 50 percent every year—meaning demand more than triples every three years.[1]

Operators are continuously challenged to cost-effectively deliver data rates that keep up with this exponential growth in demand. In 2012, Intel partnered with leading cable modem termination system (CMTS) vendors and proposed an evolution of DOCSIS* 3.0 standards to allow operators to offer gigabit-speed data rates.[2] DOCSIS 3.1 showed a path to 10 Gbps downstream using existing hybrid fiber-coaxial (HFC) infrastructure, which enabled cable operators to compete with fiber and twisted-pair alternatives—since DOCSIS 3.1 is less expensive to deploy than fiber to the home (FTTH) and offers higher speeds than twisted-pair networks.

DOCSIS 3.1 on traditional HFC does have its limitations, however. The upstream band is usually limited to low frequencies, such as 42 MHz and 85 MHz, and even the 204 MHz option introduced by DOCSIS 3.1 requires significant network upgrades (and still does not deliver true gigabit upstream service). While widespread consumer demand for gigabit-speed upstream is not here yet, operators need to be prepared as applications that require high-speed upstream bandwidth come to market.

The future is symmetrical

Announced in February 2016, Full Duplex DOCSIS 3.1 (FDX) improves upon the DOCSIS 3.1 standard to use a large part of the cable plant spectrum simultaneously in both upstream and downstream directions—enabling symmetrical multigigabit services.

The key ingredient in FDX connectivity is the echo canceller, a technology that removes the self-transmitted signal from the received signal. The transmitted signal is usually much stronger than the received signal, and it travels to the receiver through a linear channel consisting of near-end (device) and far-end (network) reflections (also called "echoes"). Although the original transmitted signal is known to the receiver, the received signal includes unknown noise and distortion, and the echo canceller must be able to estimate all these impairments with high enough accuracy to cancel out the artifacts of the transmitted signal imposed on the received signal.

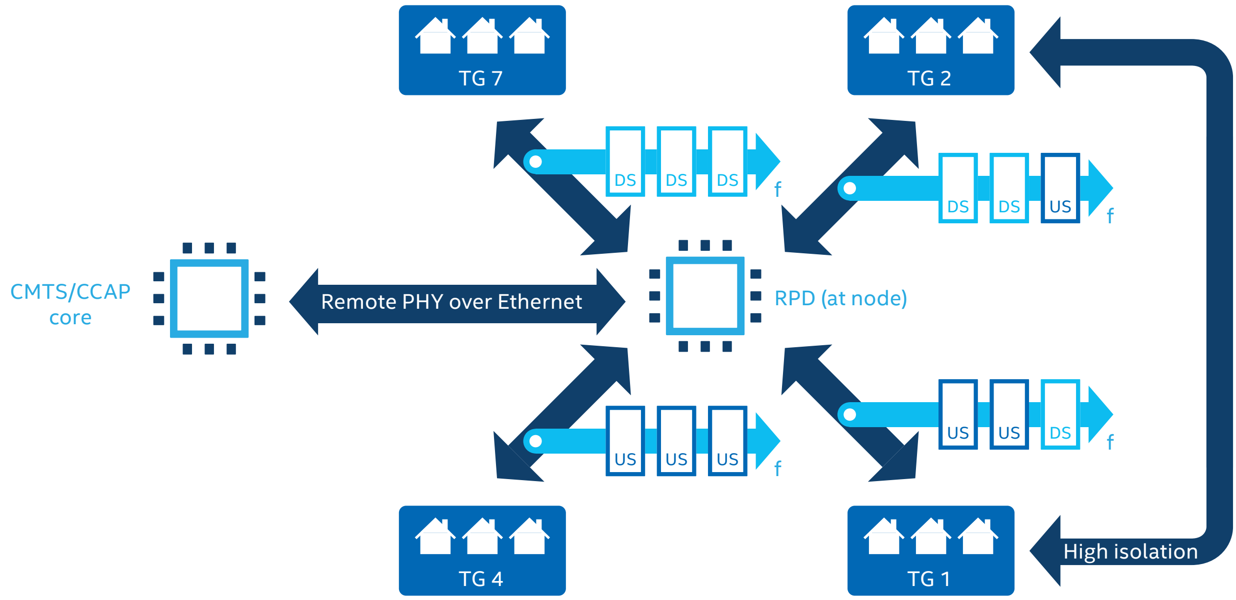

Figure 1. Full duplex communication in an N+0 node

In addition, when cable modem clients transmit they may interfere with other clients on the network receiving on the same frequency. The FDX architecture can work around the limitations of sharing media in a point-to-multipoint system while still offering high network utilization in both upstream and downstream directions. Even though network design ensures a “good” link budget between any customer premises equipment (CPE) and head-end transceiver, there are still groups of CPE devices that exhibit high loss in between each other. This tends to be higher than the link budget loss to the head-end transceiver, which means full duplex communication is possible on a group basis instead of individual CPE basis by allowing groups with high isolation between each other to transmit and receive simultaneously (Figure 1). With smart allocation of upstream and downstream resources to a group, the network is still fully utilized, and traffic simultaneously flows over the same frequency to and from the head-end transceiver.

