The Inter-PHY Protocol (IPP):
A Simple Co-Existence Protocol
Outline of Talk

Co-Existence, is it needed?

IPP overview

Time re-use concept

Simulation results

Conclusions
But also other in-home technologies are being deployed (HomePlug, UPA) and new ones will be deployed (IEEE P1901, ITU-T G.hn)…

⇒ In-home power line networks will collide with each other ⇐
The Issue of In-Home and Access Coexistence

• An in-home power line network is not contained within the home
  ➢ An access power line network will always “leak” into the home
  ➢ Utility power meter can act as a gate, but in some cases offers only a few dB of signal attenuation

• Signals from within the home can reach out to the utility LV transformer and may continue on into neighboring homes or residences

• Problem is worsened by:
  ➢ An increase in residence density, rural areas are less affected
  ➢ Cross-cable coupling in multiple dwelling units (i.e., apartments)

⇒ In-home and utility power line networks will collide!! ➡
A Solution for Efficient Resource Sharing: Co-Existence

• The Inter PHY protocol (IPP) is a simple resource sharing mechanism dedicated to IEEE P1901 devices which have the P1901 MAC and either the Wavelet OFDM or the Windowed FFT OFDM P1901 PHY

• Originally conceived to handle the dual PHY in P1901, but it can also be used to ensure co-existence in the following cases:
  ➢ Co-Existence between in-home and access/Smart grid
  ➢ Allows In-Home and Access technology to progress with different obsolescence horizons
  ➢ Will allow today’s access technology to co-exist with the next generation in-home technology – for example, the one being developed in G.hn which does not take into account access requirements
Network Status

Each system transmits special signals with appropriate timing and order

Three systems present:
- IH with PHY-A
- IH with PHY-B
- AC present

Two systems present:
- IH with PHY-A
- IH with PHY-B
- No AC present
IPP Waveform

- Sampling frequency 100 MHz
- Signal is the 16x repetition of a base signal of 5.12 μs
- Phase vectors are used to create different signals

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Time Samples</th>
<th>Time (μsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_s$</td>
<td>IFFT interval</td>
<td>512</td>
<td>5.12</td>
</tr>
<tr>
<td>$T_{ss}$</td>
<td>OFDM symbols duration</td>
<td>6,144</td>
<td>61.44</td>
</tr>
<tr>
<td>$T_w$</td>
<td>Windowing duration</td>
<td>1,024</td>
<td>10.24</td>
</tr>
<tr>
<td>$T_{total}$</td>
<td>CDCF signal interval</td>
<td>8,192</td>
<td>81.92</td>
</tr>
</tbody>
</table>
IPP Window and IPP Fields

Allocation Period $T_{\text{IPP}}$

IPP Window

IPP Field 1

IPP Field 2

$T_{\text{off}}$

$T_{\text{IPP}}$

$T_{\text{IPP}}$

Sync Points

First phase

Second phase

Third phase

IPP Field

Silence

CDCF Signal

Silence

245.76 us

81.92 us

81.92 us

81.92 us
IPP Waveform and Network Status

• IPP signal will be:
  ➢ Transmitted periodically in round robin at a fixed offset from zero crossing
  ➢ Transmitted simultaneously by all nodes (not only the masters) that are in same system type (AC, IH-A or IH-B)
  ➢ Detected by all nodes in every period
TDMA Structure

- **IH-A**: Inner Head Access
- **AC**: Access Cycle
- **IH-B**: Inner Head Break
- **IPP Window**: Initial Protection Period Window
- **TDMU**: Time Division Multiplexing Unit
- **TDM Slot (TDMS)**: Time Division Multiplexing Slot
- **Allocation Period (T_{ipp})**: The time period during which TDMUs are allocated
- **Time (t)**: The horizontal axis represents time

1 TDMU = 2 AC cycles

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Example of TDMU Allocations

- A W O - - -
- A W O - FA -
- A W - - - -
- A W - - FA -
- A - O - - -
- A - O - FA -
- - W O - - -
- A - - - - -
- - W - - - -
- - - O - - -
TDMU allocations determined by network status
- Detection of IPP signals over any period of 3·TH univocally determines the network status
- The function that associates network status to TDMU allocations must be surjective and monodromous
- TDMU allocations are changed when a change in network status is detected, thus allowing Dynamic Bandwidth Allocation (DBA)

