

## ECMA-387/ISO/IEC 13156: High Rate 60GHz PHY, MAC and HDMI PAL

### Whitepaper

March 2008

## 1 Introduction

### 1.1 Status of the work

The Ecma General Assembly approved and published the 1<sup>st</sup> edition of the High Rate 60 GHz PHY, MAC and HDMI PAL Standard for short range unlicensed communications in December 2008 as [ECMA-387](#), following [TC48](#)'s finalisation in October.

Using [Open-60GHz](#), TC48 is inviting feedback as input for Ecma's comments to JTC 1's Fast Track approval procedure for transposition of [ECMA-387](#) as ISO/IEC 13156.

### 1.2 Applications

The standard provides high rate wireless personal area network (including point-to-point) transport for both bulk data transfer and multimedia streaming.

The key usage cases and applications are:

- High definition (uncompressed / lightly compressed) AV streaming
- Wireless docking station
- Short Range Sync&Go.

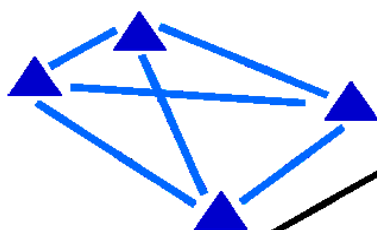
### 1.3 Heterogeneous networking

The standard defines three device types that interoperate with their own types independently and that can coexist and interoperate with the other types.

Thus it offers a heterogeneous network solution that provides interoperability between all device types.

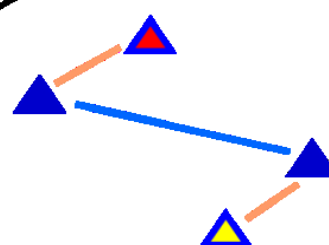
#### Homogeneous Networking

All device PHYs have the same capability



#### Heterogeneous Networking

All device PHYs do not have the same capability



### 1.4 Device Types

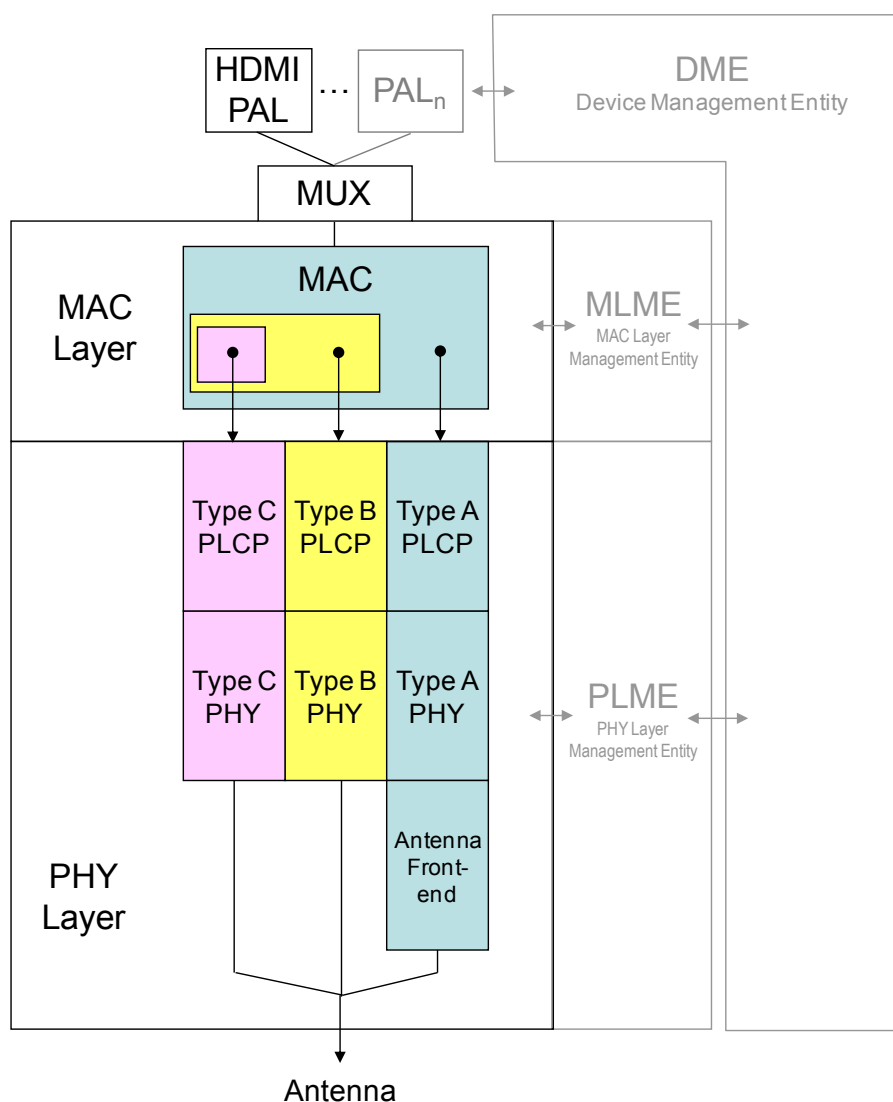
The three device types are defined as follows:

