MIPI CSI-2℠ v4.0 Panel Discussion with the MIPI Camera Working Group (Panel)

Haran Thanigasalam, Camera WG Chair, Intel Corporation
Natsuko Ibuki, Google, LLC
Yuichi Mizutani, Sony Corporation
WonSeok Lee, Samsung Electronics
Agenda

• Evolution of MIPI Imaging Conduit – Haran Thanigasalam

• CSI-2 v4.0 AOSC Optimal Transport Mode – Natsuko Ibuki

• CSI-2 v4.0 AOSC Smart Transport Mode – Yuichi Mizutani

• CSI-2 v4.0 Multi Pixel Compression – WonSeok Lee

• Q&A
Evolution of Imaging Conduit
Haran Thanigasalam, Camera WG Chair, Intel Corporation
The Big Why & Trajectory

Future is deeper human machine interaction with connected devices - two pathways:

1. Machines become more like us
2. We become more like machines
The How & Pathway

Ingredients
Photon Collectors, Transistors, Optics, Emitters, Algorithms

Evolution of MIPI Imaging Conduit Infrastructure

Applications
Broad Spectrum of Imaging & Vision Use cases targeting multiple platforms

Complex problems cannot be solved by an individual company
Need for global alliances and liaisons: MIPI | DMTF | IEEE 1722

I. Mobile - Pristine photography & video streaming on mobile platforms [CSI-2 v1.x]
   - RES_FPS_BPP | PORT_EXP | SNS_SWITCHING

II. Platforms - Support broad range of imaging applications beyond photography on multiple platforms [CSI-2 v2.x, v3.x]
    - SCR | VCX | LRTE (PDQ, ALP) | USL-Ph1 | RAW-24 | DPCM | SROI-Ph1

III. Awareness – Low Power AON Vision | Emotional intelligence | Machine perception and decision making [CSI-2 v4.0]
     - AOSC (OTM, STM) | MPC | FSAF | SROI-Ph2

IV. Scale - Open System Cloud Imaging Applications utilizing vision analytics (Schools, Hospitals, Municipalities, States)

V. Space Exploration
What’s Done

PSD
CSI-2 over C-PHY PSD emission reduction with scrambling (embedded clock and data)

LRTE (PDQ, ALP)
Packet Transfer using legacy EsT, LPS, SoT skimmers
LRTE replaces legacy EsT, LPS, SoT with EPD

USL-Ph1 (ENCAP, REPL, OPT_WIRE)

SROI-Ph1

DPCM | RAW-24

UNIFIED IMAGING DRIVER (CCS, DisCo*)
- Vertical/Horizontal Merging
- Sub-Sampled Residual Caching/Digital Crop

CSI-2 ULD and EPID
CSI-2 ULD and EPID

© 2021 MIPI Alliance, Inc.
AOSC OTM
Natsuko Ibuki, Google, LLC
**AOSC – Always On Sentinel Conduit**

- Low power interface protocol to support always-on cameras that operate in low frame rate and in low resolutions
- Uses MIPI I3C® v1.1 SDR, HDR-DDR, or HDR-BT, single lane or multi-lane, to transport image sensor data using CSI-2 like protocol
- VDSP (Vision Digital Signal Processor) is the I3C Host Controller and SNS (Image Sensor) is the I3C Target
- Images can be sent by
  - AoSC transfer only
  - AoSC and C-PHY℠ / D-PHY℠ simultaneous transfers
  - Switch between AoSC and C-PHY℠ / D-PHY℠ transfers
- **Benefits**
  - Simple because no C-PHY℠ / D-PHY℠ needed
  - Only requires 2 wires
  - Lowest power when used in low frame rate and low resolution
- **BW example**
  - QVGA 10fps raw10 (8.5 Mbps) can be supported by 1L SDR (11 Mbps effective BW)
  - 720p 10fps raw8 (81 Mbps) can be supported by 4L HDR-BT (95 Mbps effective BW)
AOSC – OTM – Optimal Transport Mode

OTM Details
- One of the 2 modes supported by AoSC (OTM and STM)
- OTM allows for multi-lane and/or HDR operations.
- CCC (Common command code) as commands by VDSP to SNS
  - ODF (On-Demand Frame, to prepare/send a video frame)
  - EHDR/XHDR (Enter/Exit HDR, to enter/exit HDR mode)
  - TPP (Transmit Packet Payload)
- IBI (In-band interrupt)
  - Used by SNS to report status including error status
  - Frame Start IBI, sent when SNS is ready to send data
- LPP# (long packet payload)
  - CSI-2 Long Packet content without header or CRC
  - Each LPP contains 1 line worth of data
- ISPB (Interconnect Synchronizing Padding Bytes)
  - Horizontal-Blanking period can be dynamically adjusted by SNS.
  - Used to compensate for difference in image sensor and I3C clock.

