Avionics Systems Hosted on a distributed modular electronics Large scale dEmonstrator for multiple tYpe of aircraft

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Power Line Communications for Safety Critical Applications

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Preface

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Safety Critical Data Buses

- Distributed embedded systems typically operate as a closed loop control system in which:
  - Information is gathered from sensors
  - Information is processed at a controller generating appropriate responses
  - Resulting responses are transferred to actuators

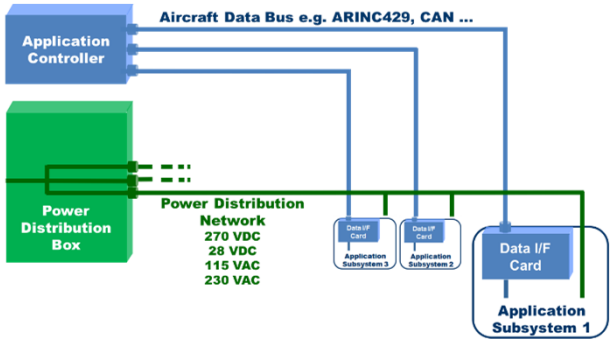
- Distributed nature of these systems means that the interconnecting data bus is an essential component

- Data bus must deterministically fulfill requirements especially for:
  - Availability: data delivered when required
  - Integrity: data delivered free of errors
  - Latency: data delivered within time bounds

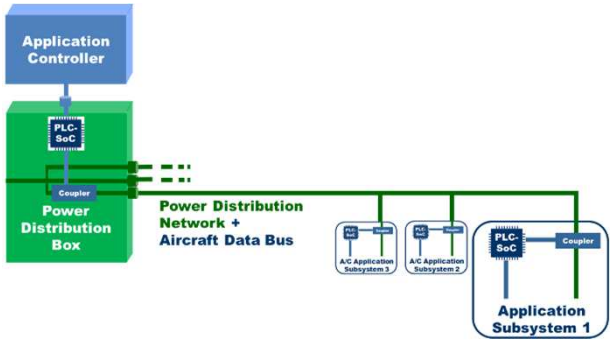
- Focus of this presentation is on the use of Power Line Communications (PLC) as a safety-critical data bus

Power Line Communications (PLC)

- PLC Concept:
  - Data transmission network completely removed
  - Single connector for power + data
  - Data transmission independent of the underlying power signal
- PLC Advantages:
  - Reduced wiring weight, volume and complexity
  - Reduced installation and maintenance effort
  - Higher data rates than traditional avionics data buses
- Challenge of using PLC:
  - Providing robust and deterministic data transmission over an unreliable medium



Traditional Avionics Architecture

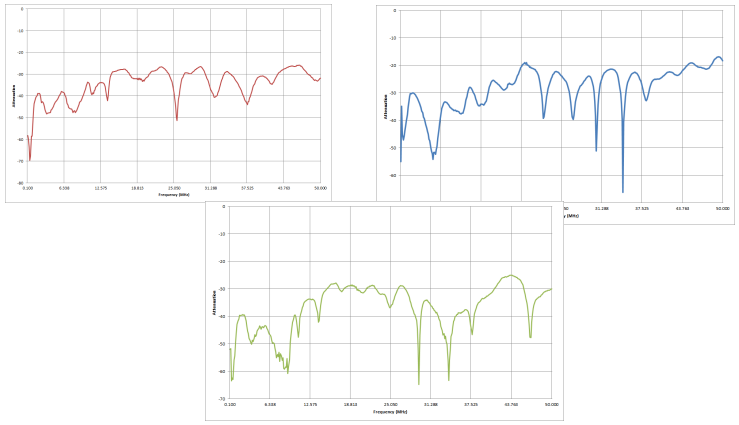


PLC-Enabled Avionics Architecture

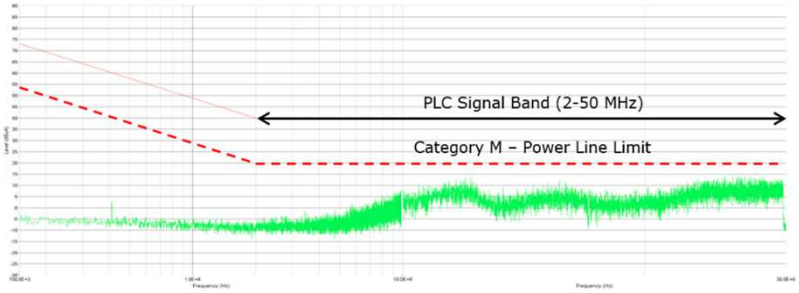
Physical Transmission Characteristics of PLC