- A type A device offers video streaming and WPAN applications in 10-meter range LOS/NLOS multipath environments. It uses high gain trainable antennas. This device type is considered as the 'high end' - high performance device.

- A second type B Device offers video and data applications over shorter range (1-3 meters) point to point LOS links with non-trainable antennas. It is considered as the 'economy' device and trades off range and NLOS performance in favour of low cost implementation and low power consumption.
- The third type C device is positioned to support data only applications over point to point LOS links at less than 1-meter range with non-trainable antennas and no QoS guaranties. This type is considered as 'bottom end' device providing simpler implementation, lowest cost and lowest power consumption.

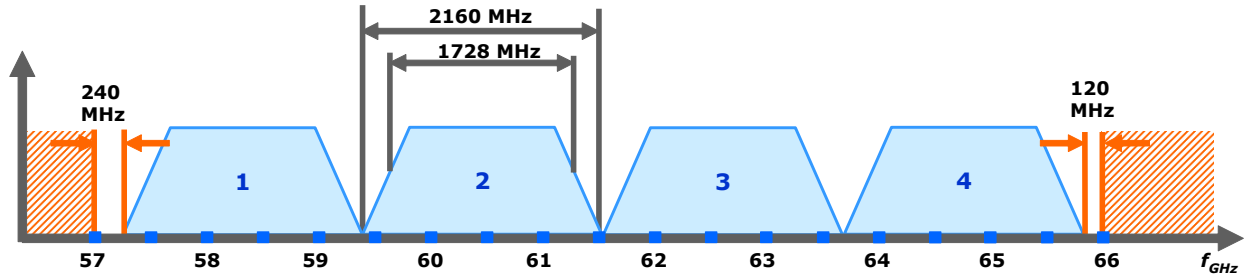
## 1.5 Protocol Structure

A single MAC-layer protocol is defined within which type B and type C devices support limited functionalities supported by their respective PHY layers as illustrated here:



## 2 PHY Layer

### 2.1 Frequency Plan



The standard specifies four frequency channels each with a symbol rate of 1.728 Giga-Symbols/second and with a separation of 2.160 GHz. All device types follow the same frequency plan. Under this frequency plan, the standard supports bonding of up to four adjacent channels. The channel bonding allows achieving higher data rates, or the same data rates while using smaller, more efficient constellations.

### 2.2 Type A PHY

The Type A PHY includes two general transmission schemes, namely Single Carrier Block Transmission (SCBT), also known as Single Carrier with Cyclic Prefix, and Orthogonal Frequency Division Multiplexing (OFDM). For beacon transmissions and to ensure interoperability among Type A devices, a common, mandatory mode is defined based on the SCBT transmission scheme. Furthermore, a mandatory Discovery Mode is defined to allow the initial communication between Type A devices, prior to antenna training. Other SCBT modes and all of the OFDM modes are optional.

All Type A devices support a flexible multi-segment frame format. This format allows the transmission of different MAC Protocol Data Units (MPDUs) using potentially different modulation and coding schemes within the same frame. It also enables flexible use and placement and/or length for frame check sums, midambles and antenna training sequences.