AoSC and OTM Features
- Two privacy modes with GPIO override
  - Mode to completely prohibit image sensors from sending any image data or interpretation of the image data to VDSP
  - Mode to allow only the interpretation of the image data (ex. IBI to notify motion detection)
- ODF – On Demand Frame vs CSF – Continuous Streaming Frame
  - ODF: SNS captures images only when instructed by VDSP
  - CSF: SNS periodically captures images w/o any CCC from VDSP
- Frame Squelching
  - In CSF mode, allows SNS to capture and send image data to VDSP less frequently than programmed FPS.
  - Ex. SNS can be programmed to operate at VGA 30 FPS, but it can be further specified to capture and send 1 frame every 10 frames.
AOSC STM
Yuichi Mizutani, Sony Corporation
Possible use cases for STM to transport:
- Low resolution and low framerate image data from SNS to VDSP as shown in the diagram on the righthand side
- Metadata (Event data) from SNS to VDSP

Possible Power Savings
- The C-PHY / D-PHY layer for CSI-2 can be turned off
- The CSI-2 Link layer processing unit in SNS can also be turned off (subject to the system architecture)

STM Details
- STM support is optional
- Supports I3C SDR mode only
- A single IBI transaction does the all (no Read Request from VDSP is required)
- Nearly unlimited sized payload by Word Count Extension (subject to the VDSP Rx buffer size)
- VDSP may abort the IBI at any time
- Supports the Long Packet Structure for D-PHY as payload
- Metadata (Event data) can be transported by utilizing User Defined STM Types
MPC
Wonseok Lee, Samsung Electronics, Co.
Why new compression standard is needed?

Problem of standard DPCM

- Standard DPCM doesn’t fully utilize a higher correlation of neighboring pixels from multi-pixel sensors

![Diagram showing correlation and compression]

**PSNR of Standard DPCM for Bayer and Tetra**

- Compression should be developed

- $\approx 0.4dB$
Multi-Pixel Compression (MPC) for multi-pixel sensors

High correlation of color channel
• MPC can utilize a higher correlation neighboring pixels from multi-pixel sensors

Apply multi-resolution scheme
• MPC encodes detail which is information of 2x2 multi-pixel
• MPC simultaneously supports multi-resolution in 1-frame of Tetra-cell image
• Tetra-cell, sensor can simultaneously output full resolution and quarter resolution image for Tetra and Bayer image, respectively.

<table>
<thead>
<tr>
<th>PSNR</th>
<th>Standard DPCM 10:6</th>
<th>MPC 10:5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47.6</td>
<td>61.3</td>
</tr>
</tbody>
</table>

MPC needs replacing to get better image quality.
Multi-Pixel Compression (MPC) for multi-pixel sensors

**Distance geometry**
- Geometrical layout of multi-pixel sensors allows smaller physical distance of pixel pitch
- MPC keeps the distance of $\frac{\sqrt{2}}{2}$ for the prediction pixel

![Diagram showing distance comparison between conventional method and MPC](image)

- **Distance of prediction pixel for conventional method**
- **Distance of prediction pixel for MPC**

**Decreased distance**
- Distance of MPC: $d_{0-3} = \frac{\sqrt{2}}{2}$
- Distance of standard DPCM

**Distance geometry between current pixel and prediction pixel**
Overview of MPC algorithm

Algorithm chain
- Each pixel, p0~p3 and averaged pixel are simultaneously compressed
- Encoded stream includes dual-resolution images (full and quarter resolution)
Experimental results (1/3)

Against existing standard DPCM for Tetra-Cell

- PSNR of MPC 10:5 is ~14dB higher than standard DPCM
- Compression ratio of MPC is 20% higher than standard DPCM
  (comp. ratio 2:1 vs 1.67:1)

<table>
<thead>
<tr>
<th>Scene</th>
<th>MPC 10:5</th>
<th>DPCM 10:6</th>
</tr>
</thead>
<tbody>
<tr>
<td>scene0</td>
<td>58.31</td>
<td>45.81</td>
</tr>
<tr>
<td>scene1</td>
<td>59.56</td>
<td>46.81</td>
</tr>
<tr>
<td>scene2</td>
<td>61.42</td>
<td>46.87</td>
</tr>
<tr>
<td>scene3</td>
<td>64.99</td>
<td>47.39</td>
</tr>
<tr>
<td>scene4</td>
<td>58.06</td>
<td>42.13</td>
</tr>
<tr>
<td>average</td>
<td>60.47</td>
<td>45.80</td>
</tr>
</tbody>
</table>

**Difference of PSNR**

<table>
<thead>
<tr>
<th></th>
<th>average</th>
<th>+14 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14dB</td>
<td></td>
</tr>
</tbody>
</table>
Experimental results (2/3)

MPC compresses pixel data while maintaining the image quality.

<table>
<thead>
<tr>
<th>Standard DPCM 10:6</th>
<th>Original</th>
<th>MPC 10:5</th>
</tr>
</thead>
</table>

scene3
Experimental results (3/3)

MPC compresses pixel data while maintaining the image quality.

- Standard DPCM 10:6
- Original
- MPC 10:5
ADDITIONAL RESOURCES

- MIPI Camera Serial Interface 2 (MIPI CSI-2)
  https://www.mipi.org/specifications/csi-2
THANK YOU!