Full duplex requires an all-passive architecture since HFC amplifiers are unidirectional when they operate on a given frequency band. This means that full duplex is only possible on an N+0 architecture (a node with no amplifiers in the network). Fortunately, the process of migrating HFC networks to all-passive coax and digital nodes is already underway.

Remote PHY (RPHY) architecture has emerged as the leading distributed network access approach. It allows the separation of the medium access control/physical (MAC/PHY) interface and can transfer it over IP networks from the CMTS core at the hub to the digital node in the field (Figure 2). This “fiber deep” architecture also provides advantages beyond full duplex. RPHY increases the signal-to-noise ratio due to its lack of analog optics, and it provides better real estate and power utilization at the hub. It also allows virtualizing all MAC and upper layers of the CMTS.[3,4]

Making FDX a reality

The FDX standard is evolving through the specification process as Intel progresses with real-world validation in the lab. However, challenges remain, and several issues that have been discovered in FDX are not isolated to individual technologies as they were in previous technology upgrades.

For example, one longstanding benefit of HFC networks is transparency. A multiple-system operator (MSO) could build out its network using a certain amount of bandwidth and allocate it for upstream and downstream, along with a certain level of signal fidelity. The operator can employ any technology within that envelope, and increase efficiency through higher modulation, improved forward error correction, and better frequency utilization. Problems with upstream and downstream pipes could also be isolated and solved independently.

With FDX, the system must be designed as a complete entity and some issues, which were previously solved individually, must now be solved within the larger system.

Solving FDX challenges

Intel and node vendors are aggressively working on solving the new challenges that FDX presents.

Coping with adjacent channel self-interference

The FDX RPHY node uses its echo canceller to implement simultaneous transmit and receive on the same frequency channel at the same time. However, cable modems also need to use echo cancellation to flexibly transmit and receive on immediately adjacent channels in the FDX band. In traditional DOCSIS implementations, diplex filters are used to isolate transmit and receive channels with a significant band gap for the filter transition band.

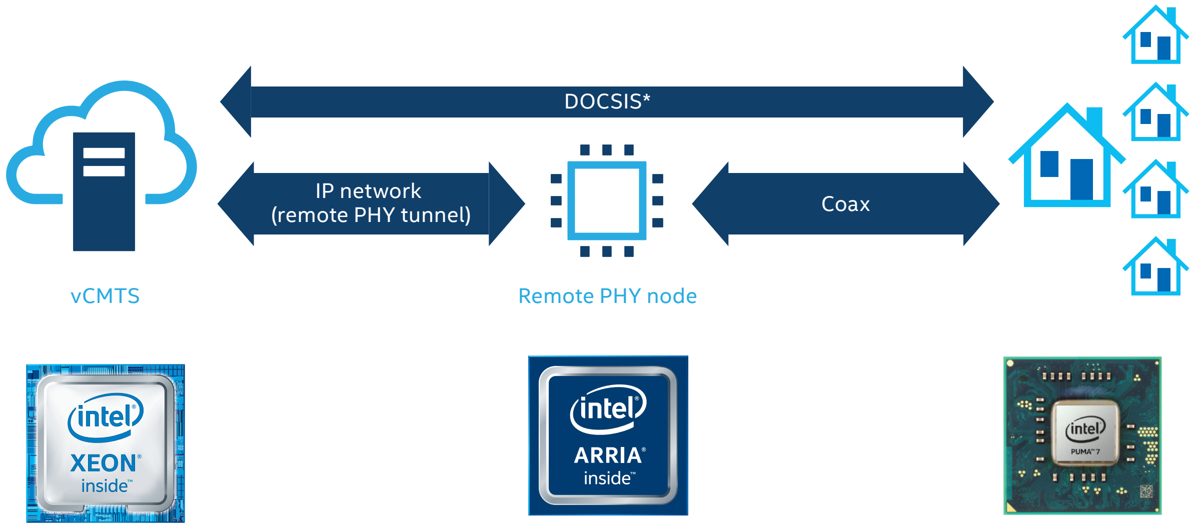

Figure 2. Distributed access architecture with programmable remote node

In the FDX band, however, to maximize spectral resources, cable modems are not allowed any such band gap. As a result, cable modems must cope with adjacent-channel self-interference problems such as leakage that comes from its own high-level upstream transmission signal and contaminates its low-level downstream receive signal. This self-interference from the transmitter gets reflected back by any impedance discontinuities such as F connectors, drop cables, and the multi-taps, where it contaminates the receive signal. Echo-cancellation techniques can help cable modems cope with this type of interference and reflections.