Unequal Error Protection (UEP) is supported through the use of the multi-segment packets or specially designed modulation and coding schemes. In the UEP coding mode, the MSB and LSB of a video signal are separated and encoded by concatenated RS and eight parallel convolutional codes. By providing stronger convolutional coding to the MSB than the LSB, a higher quality video transmission can be resulted, which can also easily be switched to Equal Error Protection (EEP) mode in the case of data signal transmission. In addition, UEP mapping with single code rate provides an alternative to UEP coding by intelligent mapping the MSB and LSB in the constellation points. The MSB-only transmission allows fast retransmission with data rate twice the original data rate. This is particularly useful for transmission of video and multimedia, where different data components will require different levels of protection.

Also, Type A devices support both open-loop and closed-loop antenna training protocols that can be used to train the antenna arrays to achieve array gain. Type A devices also support a transmit switch diversity protocol.

#### 2.2.1 Single Carrier Block Transmission (SCBT)

The SCBT transmission scheme employs an adaptive length Cyclic Prefix (4 possible length, including 0) to allow frequency domain as well as time domain equalization as well as different multipath environments. This is particularly important since the level of multipath significantly varies as a function of antenna directionality as well as the environment. The SCBT modes employ  $\pi/2$ -BPSK, QPSK, UEP-QPSK,  $\pi/2$ -NS8QAM, 16QAM and UEP-16QAM as well as multiple code rates to generate a number of transmission modes. A concatenated Reed-Solomon (RS) and convolutional code is used with for  $\pi/2$ -BPSK, QPSK modes. For the larger constellations Trellis Coded Modulation

(TCM) is concatenated with the same RS code. Using these modulation schemes, Type A SCBT supports data rates from 0.4 Gbps to 6.4 Gbps, without channel bonding. The mandatory common beaconing mode is based on  $\pi/2$ -BPSK and has a data rate of 0.4Gbps.

### **2.2.2 OFDM**

In the OFDM transmission scheme, the incoming data is split into two parallel branches for further baseband encoding and interleaving. A total of eight different data rates can be achieved using four different coding modes along with QPSK and 16-QAM modulation. Reed Solomon code is concatenated with convolutional codes to provide sufficient channel coding gain over the underlying fading channels, while a total of eight convolutional encoders is used to keep the cost of ultra-high throughput decoding under control. The coding modes employed are EEP coding, UEP coding, UEP mapping and MSB-only transmission which are designed to support diverse application requirements. The EEP and UEP modes are also combined with advanced bit interleaver to provide better performance. Efficient OFDM tone interleaver based on bit reversal operation is further used to provide error resilience with additional advantage of complexity reduction.

### **2.2.3 Discovery mode and antenna training**

The modulation and coding for the discovery mode is similar to the common beaconing mode, with the exception that a long adaptive spreading factor is used to increase the time-bandwidth product. The spreading compensates for the lack of array gain prior to antenna training.

Devices with a sector antenna use the beacons to select their sector. Phased array antenna training is accomplished through the transmission of a negotiable number of Frank-Zadoff sequences with a negotiable spreading factor. In open loop mode, the receiver responds with a similar set of FZ sequences; in closed loop mode, the receiver gives explicit feedback about the phase settings the transmitter should use. This process can be iterated a few times to increase the accuracy.

During data transmission, the devices may update their phase settings (antenna tracking) through a single iteration of this algorithm.

## **2.3 Type B PHY**

The Type B PHY has been designed using a simplified single carrier transmission scheme with a common beaconing mode based on differentially encoded BPSK modulation (DBPSK), thus allowing for both simple coherent and non-coherent demodulation and minimizing the implementation overhead to support interoperability with type A devices. The Type B beaconing mode uses the same frame format as Type A beacons. The two main differences, designed to minimize the complexity and power consumption of the receiver, are the waveform (DBPSK instead of  $\pi/2$  BPSK) and the FEC (Reed-Solomon instead of concatenated Reed-Solomon (RS) and convolutional code).

