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RFoG – Foggy, or Real?

James O. "Jim" Farmer
Enablence Systems, 1075 Windward Ridge, Alpharetta, GA 30005, USA
jim.farmer@enablence.com

Abstract: RFoG is a third type of PON, after EPON and GPON. It is specific for cable TV, and is designed to facilitate an orderly transition from HFC to PON architectures while maintaining existing systems.

1. Introduction

Passive Optical Networks (PONs) have been deployed now for 10+ years as the primary implementation of fiber-to-the-home (FTTH), with the deployment pace accelerating in the last few years. PONs have a number of advantages compared with older telecommunications architectures, including an all-passive and all-dielectric outside plant, lower loss, and higher capacity. The first two contribute to better reliability and lower operational costs, while the latter two translate into more services than either a traditional telephone company twisted pair plant, or a cable TV hybrid fiber-coax (HFC) plant.

Two standards for modern PONs have been around since 2004: the IEEE EPON (also known as GE-PON) standard, and the ITU GPON standard. Both use the same wavelength plans, both offer a broadcast overlay for video as well as being able to handle IPTV, and both offer incredible data bandwidth compared with older technologies. EPON currently offers data bandwidth of 1 Gb/s in both directions, while GPON offers 2.5 Gb/s downstream (toward the subscriber) and 1.2 Gb/s upstream. The IEEE has completed its standard for 10 Gb/s, and the ITU is working on their 10 Gb/s standard.

While the cable TV industry has watched these developments very closely, and indeed has deployed some of each standard, so far they have by-and-large sat out the deployments. There are several reasons for this, one being that HFC is the second-best residential telecommunications technology today (behind FTTH), and the industry has made a significant investment in back office management systems for DOCSIS, the cable modem standard. Accordingly, they sought a type of PON that would allow them to continue using their current back office and data infrastructure (cable modems and their headend complement, the CMTS). RFoG is the outcome of that effort.

2. History and Status of the Standard

RFoG is probably the acronym with which we have had the most fun in our career. It stands for *Radio Frequency over Glass*, a good description of the technology. Pre-standard systems using the general architecture of RFoG entered the market several years ago. The Society of Cable Telecommunications Engineers (SCTE) undertook to standardize the technology, under the auspices of its Interface Practices Subcommittee, Working Group 5, responsible for fiber optics standards. As of this writing, the first version of the standard has been submitted for balloting. The next step is to resolve any comments made during the balloting process, after which the standard will be accepted as an official SCTE standard. By the time you read this, we expect that RFoG will be an approved standard.

A second release of the standard is already being planned. It is intended to address issues which were deemed to not be of such importance that they had to be resolved in the first release of the standard, yet were of sufficient interest to warrant being standardized in the future. In addition, we presume that as more RFoG gear is installed in the next year or two, additional items needing standardization will surface. This second-generation work will likely commence in 2011.

The first release of the standard defines the RFoG physical layer architecture, which is identical to that of EPON and GPON. The wavelengths chosen permit simultaneous use of a PON structure for RFoG (presumably for residential use) and EPON or GPON (presumably but not necessarily for small and medium business use). The standard emphasizes the performance of the R-ONU, the device that mounts on the side of the house. We wanted to make sure that if an operator removed one vendor's R-ONU and replaced it with another vendor's ONU, the system would operate as if nothing had changed. In addition, there are some minimum standards for performance of the upstream receivers. Copious implementation notes are designed to aid implementers in understanding the subtleties of system operation. Future work may include more work on the physical arrangement of the R-ONU and more system-level specifications. In addition, we presume that experience will point toward other standardization needs.

