

# Novel access technology based on hybrid Ethernet passive optical network and Ethernet passive electronic network

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**Abstract** To improve the limitations of Ethernet over Coax (EoC) technology in the bidirectional reformation of the hybrid fiber-coaxial (HFC) network, this paper proposes the concept of Ethernet passive electronic network (EPEN) based on multi-point control protocol (MPCP) and the hybrid access scheme of Ethernet passive optical network (EPON) and EPEN. This paper describes the network architecture of EPEN, and introduces the implementation scheme and design of the EPEN system. At present, the project group has been working on the core technology research and key software and hardware design of the EPEN system, on which we have accomplished the hardware design and debugging, the embedded software coding and debugging, the EPEN network management protocol design and software coding. However, there is still a lot to do to achieve networking capability, management, security, quality of service (QoS) and some other functions.

**Keywords** Ethernet passive electronic network (EPEN), multi-point control protocol (MPCP), Ethernet passive optical network (EPON), full duplex, hybrid fiber-coaxial (HFC)

## 1 Introduction

At present, the digitalization reformation of hybrid fiber-coaxial (HFC) network is facing competition from various technologies such as digital video broadcasting-cable (DVB-C), Internet protocol television (IPTV), digital multimedia broadcasting-television (DMB-T) and satellite digital television. Also, bidirectional reformation and thus establishing manageable and maintainable multi-loading

networks are the final goal of local broadcasting and television operators. Presently there are over 80 million broadband users in China. The number is expected to increase to 130 million in five years, and among the increase about 30 million will be created by broadcasting and television operators, showing extremely huge market potential. For the bidirectional reformation of the HFC network, there are many choices in technology implementation mode, among which cable modem termination system (CMTS) scheme and Ethernet passive optical network (EPON) scheme are the major technology schemes [1].

Before EPON technology became mature, CMTS scheme was the preferred scheme of HFC broadband access. However, CMTS is now gradually being fringed as a result of its disadvantages such as low bandwidth, bandwidth asymmetry between upstream and downstream, high cost for unit bandwidth and loud noises in back transmission. Along with the maturity and rapid extensive application of EPON technology, EPON is becoming the mainstream technology for HFC bidirectional reformation. Meanwhile, compared with the EPON + LAN (local area network) mode, EPON + EoC (Ethernet over Coax) access mode is getting more and more popularly adopted in the bidirectional reformation of the HFC network. This is because the topology structure of EPON is similar with that of the HFC network, and using coaxial cable for the last 100 m is obviously the best choice of community antenna television (CATV) users. There are many technology schemes related to EoC, most of which are based on modulation technology except passive baseband EoC, such as Multimedia over Coax Alliance (MoCA), home phone-line networking alliance (HomePNA), HomePlug AV, lower frequency wireless-LAN, et al. However, these technology standards are mostly among the range of home area network and based on carrier sense multiple access/collision avoidance (CSMA/CA) half-duplex media access control (MAC) protocol [2], which is not very applicable

for the bidirectional reformation of broadcasting and television network and broadband access application. For example, EoC equipment based on HomePNA and HomePlug are low in physical layer rate and do not support isolation between users. MoCA has some advantages in the aspect of key technologies, but it is not mature yet due to its late introduction.

Up against the existing limitations of EPON + EoC application, a composite access solution of EPON and Ethernet passive electronic network (EPEN) is proposed in this paper. That is, at the terminal node of fiber to the x (FTTx) in the EPON system, using EPEN technique to realize broadband data access by distributing the network to enter the household through Coax. The EPEN technical scheme can be briefly described as: the EPEN uses Coax as the transmission medium, the physical layer uses orthogonal frequency division multiplexing (OFDM) modulation, the MAC layer uses Ethernet technology, and matured multi-point control protocol (MPCP) of EPON is introduced, connecting bidirectional Ethernet data into point-to-multipoint coaxial access network. Using MPCP as the access control protocol can overcome the disadvantages of having no bandwidth control, low efficiency when multi-loaded and uncertainty of access in traditional carrier sense multiple access/collision detection (CSMA/CD) network. Also, it has higher bandwidth and better management function. EPEN works on the 850–950 MHz band, not conflicting with the band loading TV signals and DVB-C digital signals in Coax. On inserting EPEN signals into Coax, the amalgamation of the three networks is available for CATV users.