The Type B device does not support cyclic prefix, neither the discovery mode used for antenna training. The type B device supports several optional other waveforms (such as DQPSK, UEP-QPSK, OOK/4-ASK and Dual AMI), as well as optional flexible multi-segment frame format and optional multiple sectors antennas (non trainable antennas). Also, Type B devices optionally transmit antenna training sequences (ATS) to assist Type A devices to train their antennas. The basic transmission rate of a type B device is 0.8 Gbps, and is optionally extended up to 1.6 and 3.2 Gbps.

## **2.4 Type C PHY**

The Type C PHY has been designed using the simplest single carrier transmission scheme based on the Amplitude-Shift-Keying (ASK) modulation scheme. It allows both coherent and non-coherent detection. For managing devices and for ensuring interoperability with Type A or Type B devices, the On-Off-Keying (OOK: 2 level ASK) with 2 symbols repetition is

adopted for beaconing (polling) mode. For a better channel reuse and power saving, the Type C device supports an optional closed loop transmission power control.

To simplify the implementation, the Type C device supports none of a multi-segment frame format, adjacent channel bonding, antenna training scheme, the convolutional coding FEC and the UEP. The Type C device uses Reed-Solomon coder for the FEC. The basic transmission rate for the Type C device class is 0.8 Gbps achieved by using non-coherent OOK and is optionally extended up to 3.2 Gbps by using non-coherent 4-level ASK.

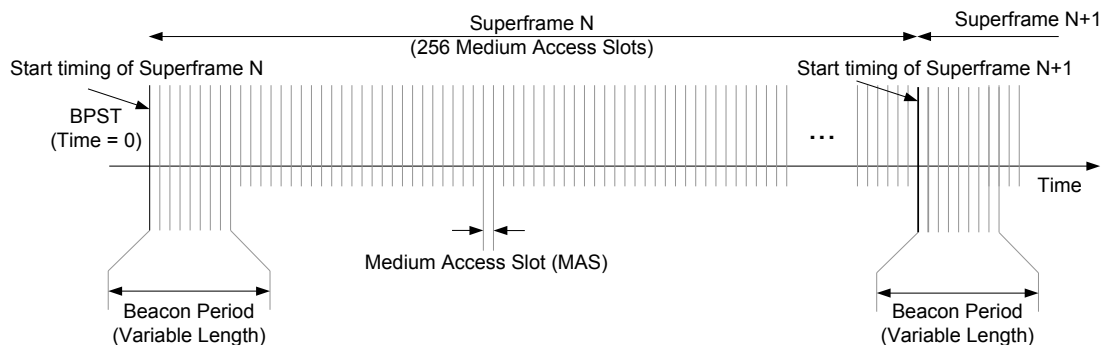
### 3 MAC Layer

The Ecma TC48 MAC is based on the ECMA-368 MAC, with “necessary” changes to support directional communication in 60 GHz for different types of devices including:

- Changes to the beaconing process
- Enhancements to DRP to support directional communication and spatial reuse
- Dedicated discovery channel, to facilitate antenna training and device discovery.
- Coexistence and inter-operability among different types of devices
- Synchronization among devices of different types
- Polling based mechanism to enable low complexity devices.

The following summarises key features of the MAC protocol.

#### 3.1 A unified superframe structure



The basic timing structure for frame exchange is a superframe. The superframe duration is composed of medium access slots (MAS), which is the smallest time unit a device can reserve for data transmission. Each superframe starts with a Beacon Period (BP), which extends over three or more contiguous MAS. All devices of Type A and B transmit beacons in the BP using the mandatory mode corresponding to their device types. Devices must follow the superframe structure once they have completed the device discovery procedure.

A Type C device uses a polling based timing structure referred to as a master-slave period in a DRP created by a Type A or B master device. At the absence of Type A or Type B devices, a Type C master device may extend the master-slave period to the entire superframe.

#### 3.2 Device discovery

Devices discover each other through the transmission of discovery beacon frames in the Discovery Channel. CSMA/CA with random backoff is used in the transmission of discovery beacon frames so that all devices have a fair and quick channel access to discover other devices.