3. The RFoG System

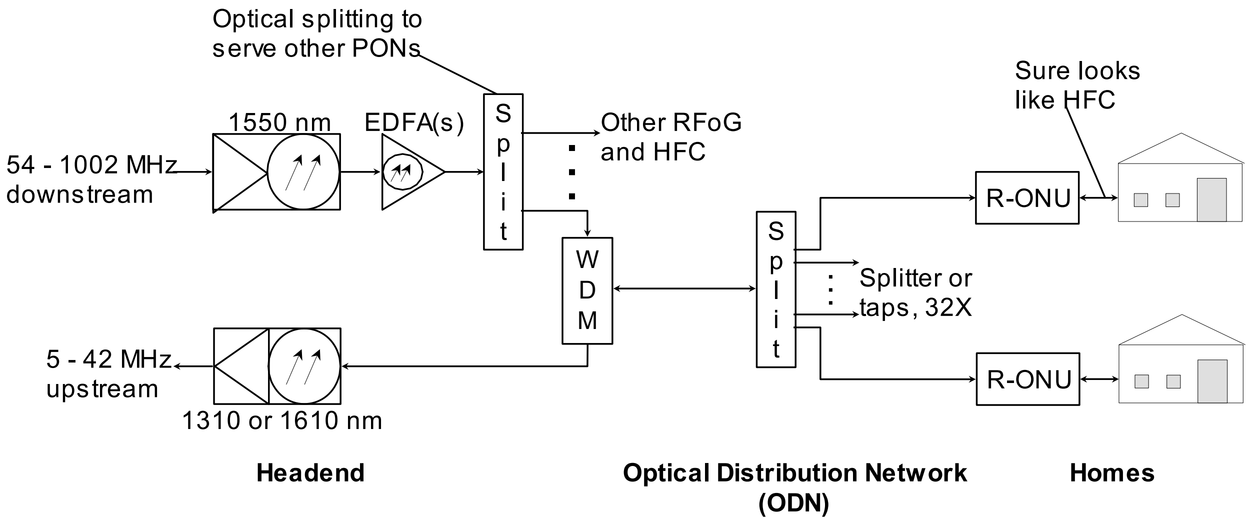

Figure 1. RFoG System

Figure 1 illustrates the RFoG system. To the left is the headend, which comprises a 1550 nm downstream optical transmitter driven by the same complement of RF signals as would drive an HFC system. It supplies signals to erbium-doped fiber amplifiers (EDFAs) as needed in order to get enough signal level to the R-ONUs at homes. The output of the EDFA is split to serve PONs as required. For each PON, this downstream signal is wave division multiplexed (WDM'ed) with the upstream optical signal. This upstream optical signal is either at 1610 nm (for compatibility with EPON or GPON), or 1310 nm (for lowest cost).

As stated above, the Optical distribution network (ODN) is identical to that of an EPON or GPON system. It includes the outside fiber and a splitter. Alternatively a series of taps may be used as in cable TV practice, though most people have found it more efficient to put all splitting in either one or two locations. The maximum length of the ODN is 20 km, to be compatible with EPON and GPON, though there is interest in defining a longer distance in the phase 2 specification. The "sweet spot" in PON splitting today is a 32-way split, though 64-way splits are sometimes used. While there is interest in splitting more ways, the present state-of-the-art precludes doing so in most cases: there is a minimum optical signal level required at the home, and a maximum signal level that can be launched into the fiber, and those numbers make it hard to achieve greater than a 64-way split. Besides, the current practice in EPON and GPON is also 32- and 64-way splits, 128-way splits being difficult to achieve at the present state-of-the-art. In the future, we expect advances to allow higher splits.

The device on the side of the home is called the ONU (optical network unit) or ONT (optical network terminal) in EPON and GPON systems. Originally, an ONU implied a simpler termination, and an ONT implied more complex signal processing, but the terms tend to be used interchangeably today. We adopted the term R-ONU for the RFoG unit in order to distinguish it from the other forms of ONUs. It features a single (usually) RF interface that looks identical to the interface with an HFC plant.

4. The RFoG ONU

Figure 2 illustrates the R-ONU. Connected to the ODN is a wave division multiplexer, which complements the one in the headend, separating the downstream and upstream wavelengths. The downstream signal goes to a 1550 nm optical receiver, whose output is the RF spectrum that went into the transmitter at the headend. This output is supplied to the high port of a diplexer, the RF equivalent of a WDM, which separates signals according to RF frequency. Downstream signals are carried between 54 and 1,002 MHz in North America. In other countries, the minimum frequency is higher, and the RFoG unit may be modified accordingly. Upstream signal in North America occupy the band 5 – 42 MHz. These signals come out of the home, being generated usually by either a cable modem or a set top box.

The slightly unusual thing about the R-ONU is the RF detector. Since typically 32 optical transmitters feed back to the same headend receiver, if we left all the optical transmitters on all the time, we would find that we had intolerable interference and noise build-up at the headend. Thus, we must shut off each upstream transmitter except when it is actually sending a signal upstream. The RF detector determines that an upstream signal is coming from this home, and turns on the upstream optical transmitter. A lot of deliberation in the RFoG committee revolved around defining the proper turn-on and turn-off characteristics of this circuit. If it turns on or off too fast, it will create interference at the headend. If it turns on or off too slowly, it could cause the RF receiver (e.g., in the CMTS) to fail to synchronize on the upstream signal.

