The Time-Triggered Ethernet

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Overview

- Introduction
- Time-Triggered Ethernet
- Different configurations
- Related Work
- Conclusion
Introduction

• Embedded safety-critical real-time systems deploy time-triggered communication
• Time-triggered systems guarantee predictable and deterministic communication (achieved through a static TDMA scheme)
• Constant transmission latencies and bounded jitter
• Composable and simple
• Inflexible
• ASIC implementation of comm. controllers (TTP/C, FlexRay, TTCAN)
Requirements for flexible comm.

- Additional requirements flexible communication
- Examples
  - FlexRay and
  - DECOS integrated architecture (using TTP/C) implement that using a statically reserved resources for (flexible) event triggered messages – sometimes leading to communication resource wastage
Bandwidth requirements

• Existing time-triggered solutions work with bandwidths
  – TTP/C – 25 Mbit/s,
  – FlexRay -10 Mbit/sec
  – TTCAN – 1 Mbit/sec

• All these are lower than those of most used network technology, like Ethernet.
Time-Triggered (TT) Ethernet

- A novel communication system, which integrates time-triggered and event-triggered traffic into a single hardware infrastructure
- Using inexpensive and commercially available components
- Bandwidth (100 Mbit/sec, 1000Mbit/sec)
- We call it: Time-Triggered Ethernet (TT Ethernet)
- Similar solutions exist – comparison with them is given latter.
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State / Event Messages

- State messages: periodic exchange of state information
- Event messages: sporadic exchange of event information
- State messages and event messages are two extremes of a spectrum of information type and transmission trigger combinations [Bauer 03]
State Information

- At sender:
  - At-least-once transmission
  - Non-consuming sending, one can send the same status data many times.

- At Receiver:
  - Update in place
  - Non-consuming read (one can read the last valid message)

Event Information

- At sender:
  - Exactly-once transmission
  - Consuming sending

- At receiver:
  - Queuing
  - Consumed upon read
Time-Triggered Ethernet – Standard Configuration
Principle of Operation

- TT Ethernet switch - transmits TT msg. with a constant delay
- Transmission of ET msg. is preempted,
  - if during the transmission a TT msg. arrives at a switch port, ET msg. is stored in the buffer of the switch, and retransmitted as soon as the transmission of the TT msg. is finished
- If during the transmission of TT msg. an ET msg. arrives in a port of the switch, the ET msg. is stored in the buffer of the switch and transmitted after the transmission of TT msg. is finished
**TT Ethernet - Time Format**

**Time horizon**
about 30,000 years,
elapsed seconds since
January 6, 1980 at 00:00 (GPS base).

**Time granularity**
about 60 nanoseconds
determined by the precision of GPS

TT Ethernet time format (8 bytes)
TT Ethernet - Time Format (2)

Period ID (Msg ID)

<table>
<thead>
<tr>
<th>Period bit</th>
<th>Phase bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
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<td>8</td>
<td>9</td>
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<tr>
<td>10</td>
<td>11</td>
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<tr>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
</tr>
</tbody>
</table>

Period of $1/2^4$ (i.e. 1/16)
Phase of $1/2^6 + 1/2^{11} = 16113$ sec.

- Period bit
- Phase of the Period

$2^{39}$ seconds

1 sec bit 24

$2^{-24}$ sec
Message Naming

• Naming scheme for messages to support the identification of a message type (in the literature this is often called a message name) and a message instance.
• The message type name denotes a sequence of messages of the same type.
• Two bytes period ID as the message type name.
• A particular message instance can be identified by
  – the concatenation of the message type name (the period ID)
  – with the send instant of the message
### TTE Frames

- **Standard Ethernet frames**
- **Standard frame type field** 0x88D7
- **Ethernet data field contains the header and the data fields of different TT Ethernet frames**