The composite access technology of EPON and EPEN proposed in this paper realizes the maximum coverage of the single optical network unit (ONU) + EPEN, with the user access bandwidth and the largest number of users supported both greatly improved compared with other EoC technical standards.

## 2 EPON and EPEN hybrid access network architecture

### 2.1 Network architecture

EPON is a kind of point to multi-point (P2MP) single fiber bidirectional optical access network. Its typical topology is a tree type. The EPON system is composed of optical line terminal (OLT), optical network unit (ONU) and optical distribution network (ODN). In the downstream (from OLT to ONU), signals sent by OLT will arrive at every ONU through ODN. In the upstream (from ONU to OLT), signals sent by ONU will only arrive at OLT, not other ONUs. In order to avoid data conflicts and improve network utilization efficiency, time division multiple access (TDMA) method is used in the upstream and data sent by ONUs is arbitrated. ODN is made up of optical fibers and one or more passive optical splitters, providing optical connections between OLT and ONU [3].

According to the topology differences in CATV scenarios, the EPON system used in HFC network can be further divided into single-fiber-triplex and two-fiber-triplex application modes, among which the single-fiber-triplex application system reference architecture is shown in Fig. 1.

Figure 1 is the EPON system reference architecture of wavelength division multiplexing (WDM) combiner inside OLT. In downstream, CATV signals uses 1550 nm wavelength to transmit, and the wavelength is transmitted in an optical fiber after merging with the original 1310 nm/1490 nm wavelength at *B* reference node, using the same ODN transmission, de-combiner laid inside ONU, while the ONUs terminate CATV optical signals and output radio frequency (RF) signals.

As for two-fiber-triplex mode, in downstream, CATV signal is transmitted at 1550 nm or 1310 nm through an optical fiber, while the 1310 nm/1490 nm data signals of

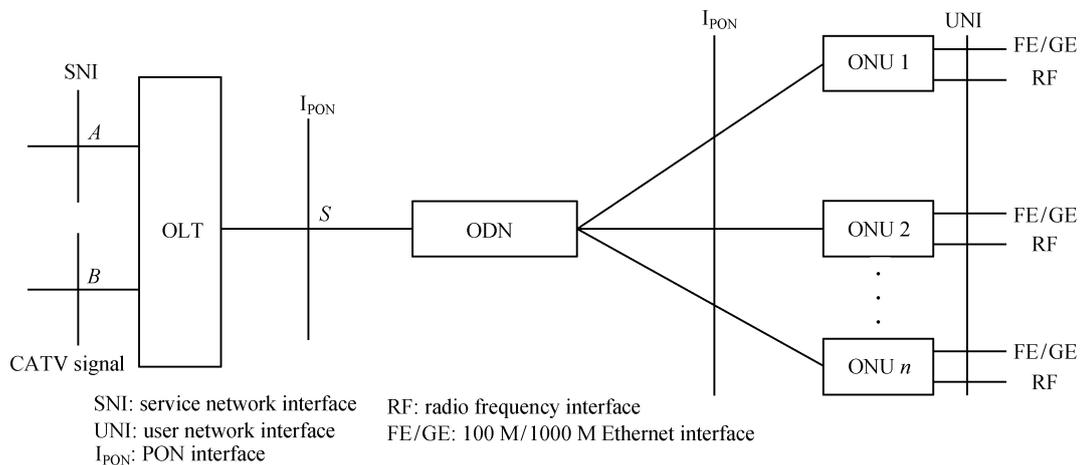


Fig. 1 EPON system reference architecture

the EPON system is transmitted through another optical fiber. The two signals are separately transmitted through respective ODNs.

In the EPON and EPEN composite access application mode, ONU needs to provide FE/GE Ethernet port and CATV RF interface. The bandwidth of CATV RF interface is supposed to meet the requirement of 47–850 MHz, and CATV network performances are supposed to meet requirements such as: carrier-to-noise ratio (CNR)  $\geq 47$  dB; composite second order (CSO) distortion  $\geq 54$  dB; composite triple beat (CTB) distortion  $\geq 54$  dB, etc.

EPEN uses coaxial network as the transmission medium, sharing a similar topology with EPON, both as P2MP architecture. The EPEN system reference architecture is shown in Fig. 2.