Nodes make local decisions
- Network status is a “per node” concept
- There may be multiple TDMU allocations usable by nodes even within the same system
- Nodes must agree on common allocations for communicating
Synchronization Procedure

• Start-Up for AC devices
  ➢ Scan for IPP signals, detects network status, joins AC network
  ➢ Report network status back to master
    o If no IH system, masters instructs device of IPP timing, device joins all other AC devices in transmitting IPP signal
    o If IH system present, master instructs device of IPP timing, devices sends re-synch signal to detected IH systems

• Start-Up for IH devices
  ➢ Scan for IPP signals, detects network status, joins IH network
  ➢ Report network status back to master
    o If AC present, masters instructs all slaves to execute re-synch procedure
    o If one unsynched IH is present, master starts re-synch procedure
      ▪ Other system can refuse to synch only if it is synched to AC
    o If multiple unsynched IH are present… that’s another paper!!
Re-Synchronization Procedure

• All stations monitor every sync point for IPP signals in order to detect the presence of other unsynched systems

• Access Requested Re-Synch for an IH System
  ➢ If AC node detects unsynched IH system, it notifies master
  ➢ The AC node transmits the IPP signal in the resync field of the unsynched IH system and transmits (as usual) the IPP signal in the AC Window to provide the reference to the IH
  ➢ IH nodes that detect IPP signal in re-synch field cease transmitting, scan for IPP signal of AC and synch with it
In order to share resource efficiently among systems with different PHY, there has to be a mechanism that allows devices to use the same time slots simultaneously (STR).

**Concept**

- a) Every node in a system transmits IPP at the same time
- b) Each node in a system detects the superposition of all the IPPs transmitted by the nodes in another system, and detects the network status
- c) Nodes make local decisions whether they have to share resources or not

Nodes x and z in system (A) do not detect IPP from system B → no sharing

Node y in system (A) detects IPP from system (B) → sharing needed
Data streams: $x$, $y$, and $a$, $b$.

The common TDMSs between the TDMA patterns of node $x$ and $y$, are 1, 4, 5, 8, and 9 and can be used for data exchange.

All TDMSs can be used by nodes $a$ and $b$ for data communications.

Time re-use has been achieved in system B: 10 TDMSs are used in place of 5
Average time-reuse gain: 50%
Time Slot Re-Use: 2 IH Systems

![Graph showing the relationship between Intersystem ATT [dB] and Average TR Gain [TDMS/Beacon] for 5, 10, and 20 Nodes.]

- **5 Nodes**
- **10 Nodes**
- **20 Nodes**

The graph illustrates the percentage gain in TR efficiency as the Intersystem ATT increases for different node configurations. The x-axis represents the Intersystem ATT in dB, while the y-axis shows the average TR gain in percentage terms.
Time Slot Re-Use: 3 IH Systems

![Graph showing the relationship between Intersystem ATT (dB) and Average TR Gain [TDMS/Beacon] for 5, 10, and 20 Nodes. The graph illustrates how the gain increases with Intersystem ATT.

- **5 Nodes**
- **10 Nodes**
- **20 Nodes**

The graph indicates that as the Intersystem ATT increases, the Average TR Gain also increases, reaching around 200% for higher ATT values.
P1901 STR and Optimal - IH Systems
(2 IH Systems + 1AC System, Multi-PHY, Max I-ATT=60dB)
IH Systems: N Nodes; AC System: 2 Nodes

Time Slot Re-Use: 3 Systems, 2 IH and 1 AC
Conclusive Remarks

• Fundamental issue for success of technology is coexistence:
  o Coexistence is the ability for different PLC systems to function simultaneously at acceptable levels of performance

• The Inter PHY protocol (IPP) is a simple and flexible co-existence mechanism being developed in IEEE and ITU-T

• Originally conceived to handle the dual PHY in P1901, but it can also be used to ensure the following important features
  o Allows co-existence between in-home and access.smart grid
  o Allows co-existence between today’s technology and tomorrow’s

• The IPP allows achieving fine synchronization among neighboring networks and time-reuse gains to alleviate self-interference issues