Accomplishing simultaneous transmit and receive

New technologies must be developed within the RPHY node to enable simultaneous transmit and receive on the same frequency at the same time. For example, they would transmit power leakage into the receiver, including both the known transmitted signal and noise from the power amplifier. While challenging, these problems are constrained to the node and can be addressed through the coordinated efforts of chipset and node vendors. Research engineers are developing new approaches for isolating the transmit and receive paths.

The cable plant presents an additional set of challenges. For example, RPHY nodes and CPE must be able to handle:

1. Unknown plant topologies and echo responses, plus a wide range of received power levels and delays.
2. Echo drift over time due to temperature or wind variations in aerial plants.
3. Transmit versus receive capacity trade-offs: A certain amount of net performance is possible in each node for a given amount of echo cancellation and can be split between the upstream and downstream paths.
4. Transmission degradation due to common plant impairments.
5. A broad assortment of in-home environments and self-install scenarios.

The RPHY primarily needs to address challenges 1–5 above, and since it operates with significant cochannel interference (potentially 20 db higher than the received signal), the margin for error is quite small. While various topologies can be planned in advance, the ways the plant can change over time may vary considerably. These variables require a highly flexible and adaptive echo-cancellation design that can ensure operation in unforeseen scenarios. With respect to challenges 3–5, the CPE also needs to operate in dynamic environments, and ensuring safe operation of FDX in plants with legacy equipment is vital for success. Despite these challenges, FDX works today and is a key technology for providing new levels of performance on HFC networks. It does, however, require new system-level design and higher intelligence and adaptability in the network than with previous standards.

Isolation sounding procedures

Another challenge with FDX is ensuring that modems are properly coordinated to minimize interference. The head-end CMTS employs algorithms to schedule individual cable modems so that upstream transmissions from any given modem do not interfere with concurrent downstream receptions to other neighboring cable modems. As more cable modems get deployed in a neighborhood, the possibility of neighboring interference increases. To avoid such interference, the CMTS needs to know which modems are nearby and must also cooperate with the modems to perform "sounding" of the isolation between modems on any given passive coax plant.

Sounding involves the CMTS alternately designating a modem to transmit specially designed sounding signals, while other modems listen for the presence of the sounding signals. If the sounding signal is not heard by a modem, then that particular modem is distant and not interfered with by the modem transmitting the sounding signal. If the sounding signal is received at a level sufficient to interfere with reception, then that modem is nearby the transmitting modem. The level of isolation between modems is measured by the modems, reported through the RPHY node to the CMTS, and then used by the scheduler. Depending on the level of isolation, the scheduler can decide to separate transmission grants or adjust the downstream bit loading in an optimal fashion.

The CMTS may also categorize its modems on a given passive coax plant into Interference Groups or Transmission Groups for use in scheduling modem transmissions. Sounding of the Interference Groups would then occur as modems come onto the network and periodically afterward. Sounding procedures are currently being prototyped by Intel for future use in field trials.

The Intel approach

With a focus on the future, Intel invests in technologies that increase bandwidth and maximize the value of existing wiring infrastructures—including DOCSIS 3.1, Full Duplex DOCSIS 3.1, programmable digital nodes with FPGAs, and virtualization. Intel participates in the standards committee for FDX and is collaborating with industry leaders to develop proofs of concept for the new standard.

These efforts allow MSOs to harness FDX and deliver significantly faster upstream and downstream speeds, while extending the life and value of existing infrastructure. While FDX is changing the rules across the cable industry, it is also part of a larger trend toward virtualization that sets the stage for future transformations, such as backhaul for 5G networks.

From client to cloud, Intel provides cable network operators with high-performance, cost-effective solutions for meeting fast-growing demands for bandwidth and achieving new levels of high-velocity, agile service delivery. With a breadth of solutions across the connected home, access network, service provider edge, and data center, Intel is helping MSOs meet demands for bandwidth, enhance flexibility, simplify upgrades, and manage costs today—and prepare for the next-generation access technologies of the future.

Learn more: intel.com/connectedhome

1. Nielsen, Jakob, Nielsen Norman Group, Nielsen's Law of Internet Bandwidth, April 5, 1998.
2. Chapman, J.; Emmendorfer, M.; Howald, R.; Shulman, S., NCTA 2012 conference, "Mission Is Possible: An Evolutionary Approach to Gigabit-Class DOCSIS."
3. CableLabs, Data-Over-Cable Service Interface Specifications: Remote PHY Specification, 2017.
4. Salinger, Jorge D., Remote PHY: Why and How, Comcast Cable, 2014.

1017/SGL/CMD/PDF 336524-001US