Based on the device types, devices follow different procedures using their own mandatory PHY modes. Type A devices can discover each other via transmission and reception of

omni-directional discovery mode beacons in a peer-to-peer manner, while Type B and Type C devices can discover the devices of their own types via directional mode-B0 beacons and mode-C0 polls, respectively. Device discovery among heterogeneous types of devices is achieved using polling based mechanisms on a master-slave basis.

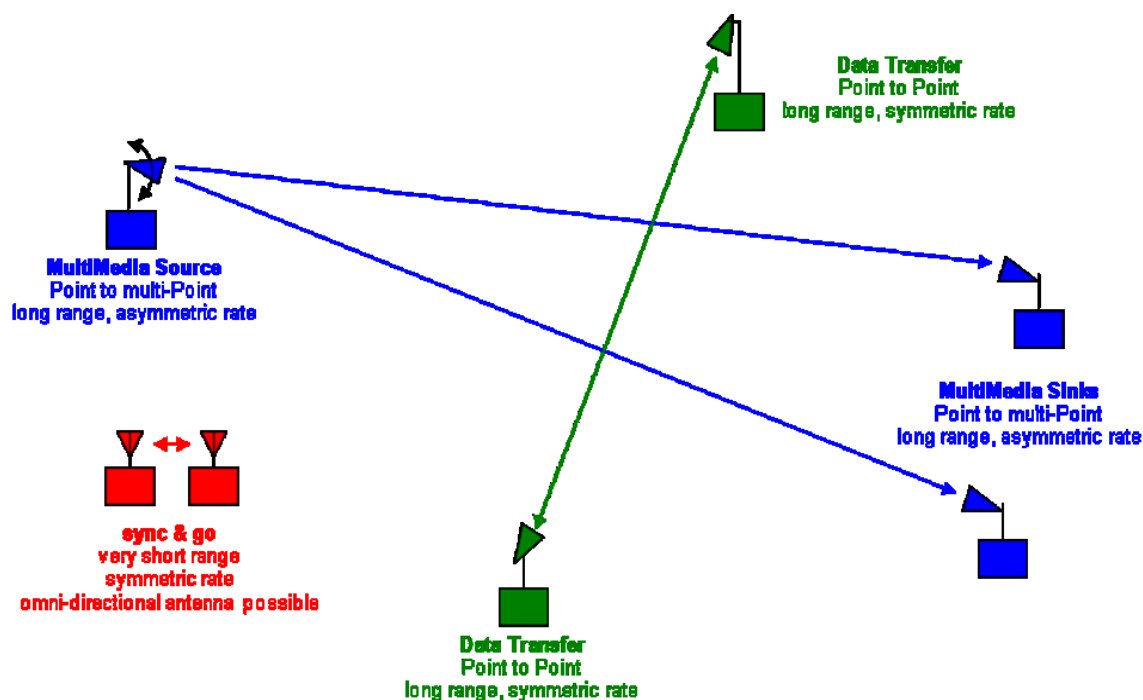
### 3.3 Beacon transmission

Devices send beacon/polling frames to their neighbours to exchange coordination information such as reservation of channel time or time synchronization. Unlike omni-directional beacon transmission in ECMA-368, beacons are transmitted using directional antennas to support simultaneous connections (thus, maximizing the spatial reuse).

Devices of Type A or B transmit beacons in unique beacon slots within the BP of each superframe using the enhanced ECMA-368 Beacon Protocol. A device might send more than one beacon because a single directional beacon might not be heard by all devices with which the device needs to communicate due to the narrower beam used in the beacon transmission. Moreover, a Type B device needs to send a mode-A0 beacon along with each transmitted mode-B0 beacon (referred to as a dual-beacon) so that Type A devices will honor the reservation of the Type B devices.

In order to further reduce protocol complexity, Type C devices only need to send polling frames in a master-slave period to announce its presence and timing information.

### 3.4 Spatial reuse



Since beacons, except the mode-D0 discovery beacons, are transmitted using directional antennas, they are broadcasted over a more confined area, thus resulting in a smaller “interference zone”. Therefore, more links can be established simultaneously, thus enabling the spatial reuse of the channel time.