The EPEN system is composed of electronic line terminal (ELT) which access FTTx optical node in EPON, electronic network units (ENUs) in subscriber units and passive electronic distribution networks (EDNs). It is a two-way access system based on coaxial cable. In the downstream (from ELT to ENU), signals sent by ELT will arrive at every ENU through EDN. In the upstream (from ENU to ELT), signals sent by ENU will only arrive at ELT, not other ENUs. In order to avoid data conflicts and improve network utilization efficiency, TDMA method is used in the upstream and data sent by ENUs is arbitrated. EDN is made up of coaxial cable and branches of one or more passive electronic splitters, providing electrical connections between ELT and ENUs.

## 2.2 Protocol layers of EPEN system

EPEN uses Coax as the transmission medium, the physical layer uses orthogonal frequency division multiplexing (OFDM) modulation, the data link layer uses Ethernet technology, and point-to-multipoint communications control technology is introduced, connecting Ethernet into a

P2MP coaxial access network. Its protocol layer is shown in Fig. 3, where MII is media independent interface; MDI is medium dependent interface; OAM is operation, administration, and maintenance; ELT is electronic line terminal; ENU is electronic network unit; PHY is physical layer device; RS is reconcile sublayer.

The EPEN system uses master-slave mode for HFC access network structure, ELT as the master equipment, ENU as the slave equipment, managed and controlled by the master equipment. In the EPEN system, TDMA method is used to broadcast to every ENU in the downstream, the upstream is based on MPCP, and ENU upstream only in authorized time windows. The downstream band of EPEN technology is 850–900 MHz, and it is 900–950 MHz for upstream, which can reach 100 Mbit/s full duplex speed.

## 3 Design and implementation of EPEN system

### 3.1 EPEN technical scheme

The EPEN system follows a completely original and innovative technical route: its physical layer uses OFDM modulation mode, which improves the PHY layer technology of modulated EoC and redesigned MAC layer technology. Referring to the mature MPCP in the IEEE802.3-2005 standard, we work on the implementation of multi-point access control in order to make it more suitable for the bidirectional reformation model of the HFC network.

The design of the EPEN equipment schematic is shown in Fig. 4. The EPEN physical layer realizes OFDM [4,5] function by a digital signal processing (DSP) chip, automatically choosing among binary phase shift keying (BPSK), quaternary phase shift keying (QPSK), 16-256

