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## HomePlug Command & Control (C&C) Overview White Paper



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## **Introduction**

The focus of high speed Home Area Networks (HAN) is an application that has limits of distance and noise interference. In order to address the need of reliability for a robust and immune from many types of line interference, the HomePlug Powerline Alliance has defined the HomePlug Command and Control (HomePlug C&C) specification. The HomePlug C&C v1.0 specification creates a standard for low bandwidth, low cost and highly reliable Powerline Communications (PLC) applications for residential and industrial environments. This technology is complementary to the HomePlug Powerline Alliance's existing HomePlug 1.0 as well as the new HomePlug AV and BPL standards. The HomePlug Powerline Alliance has approved layer 1 (PHY) and layer 2 (MAC); while the Network and Host layers are awaiting approval. HomePlug C&C devices will coexist regardless of the product, vendor, application and protocol layer implementation. The HomePlug C&C Protocol Stack interfaces to the MAC layer, and provide complementary services and functions. The main purpose of the upper stack is to ensure full interoperability between different devices from different manufacturers, provide advanced services and functions, and provide easy development and installation of HomePlug C&C devices.

## **How was the standard created?**

The HomePlug Powerline Alliance announced a strategic plan in March 2005 to develop a specification for an advanced command and control technology that would serve as the foundation to enable a new era of convenience, safety and security in the home. A Technology Evaluation Committee was established to conduct extensive lab tests on several available PLC command and control technologies. Subsequently, the Alliance established a Specification Working Group (SWG) to define the full specifications. Version 1.0 of the PHY and MAC specification was ratified in 2007 and work on developing upper layers, including a networking layer, transport layer, session layer and profiling is ongoing. The full specification is slated for final release by the end of 2008. Members of the Command & Control Specification Working Group include HomePlug Alliance members Ariane Controls, Corporate Systems Engineering, GE Energy, LG Electronics, Sharp, Simply Automated, Texas Instruments, Watteco and Yitran Communications - all of whom have substantial experience with command and control communication technology.

## **HomePlug C&C Objectives**

- HomePlug C&C is the ideal solution for command and control for home appliances, security and home automation with full coverage throughout the home.
- Provide a logical extension of Smart Grid energy management communication technologies into the residential, commercial or industrial market for demand response and demand management applications.
- HomePlug C&C will be an extremely low cost solution that can be added into any device and appliance used within the home.
- HomePlug C&C devices are plug and play, requiring no technical expertise or complicated set up, and will provide the ability to form a secured network with high integrity.

- The addition of the protocol firmware stack provides full interoperability between devices from different manufacturers.
- HomePlug C&C allows any device or appliance to trigger events (i.e. upon occurrence of an event, send a message), and any device on the network should be able to take action based on this event/message and to send status back to the originating command and control point.

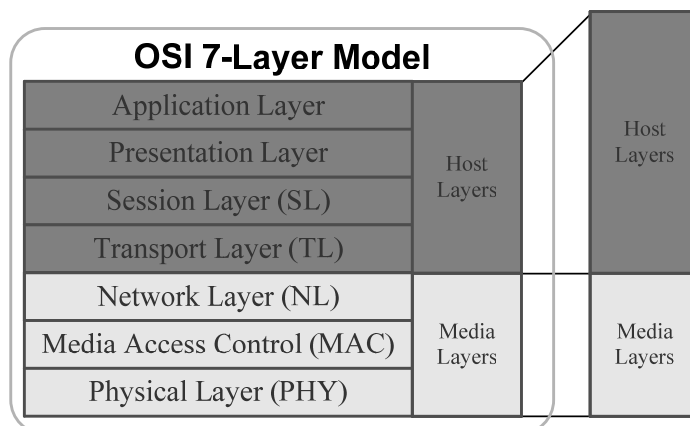
### Key Applications & Products

The following applications are seen as market drivers for HomePlug C&C. Conversely, HomePlug C&C provides a technology solution upon which these applications will be built. This list is instructive and is not intended to limit applications.

- Automatic Meter Reading and Energy Management - Smart Meter, Thermostat, Circuit Breaker, HVAC, Water heater, power measurement, data collecting, load controller, smart switches, etc.
- Demand Response and Demand Management
- Home Appliances Automation, remote command and control. Actuators – Ceiling fan, shade and drape control, audio source control, audio volume control, gate controller, door position monitor and controller, window monitor and controller, sprinkler system, motors & solenoid controllers, etc.
- Monitoring Security and Safety including remote access and control via the internet.
- Street light control.
- Industrial Automation.
- Sensors and Life Safety Devices – Smoke detector, motion detector, water, heat, health monitoring, etc.
- Various indoors controllers – Lighting control, switches, and dimmers, door and windows lock, garage door, fountain, pet-door, LCD, Touch screen devices, etc.
- Bridge to other technologies – RF such as ZigBee and Z-Wave, IR, Ethernet (TCP/IP), RS232, RS485, HomePlug V1 and AV, etc.