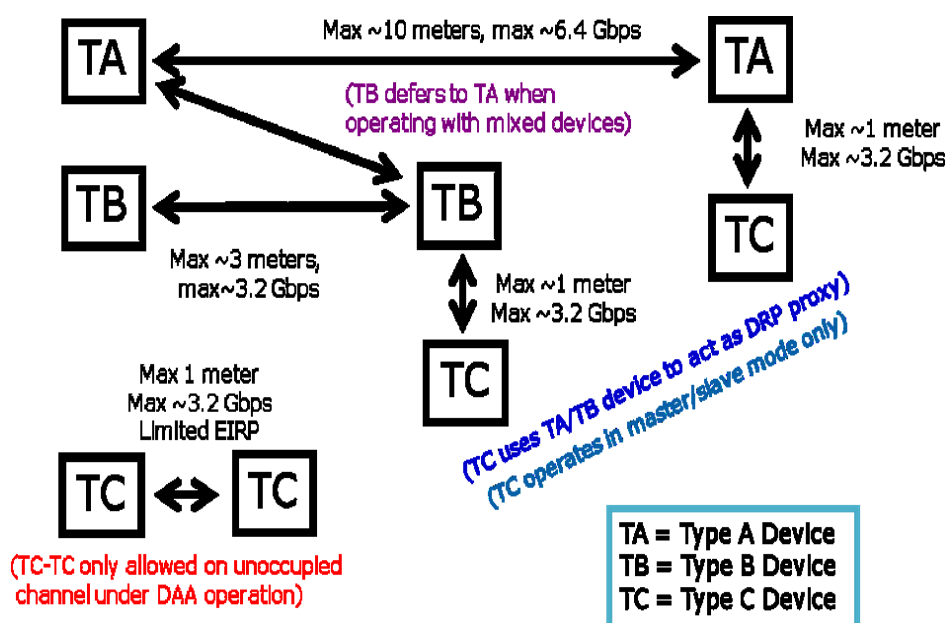
Spatial reuse is further maximized via a new reservation protocol. The new protocol is based on the ECMA-368 Distributed Reservation Protocol (DRP), which enables devices to reserve channel time that the device can use to communicate with one or more neighbours. To support simultaneous transmissions using the existing DRP, devices that use the DRP for transmission or reception will include the antenna information such as beam number in the DRP IEs of their beacons. Devices that attempt to make new reservation will check both

time and directionality of the existing reservations via the information provided in the received DRP IEs.

### 3.5 Coexistence and interoperability

Although the coordination of channel usage among devices is achieved via exchange of beacons, devices of certain types may not be able to decode all beacons due to hardware or software limitation. To prevent potential interference from the devices with limited capabilities, devices of different types are given priorities in terms of sharing the channel with other devices. In general, a type C device is given the lowest priority, and thus has to surrender the channel usage to any type A or type B device whenever they are present. A type B device can claim the ownership of a reservation it made via the mode-A0 beacons so that a type A device will not interfere.

To support data exchange between heterogeneous types of devices, devices establish a master-slave relationship via polling frames. In particular, a type A device will be the master of a type B or type C device with which the type A device communicate and a type B device will be the master of a type C device. The master device is responsible for reserving the channel time and coordinating the communication via polling.