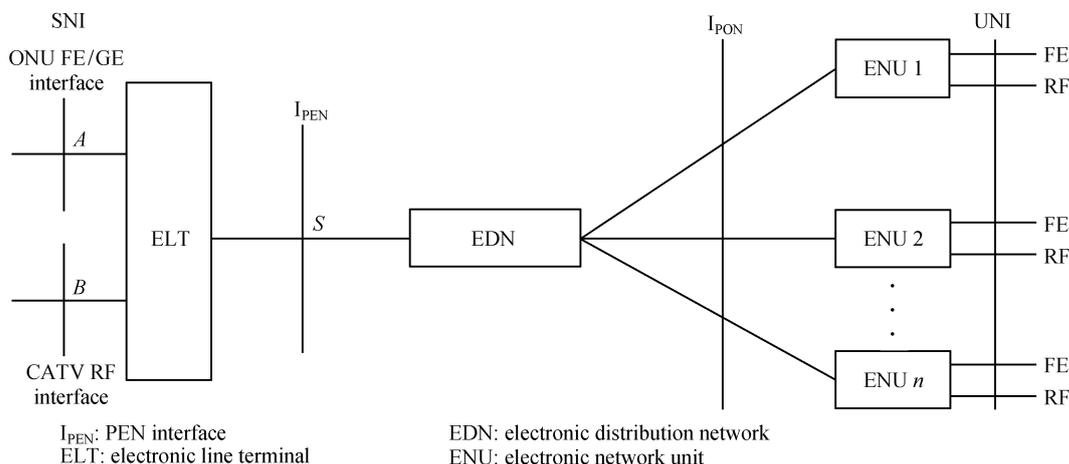


Fig. 2 EPEN system reference architecture

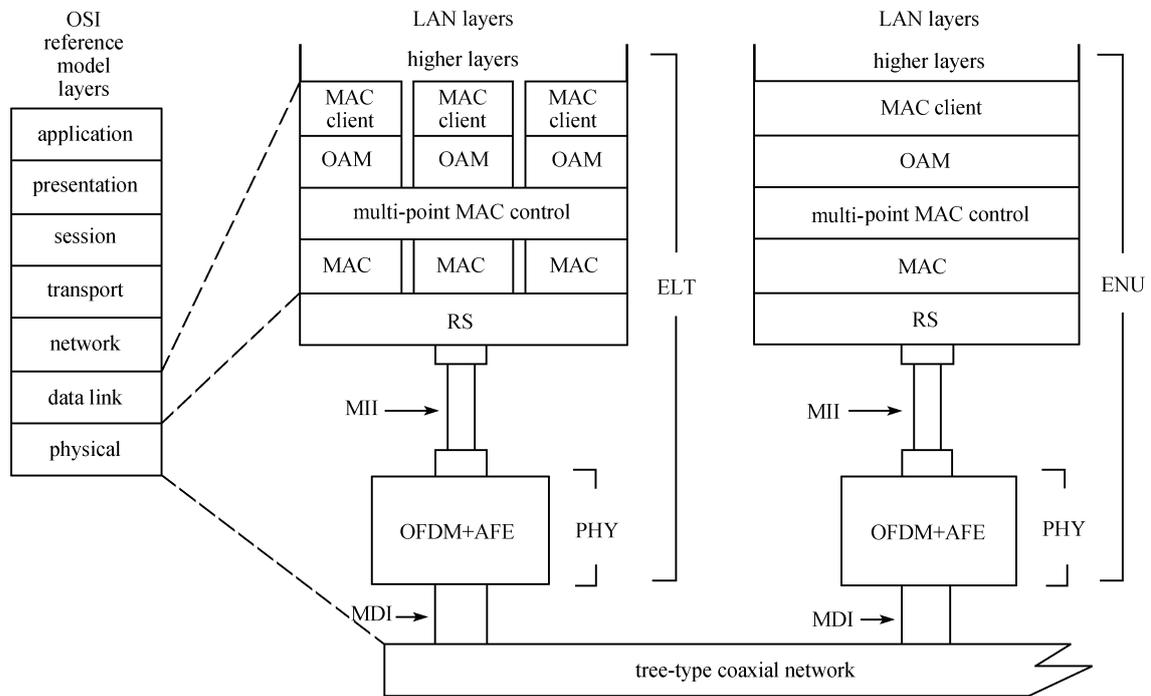


Fig. 3 Protocol layers of EPEN system

quadrature amplitude modulation (QAM) and the frequency of sub carrier wave can shift at 25 MHz in step, with strong anti-jamming potency. The analog front end (AFE) chip uses the AFE chip especially for MoCA technology, which can be modulated into 850–1500 MHz band, where the bandwidth of each channel is 50 MHz. In EPEN system design, to realize full-duplex access mode, upstream and downstream use two different bands, where downstream is 850–900 MHz and upstream is 900–950 MHz. There is a wide range of automatic gain control (AGC) function of internal EPEN equipment, allowing three-stage amplification at most. Usually, it works well under the attenuation of 0 to 60 dB, which can fully satisfy the coverage demand of connecting from optical nodes to household under the present HFC network.

The DSP chip implements a standard physical layer architecture which supports a 100 Mbit/s data rate MAC interface connecting with the FPGA chip and modulates Ethernet frames with OFDM technical scheme and fulfills a high speed analog-digital converter (ADC) and digital-analog converter (DAC). The AFE chip connects with the DSP's baseband interface and coaxial coupled circuit whose function is modulating baseband differential signal into RF signal to transmit across the coaxial network. The ARM chip realizes device and system management and provides a management port. The EPEN system is managed through private OAM protocols. Command-line interface (CLI) and web management have been achieved.

We have realized multi-point control MAC protocol in the EPEN system by means of time division multiplexing (TDM) mechanism in the upstream. The key difficulties which have been overcome at the physical layer are signal clock locking and synchronization technology of burst-mode OFDM receiving. We implement the EPEN system maintenance and configuration management by OAM protocol, and at the same time, extend the protocol to meet some special requirements. The design of the P2MP control protocol in the EPEN system is named as EPEN control protocol (ECP).