<table>
<thead>
<tr>
<th>Bytes</th>
<th>Preamble</th>
<th>SOF</th>
<th>Destination Address</th>
<th>Source Address</th>
<th>Type</th>
<th>Data Field (Payload)</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>46 - 1500</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bytes</th>
<th>0x88D7</th>
<th>Control Field</th>
<th>Msg Length</th>
<th>Parameter Field</th>
<th>Data Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4-12</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bytes</th>
<th>7</th>
<th>1</th>
<th>6</th>
</tr>
</thead>
</table>
Message Categories

1. Event-Triggered (ET) messages
2. Free Form Time-Triggered (FFTT) messages
3. Unprotected Start-up messages
4. Unprotected Synchronization messages
5. Unprotected periodic TT messages
6. Unprotected sporadic TT messages

} unprotected TT msg
Event –Triggered (ET) message

- ET messages are handled in conformance with the IEEE Ethernet e.g., IP, UDP, IPX, Appletalk etc.
- Message queue (event semantics)

Free Form Time-Triggered (FFTT) message

- FFTM are handled similar as ET, with a small difference.
- Sent with TT priority (for the switch), can preempt ET messages
- Message queue (event semantics)
Unprotected Start-up message

• The TT startup messages establish an initial synchronization
• After this initial synchronization has been achieved, the *startup phase* is terminated → operational phase

Unprotected Synchronization message

• maintain the clock synchronization during the operational phase, they are sent periodically
• The length of the period (the resynchronization period) is determined by the quality of oscillators and the required precision of the global time
Unprotected TT message

- Unprotected TT messages (UTTM) transport user data from a sender to one or a set of receivers
- Messages with state semantics
- In case of a *non-silent failure* of a node, an UTTM of one node might be corrupted by a TT message from another node.
- UTTMs are intended for multimedia applications
- In TT Ethernet, we distinguish between two kinds of UTTMs, the *periodic UTTMs* and the *sporadic UTTMs*. 
Unprotected periodic TT message

- Periodic, always sent, until the last message bit is set
- Message length is variable
- Information pull mode interface to the host

Unprotected sporadic TT message

- Periodic
- Message length is variable
- Only sent when the host updates the message
- Information push mode interface to the host
TT Ethernet Safety-Critical Config.

- The Guardian
- Two busses
New Message Categories

1. protected Start-up message
2. protected Synchronization message
3. protected TT message

- Use TDMA scheme, TDMA rounds divided into time slots for each msg.
- **Messages length is fixed**
- Sent through two redundant channels
- Protected TT messages are always sent (no message last bit)
- Protected by the bus guardian
- Nodes that suffers from faults within the fault hypothesis cannot affect the transmission of protected TT traffic
Fault hypothesis

- Unit of failure: fault containment region (FCR)
  - node: communication controller + host computer
  - TT Ethernet switch + Guardian
  - One communication channel (channel 0, channel 1)
- One arbitrary failure of one FCR at a time
- Never give-up (faults outside fault hypothesis are detected)
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Different configurations : standard
Different configurations: safety-critical
Communication Schedule Example

The Time-Triggered Paradigm

- Fixed TT
- Max bandwidth reservation for TT var. msg
- Max bandwidth reservation for ET msg

Guardian

Slot_1 Slot_2 Slot_3 Slot_4 Slot_5
node_1p node_2p node_3p node_4p node_5p
msg_1 msg_3
node_1u node_3u
msg_2 msg_3
node_2u node_3u

TDMA round_1 TDMA round_2
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Related Work

• **RTnet**, timed UDP, RTAI OS *(Hannover University)*
• **PROFInet**  SW and HW implementation *(PSB, Siemens)*
• **ETHERNET Powerlink** *(B&R Industrie-Elektronik)*
• **Switch with Time-Server** *(Ontime Networks)*
• **AFDX** *(Condor Electronics)*

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• **Overview**: *(http://www.real-time-ethernet.de)*
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- A comm. infrastructure for integration of real-time and non real-time traffic
- Compatible with Ethernet standard
- Different application of different level of criticality
- Currently working in two implementations in Vienna
  - Linux RTAI based implementation
  - Network adaptor with PCMCIA interface (FPGA)
- Main difference with existing real-time Ethernet solutions is interrupt mechanisms of TT Ethernet Switch