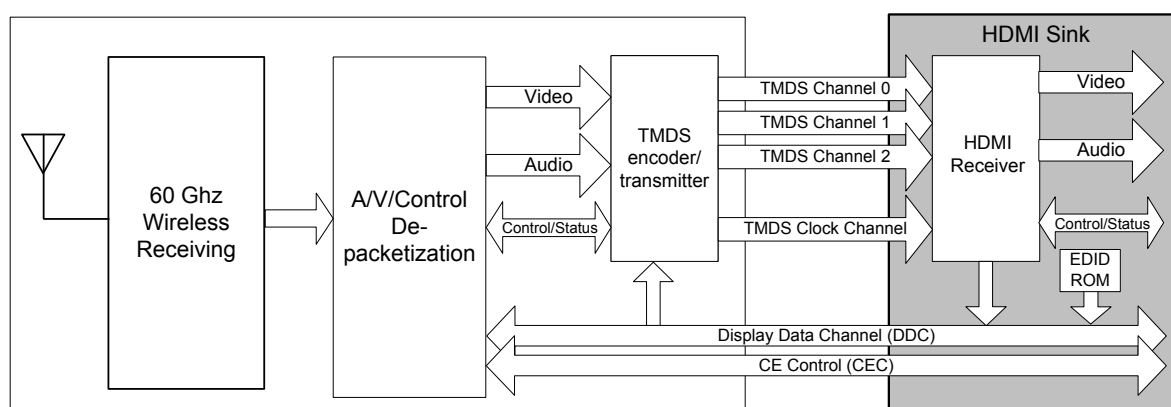
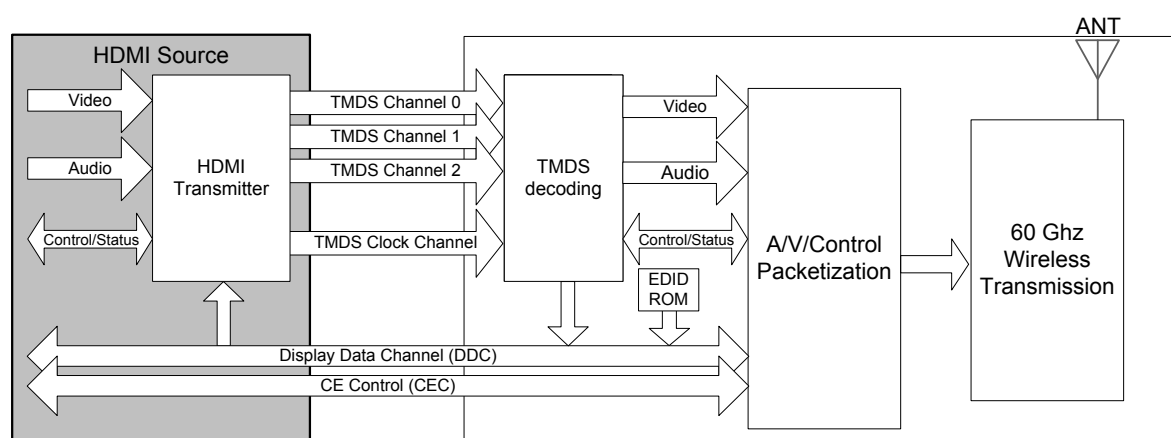


### 3.6 Other features

In addition to all above functionalities, the MAC protocol provides out of band control and dynamic relay transmission for blocked path. To cope with strong directivity and high path loss in 60GHz band, LOS (line of sight) communication with antenna training is desirable. However, when the LOS is blocked, data transmission is no longer available. In order to resolve this blocking problem, the data transmission can continue by using a reflected ray or by another path via a relay device. The relay device is considered as Type A device with amplify-and-forward function. To support the functionality, it should include at least two antennas capable of antenna training.

## 4 HDMI PAL

The 60 GHz wireless solution is placed between the HDMI source and HDMI sink as shown below. In the wireless HDMI transmitter, the TMDS coding is removed prior to transmission. The three data channels are then multiplexed together, along with the display data channel and the CE control. Video is flagged for unequal error protection (UEP). If the data is not video, then it is flagged for equal error protection (EEP). The serial bit stream is then framed and presented to the MAC-SAP. In case of sequential UEP, the serial bit stream should be divided into MSB bits and LSB bits and framed as separate MSB and LSB frame. In the wireless HDMI receiver, the packet is received via the MAC-SAP. The PAL header is read to indicate if the packet is video, audio, control or DDC/CEC. If the packet is video then the TMDS coding is applied prior to passing the video data onto the HDMI receiver. The three data channels are de-multiplexed, along with the display data channel and the CE control.



Contact information:

TC48 chair: Ruud van Bokhorst, [Ruud.van.Bokhorst@Philips.com](mailto:Ruud.van.Bokhorst@Philips.com)

TC48 vice-chair: Stephane Pinel, [pinel@ece.gatech.edu](mailto:pinel@ece.gatech.edu)

Ecma International: Onno Elzinga, [Onno@Ecma-International.org](mailto:Onno@Ecma-International.org)