### 3.2 ECP design

EPEN protocol design learned from the matured EPON technology, mainly for MPCP and dynamic bandwidth allocation (DBA) algorithm [6], though to much extent simplified. Simplifying the adoption of MPCP, we have defined the EPEN control protocol and named it as ECP protocol. ELT regularly delivers network maintain status via the ECP data unit (ECPDU) protocol frames. DBA is mainly used to control ENU upstream access bandwidth, which can guarantee ENU quality of service (QoS) through configuring DBA parameters. In addition, DBA is also in charge of registering ENU, discovering and allocating relevant bandwidth.

ECP frames are commonly referred to as ECPDUs. ECP defines four messages used to exchange information

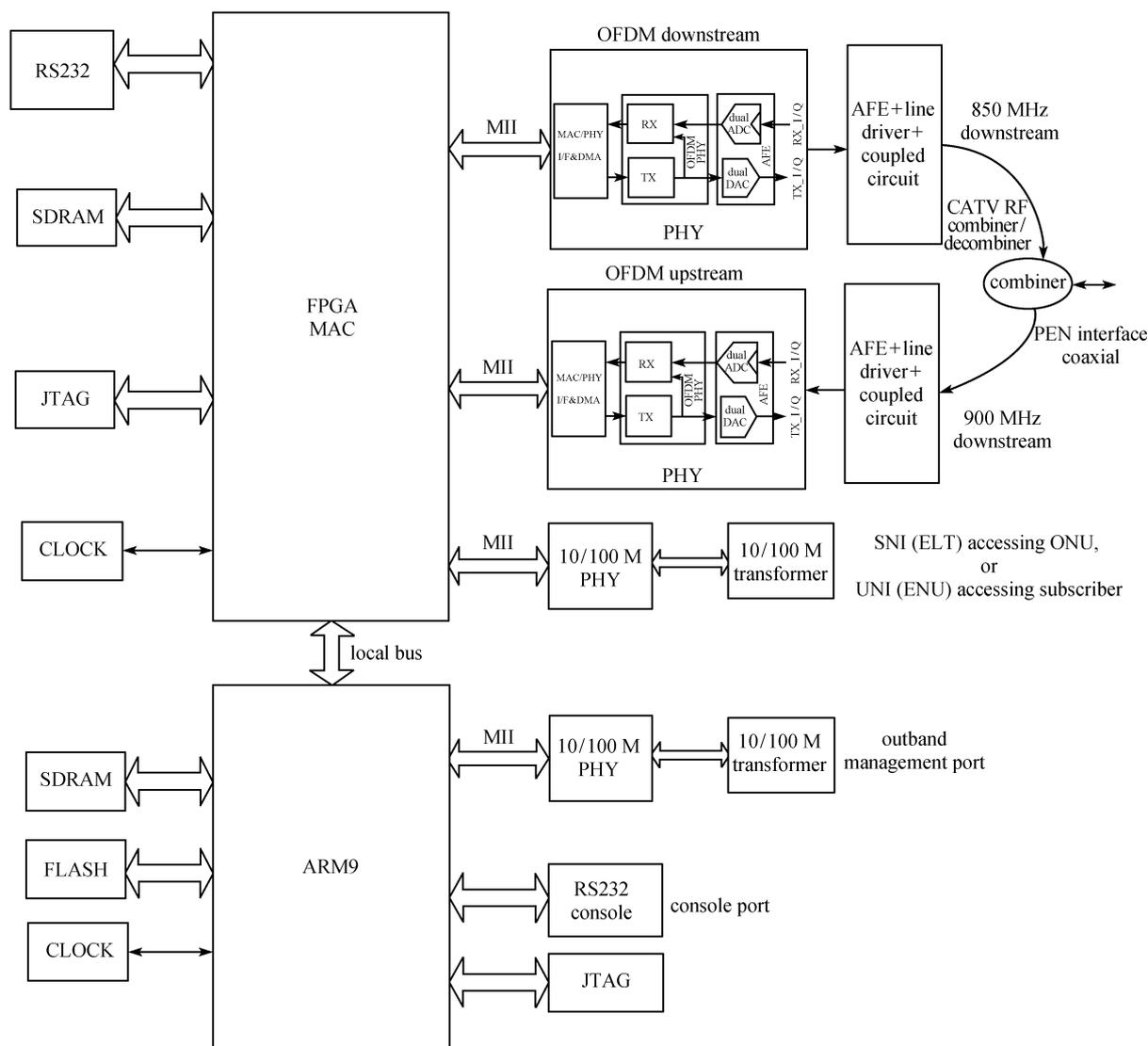


Fig. 4 EPEN equipment principle diagram

between the ELT and ENUs, such as GATE, REGISTER\_REQ, REGISTER, and REGISTER\_ACK.