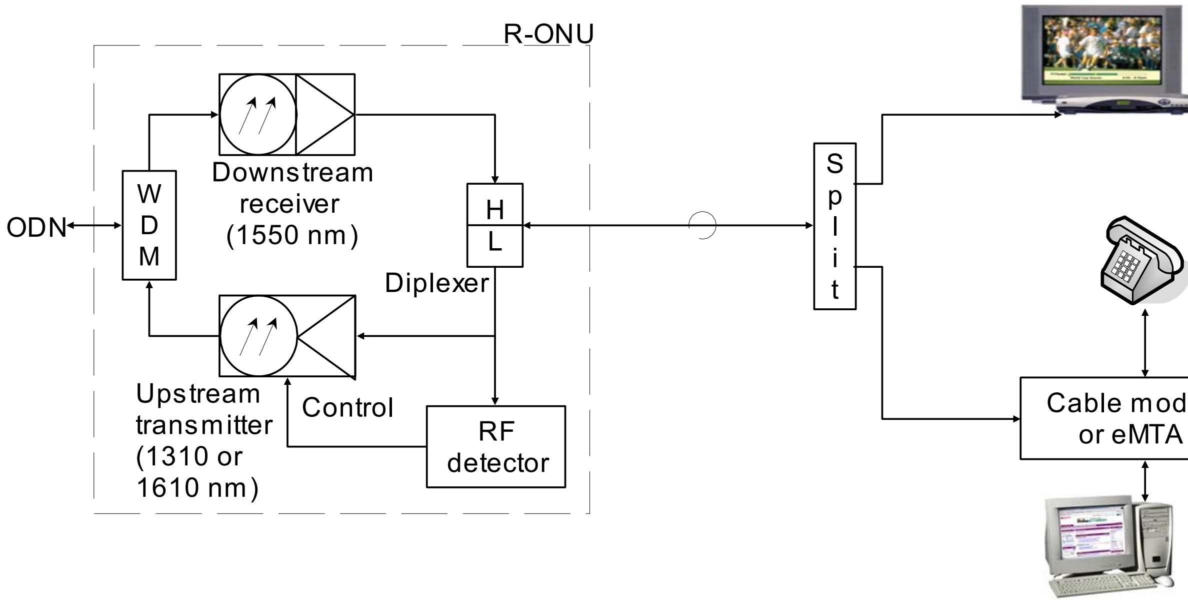

Figure 2. R-ONU and in-Home Equipment

The configuration in the home is identical to the configuration for an HFC system: video signals are supplied to TVs, usually through set top boxes (though some direct analog connections still exist). Data signals are supplied to either a cable modem (data-only) or an embedded Media Terminal Adapter (eMTA – a cable modem and telephone interface in the same box) if telephone service is also supplied. There are a number of cable modems connected to the RFoG system, and it is the responsibility of the CMTS to keep them from transmitting at the same time (though in DOCSIS 3.0 there are times this can happen, using different frequencies). A more troubling scenario is that a set top may try to transmit upstream at the same time a cable modem is transmitting. There is a potential for *optical beat interference* (OBI) to occur if a cable modem in one home and a set top in another turn on at the same time, but at this time the Committee believes the probability of interference problems affecting service is slight.

5. Competition for RFoG

A competing approach to putting in RFoG is an initiative recently taken over by CableLabs called DPoE (DOCSIS PON over Ethernet). DPoE uses a more-or-less conventional EPON, but managed as if it were a DOCSIS system. There are a few enhancements to EPON that make this implementation more straightforward, but they can be done within the EPON standard. Essentially, a layer of software (sometimes called a *shim*) is placed between the EPON management and the DOCSIS interface. This shim will be integrated more closely with the hardware in the future. In addition, the IEEE 302.3 committee responsible for EPON (as well as the rest of the Ethernet standards) has an effort underway called SIEPON, which seeks to standardize certain additional parameters deemed important for the widespread implementation of EPON in business and residential telecommunications.

6. Conclusion

RFoG is seen by some people as an interim technology designed to allow cable operators to begin installing PONs today while keeping their investment in cable modems and back-office systems. Ultimately some feel that the industry will transition to EPON or maybe some advanced PON standard, but the RFoG systems put in will continue to serve well for many years. RFoG does offer advantages over HFC, including higher reliability, lower operational costs, non-existent RF ingress/egress headaches, and greater immunity to noise.