### System Architecture

HomePlug C&C was designed after the OSI-7 layers reference model.



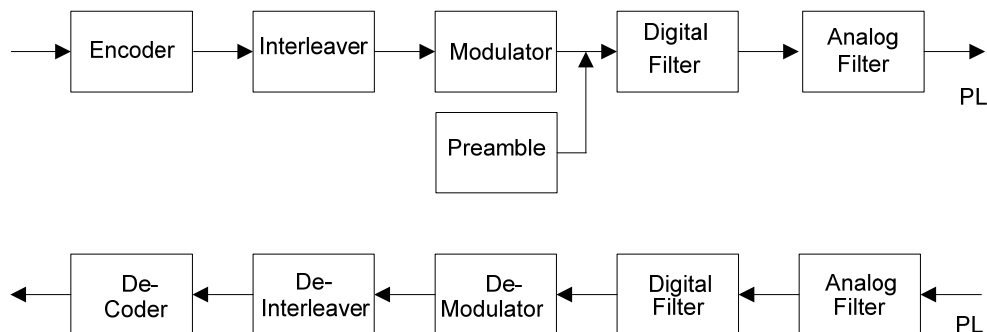
### PHY Layer (included in HomePlug C&C V1.0)

The PHY (Physical) Layer is the first layer in the seven-layer OSI model. It defines the electrical, mechanical, procedural, and functional specifications for activating, maintaining and deactivating the physical link between communicating network systems. These include characteristics such as voltage levels, timing of voltage changes, physical data rates, maximum transmission distances, and physical connectors.

HomePlug C&C's PHY Layer features:

- DCSK - Differential Code Shift Keying spread spectrum for extremely robust communication.
- Extremely high in-phase and cross-phase reliability (high dynamic range)
- High immunity to signal fading, various noise characteristics, impedance modulation and distortion (power line medium phenomena)
- Configurable to support worldwide regulations compliance (FCC, ARIB, CENELEC A & B)
- Multiple data rate mode:
  - SM (DCSK6, 7.5Kbps),
  - RM (DCSK4, 5Kbps)
  - ERM (DCSK4 with repetition code, 1.25Kbps in FCC/ARIB Bands
  - RM (DCSK4, 2.5Kbps) and ERM (DCSK4 with repetition code, 0.625Kbps) in CENELEC Bands
- Frequency diversity - 3 reception Digital channels provide high immunity to interference
- Powerful Error Correction Code (ECC) and packet detection schemes
- Adaptive packet detection
- CRC-8 for packet header and CRC-16 payload for additional reliability
- Clock recovery algorithm for low accuracy, low cost XTAL (150 PPM)

### PHY Block Diagram:



### PHY performance:

- Wide dynamic range (>90dB)
- High sensitivity (<1mV)
- High immunity to CW interference (SNR<-25dB), AWGN Additive White Gaussian Noise (SNR<-5dB) and periodical burst noise in AC line harmonics (up to 40% signal blocking) (data stated for PER<10e-2)
- High immunity to distortion and impedance modulation

### **About DCSK (Patented technology):**

- Close to the theoretical reliability limits over AWGN
- Resistance to pulse noise; linear and non-linear distortion, synchronization errors and timing jitters.
- Adaptive operation handles fast variations in medium characteristics.
- Fast recovery from severe fade or jamming.

The fundamental building block is the specially designed 800 micro seconds “chirp signal” wave form in the 100 KHz to 400 KHz frequency band for the USA and other bands for Europe and Asia. The digital map of this wave form [2048 samples at 10 bits per sample] is kept in the ROM in the PHY. This digital map is the zero shifted [or rotated] pattern of this waveform. This waveform represents the basic symbol. In DCSK4 modulation (RM), each symbol represents 4 bits. 16 equally time shifted patterns of this wave form are generated representing 16 4bit groups from “0000” to “1111” with “0000” represented by a zero shifted wave form.

In DCSK6 modulation (SM), each symbol represents 6 bits. 64 equally time shifted patterns of this wave form are generated representing 64 6bit groups from “000000” to “111111” with “000000” represented by a zero shifted wave form. Obviously, the “distance” between two neighboring symbols is smaller so the probability of error is higher (indicating wrong shift), thus reducing robustness.

On the “transmit” side, the incoming data is segmented into 4 bit or 6 bit groups depending on the modulation request from the DLL and the linear time shift for the chirp signal is calculated from the value of the group bit pattern. This time shift is then used as the index in the stored digital map of the zero shifted wave form to determine the starting point (time wise) and the corresponding wave form is generated.