- Physical wiring topology and load impedances lead to frequency selective channel attenuation
- Potentially large variation in received signal strength from different nodes
- Loads attached to the power line generate additional constant and transient noise
- Unshielded cabling leads to a stronger influence from external disturbances
- EMC regulation (DO-160) limits the allowed transmission power

Sample PLC Channels



RTCA DO-160 Limit



PLUS Protocol

- HLU has developed a PLC protocol dedicated for use in safety-critical systems
  - **P**ower **L**ine data b**US** (PLUS)

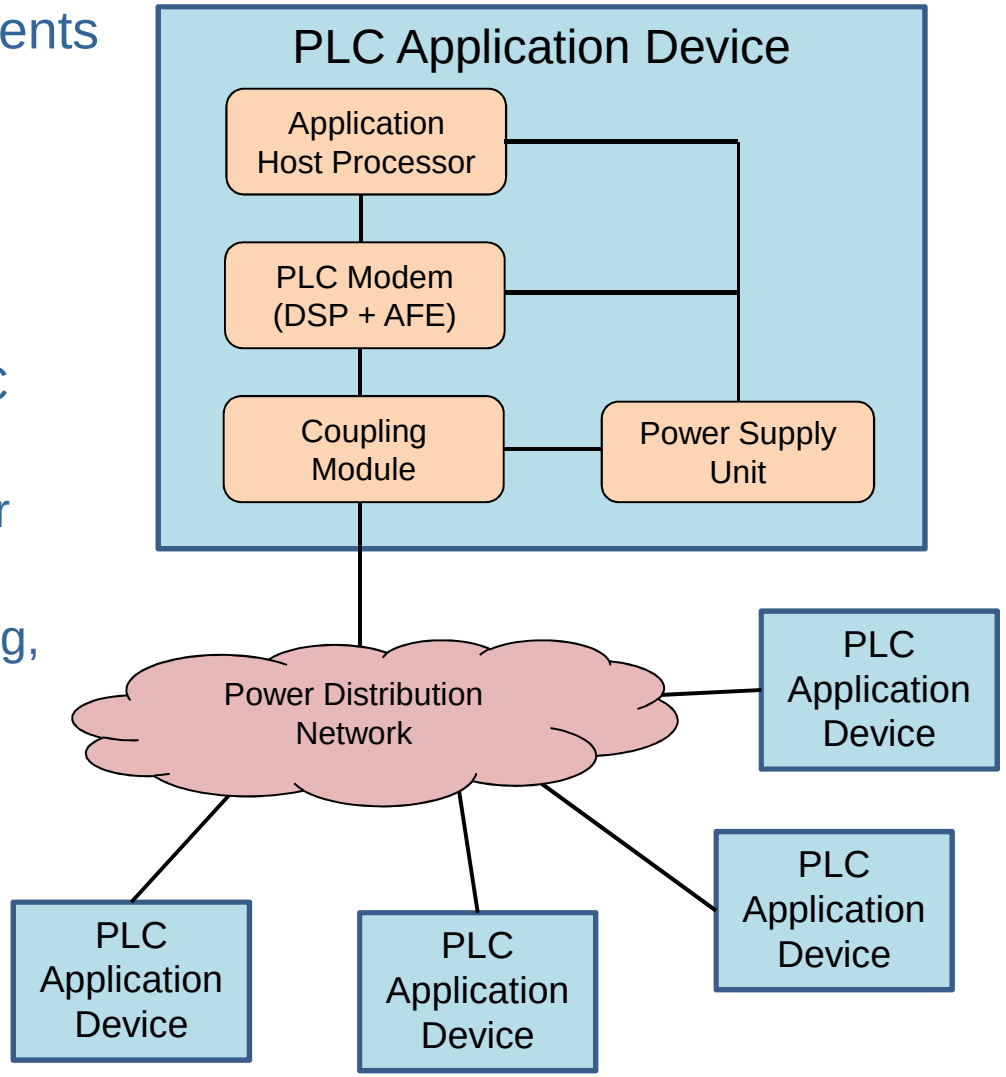
- PLUS has been designed around
  - Proven standard from other industries for the physical layer (IEEE 1901)
  - Proven avionics standard for bus arbitration (ARINC 629)
  - Custom optimizations and additional protocol layers
  - Using available bandwidth to optimize data availability and integrity
- Prototypes have been developed and will be used in the ASHLEY project for:
  - Demonstration of the protocol functionality within the ventilation control system demonstrator
  - EMC measurements as part of advanced studies in PLC