As an example, the following ENU autodiscovery mechanism illustrates the principle of ECPs. Figure 5 illustrates the interaction of various processes involved in autodiscovery. The autodiscovery handshake procedure consists of the following steps:

1) The discovery agent in the ELT instructs the gate generation process to send a discovery GATE message. The discovery GATE ECPDU is received and verified by the gate reception process at the ENU. The received discovery grant is stored for future activation.

2) Upon initialization, the discovery process in the ENU generates a REGISTER\_REQ message. This message remains buffered until the discovery grant activates, i.e., until the transmission window opens. Then the

REGISTER\_REQ is transmitted upstream to the ELT on the broadcast channel.

3) Upon processing the REGISTER\_REQ message from the ENU, the discovery agent issues a unique logic link ID (LLID) value and then transmits a REGISTER ECPDU to the ENU.

4) Following the transmission of REGISTER ECPDU, the DBA agent allocates a normal grant to the newly registered ENU. This grant is needed to give the ENU an opportunity to transmit an acknowledgment back to the ELT.

5) When the grant activates, the discovery process at the ENU transmits a REGISTER\_ACK ECPDU.

The final registration process at the ELT is responsible for issuing a unicast GATE message to an ENU and receiving the REGISTER\_ACK frame. This process is

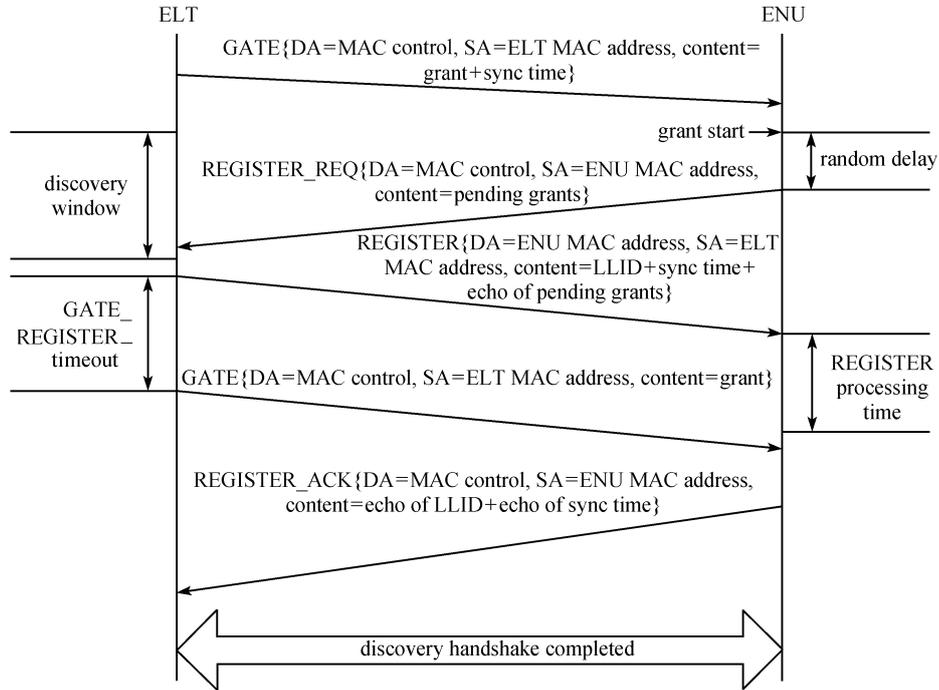


Fig. 5 Auto discovery message exchange

instantiated for each logical port at the ELT, except the port connected to the broadcast logical link.

## 4 Conclusion

This paper projects a scheme of EPON and EPEN composite access, which originally proposes the concept of EPEN, and describes its architecture and technical scheme. So far, the project group has been working on the core technology research and key software and hardware design of the EPEN system, on which we have accomplished the hardware design and debugging, the embedded software coding and debugging, the ECP network management protocol design and software coding. However, there is still a lot to do to achieve networking capability, QoS security, network management, network security and some other functions.

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