Before the data symbol is transmitted, the receiver sends 7 zero shifted wave for synchronization by. From these 7 synchronization wave forms, the receiver determines the time difference between the symbols, thus the modulation scheme used during transmit (each modulation having a unique synchronization sequence).

On the “receive” side, the received symbol is converted into digital representation (2048 samples/10 bit per sample) and compared against the zero shifted digital map stored in the ROM to determine the time shift. This time shift is used as index into the appropriate data table (4 bit group or 6 bit group) to determine the data sent and thus received.

#### **Bandwidth Calculation:**

DCSK4 = 4 bits per symbol / (800x10<sup>6</sup>) = 5000 bits/sec

DCSK6 = 6 bits per symbol / (800x10<sup>6</sup>) = 7500 bits/sec

#### **ERM Modulation:**

This is a special case of DCSK4 modulation in which each data symbol is transmitted 4 times as a group. The time difference between the symbol groups is same as DCSK4. Thus, the bandwidth for ERM is one quarter of the normal DCSK4 = 5000/4=1250 bits/sec.



### **MAC Layer** *(included in HomePlug C&C V1.0)*

The Media Access Control (MAC) data communication protocol sub-layer provides data services and channel access control mechanism that make it possible for many nodes and devices share the power line media and communicate without mutual interference.

MAC layer features:

- Adaptive CSMA/CA Channel Access
- Channel Access Priorities (High, Normal, Low)
- Address filtering based on Network ID & Node ID
- Up to 1,023 logical networks and 2,047 nodes/network
- Reliable Packet transmission & reception
- Acknowledged & Unacknowledged data transmission services
- Fragmentation and re-assembly of long packets - 16 fragments of 110 bytes (max. 1760 bytes per packet)
- Internetworking packet transmission service (to nodes on a different Network)
- Virtual Jamming Algorithm
- Full security suite, based on AES 128-bit encryption with authentication, and packet repeating attack protection.
- Supports Standard (DCSK6), Robust (DCSK4) and Extremely Robust transport modes and Adaptive Rate Control

### **Network Layer** *(currently in the final stages of certification)*

The NL will include:

- Internetworking and Intranetworking data services.
- Management services; creating logical networks, automatic routing and addressing, security, optimized overhead.
- Tree and Mesh Adaptive Routing
- Secured network formation
- Network Layer Performance
  - Network size – 1000 elements
  - Network depth – 16 hops
  - Network ID Selection – 15 seconds
  - Network ID Duplication Detection – 5 minutes
  - Network ID Replacement – 5 minutes
  - Node Address Assignment – depends on Network size
  - Route Discovery – depends on Network size
  - Link Disconnection Discovery – 5 minutes
  - Network Layer throughput usage – up to 5% from available bandwidth

### **Host Layer** (*currently in the final stages of certification*)

One of the main goals of the standard is to ensure interoperability among devices that support the HomePlug C&C stack from different manufactures. For example, a gateway from one manufacturer should be able to control home appliances from various companies without any special requirements from the home owner.

Device Profiling provides a common description language for defining devices in terms of:

- Description of the services supported by the device.
- Description of each service properties and actions.

The Host Layer will include Transport and Session layers profiles, that provide a common description language to define devices in terms of services supported, service properties and actions, and sub-devices as well as implements device profiles and interfaces lower layers' services. Advanced end to end communications services include:

- **Discovery** - enables devices to discover other devices and/or be discovered by other devices.
- **Binding** – enables the creation of bindings between devices, where services from different devices are bound together.
- **Controlling and Eventing** – enables remote command and control over bound device behavior and remote monitoring of the bound device state.
- **Monitoring** – enables the query values of selected properties remotely (bound or unbound).



## Summary

HomePlug Powerline Alliance member companies have introduced innovations to firmly establish PLC as the most robust, cost effective and reliable choice for all manner of command and control applications suited for a fully networked home of the future. The HomePlug Powerline Alliance focuses on pressing the world's largest wired network into double-duty. Having already developed standards for high-speed PLC, HomePlug C&C is a key market-unifying standard, paving the way for companies to compete by producing great products that work together with a common underlying technology. The winners in this expanded marketplace are product manufacturers and consumers. Analysts believe the HomePlug C&C standard will increase the total market for command and control applications with millions of command and control nodes sold each month in the coming years.

HomePlug Command and Control technology platform ushers in a new era of home automation and creates a wide variety of innovative solutions that improve the quality of peoples' lives. Consumers can expect to see a breadth of solutions, including advanced energy management and whole-house control of lighting, appliances, climate, security and other devices.

For more information about the HomePlug Powerline Alliance and/or HomePlug Command and Control, please visit [www.homeplug.org](http://www.homeplug.org).