PLC Architecture

- Ultimately PLC specific components can be integrated directly into application equipment

- Coupling module
  - Coupling of high frequency PLC signal onto the power line
  - Filtering of low-frequency power signal
  - Protection of transients, lightning, HIRF

- PLC Modem
  - Protocol chip (e.g. DSP, FPGA)
  - Analog Front End (AFE)



Data Availability – PHY Features

- Digital Signal Processing (DSP) techniques at the physical layer provide robust data demodulation over a harsh channel:
  - Orthogonal Frequency Division Multiplexing (OFDM)
    - ✓ The overall signal is transmitted upon multiple sub-carriers which mitigates frequency selectivity of the channel
  - Mapping
    - ✓ PSK/QAM modulation on each sub-carrier
    - ✓ Flexible configuration of individual sub-carriers (enable/disable, modulation scheme, output power)
  - Forward Error Correction (FEC)
    - ✓ Powerful convolutional turbo coding provides for error correction at the receiver
    - ✓ Different code rates are possible

PLUS:
Raw physical data rates assuming signal spectrum from 2-50MHz

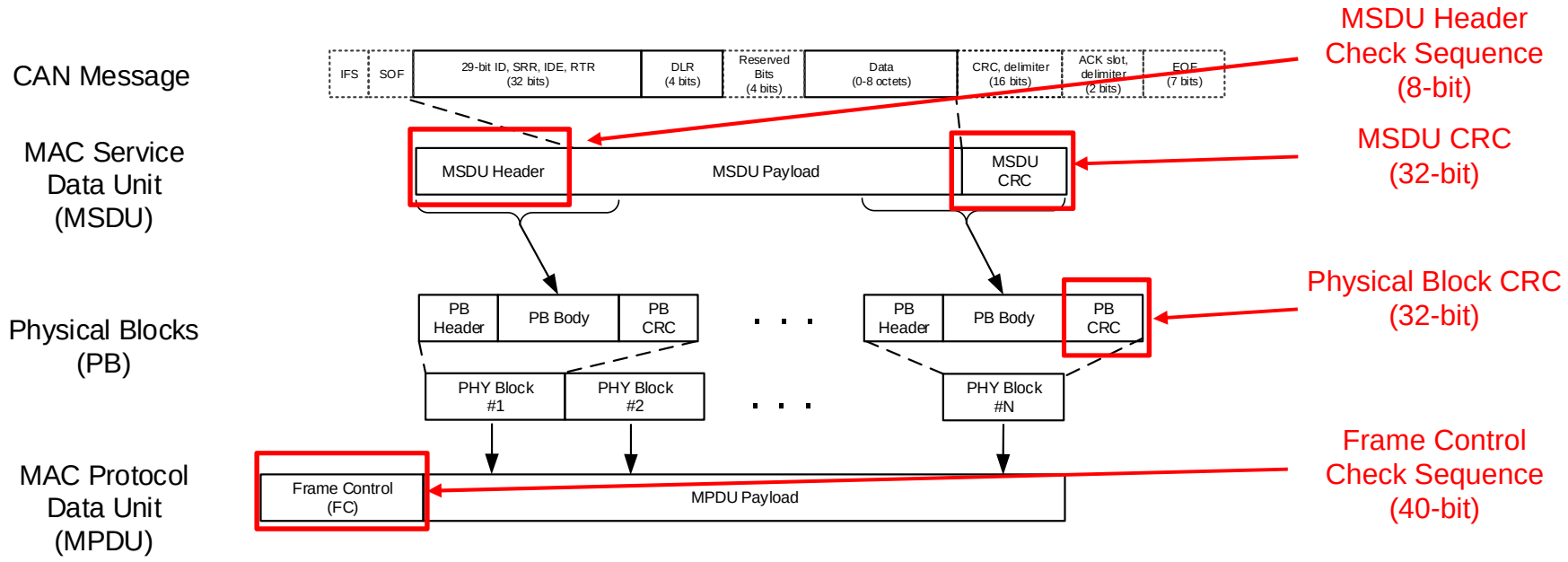
Modulation/ CodeRate	BPSK	QPSK	8-QAM	16-QAM
1/2	20 Mbps	41 Mbps	60 Mbps	81 Mbps
16/21	31 Mbps	62 Mbps	93 Mbps	124 Mbps
16/18	36 Mbps	72 Mbps	108 Mbps	144 Mbps

Data Availability – PHY Features

- Processing of a known preamble symbol (Receive Estimation) is also critical for providing a robust decoding
  - Frame Synchronization:
    - ✓ Allows receiver with asynchronous clock (to the transmitter) to determine the starting point of the first OFDM symbol
    - ✓ Decoding of a frame may not begin unless frame synchronization is successful
  - Channel/Noise Estimation:
    - ✓ Channel estimation and equalization compensate frequency-dependent attenuation and time delays of the channel for demodulation
    - ✓ Noise estimation compensates frequency dependent noise by adapting weighting factors used during decoding
  - Automatic Gain Control (AGC):
    - ✓ AGC dynamically adapts the receiver gain from the AFE in order to optimally use the available resolution of the analog digital converter
    - ✓ Gain settings must be updated at the reception of each frame based on measurements during the preamble

Data Integrity – Error Detection

- Detection of any bit errors is critical to providing high data integrity
- PLUS has been designed to be able to detect errors *even when decoding purely random data*, e.g. noise
- Reception of a single PLUS frame is protected at multiple levels with four independent CRCs
- Failure of any of these CRCs leads to frame being discarded

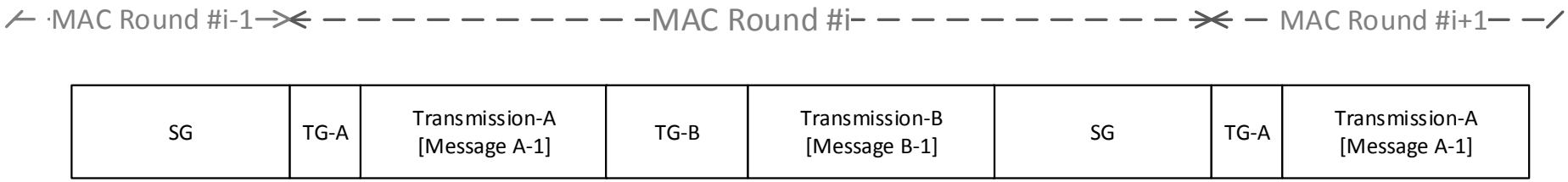


Deterministic Latency – Bus Arbitration

- In order to avoid dependencies on master node or global synchronization a peer-to-peer architecture has been selected

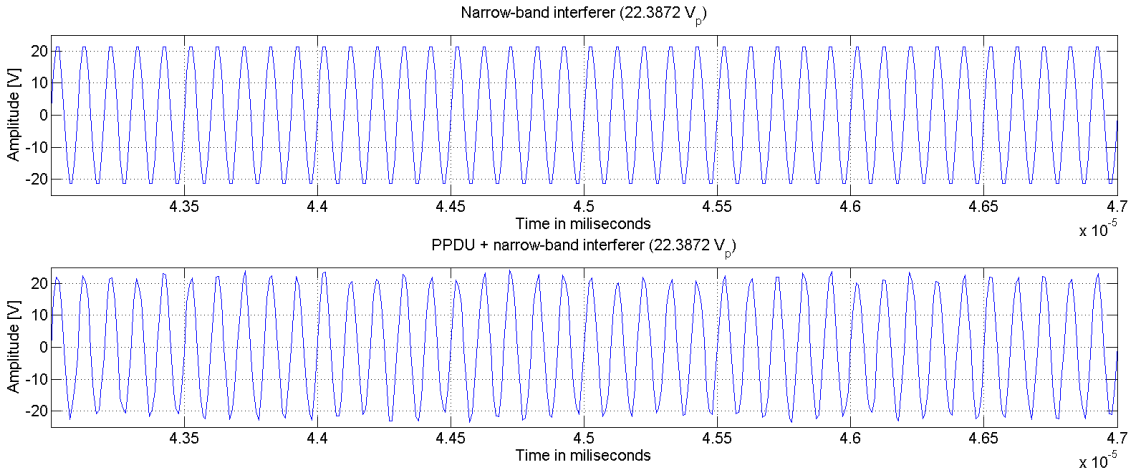
- PLUS bus arbitration protocol is based on algorithm from ARINC-629
  - Next transmission slot determined through synchronization to previous transmission
  - For basic protocol three timers determine the transmission slot
  - Timers count during bus quiet periods
  - Bus arbitration is dependent upon each node's unique timer TG
  - In the steady state transmission order remains constant

- Providing a reliable Physical Carrier Sensing (PCS) is critical



Deterministic Latency – Physical Carrier Sensing

- PCS algorithm must
  - Minimize state change detection latency (transmission detected late)
  - Maximize positive detection rate (transmission correctly detected)
  - Minimize false positive detection rate (noise detected as transmission)
- PCS challenges with PLC:
  - Detecting received transmissions with varying signal strength
  - Detecting received transmissions with low SNR
  - Distinguishing PLC transmission from strong interference (e.g. HIRF)
- Innovative frequency-based filtering scheme has been developed



HIRF Interferer

HIRF Interferer + PLC Signal

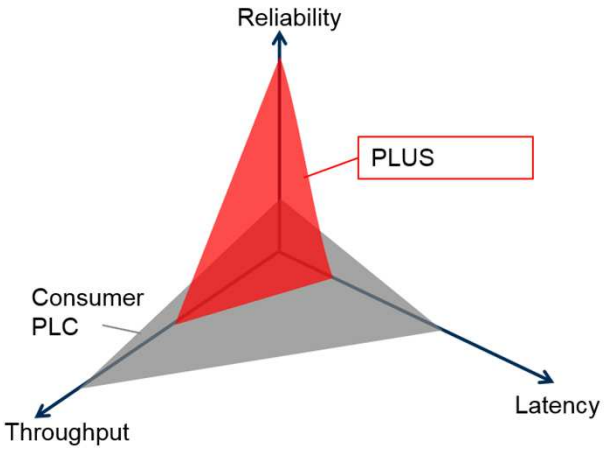
Further PLUS Protocol Features

- No protocol management traffic
  - Stateless connections
  - No network setup
- Optimized transport for small messages (<20 bytes)
- Multiple data services may be multiplexed onto a single bus
  - Currently supporting CAN, Ethernet
- Optional features for improving availability/integrity:
  - Physical block redundancy mode
    - ✓ Transmission of duplicate PBs
    - ✓ Voting process at the receiver
  - Automated Repeat reQuest (ARQ)
    - ✓ Retransmission of lost data
    - ✓ Efficient support for broadcast transmissions

Summary

- A PLC-based aircraft data bus potentially provides a number of advantages
- PLUS protocol has been developed specifically for safety-critical applications
  - Physical layer signal processing provides robust communications
  - Powerful error detection is provided
  - Bus arbitration provides deterministic behavior
- PLUS has been realized on a number of prototypes and will be demonstrated within the ASHLEY project

PLUS Optimization



Any questions?

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Avionics Systems Hosted on
a distributed modular electronics Large scale dEmonstrator
for multiple tYpe of aircraft

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