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28-29 SEPTEMBER 2021

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

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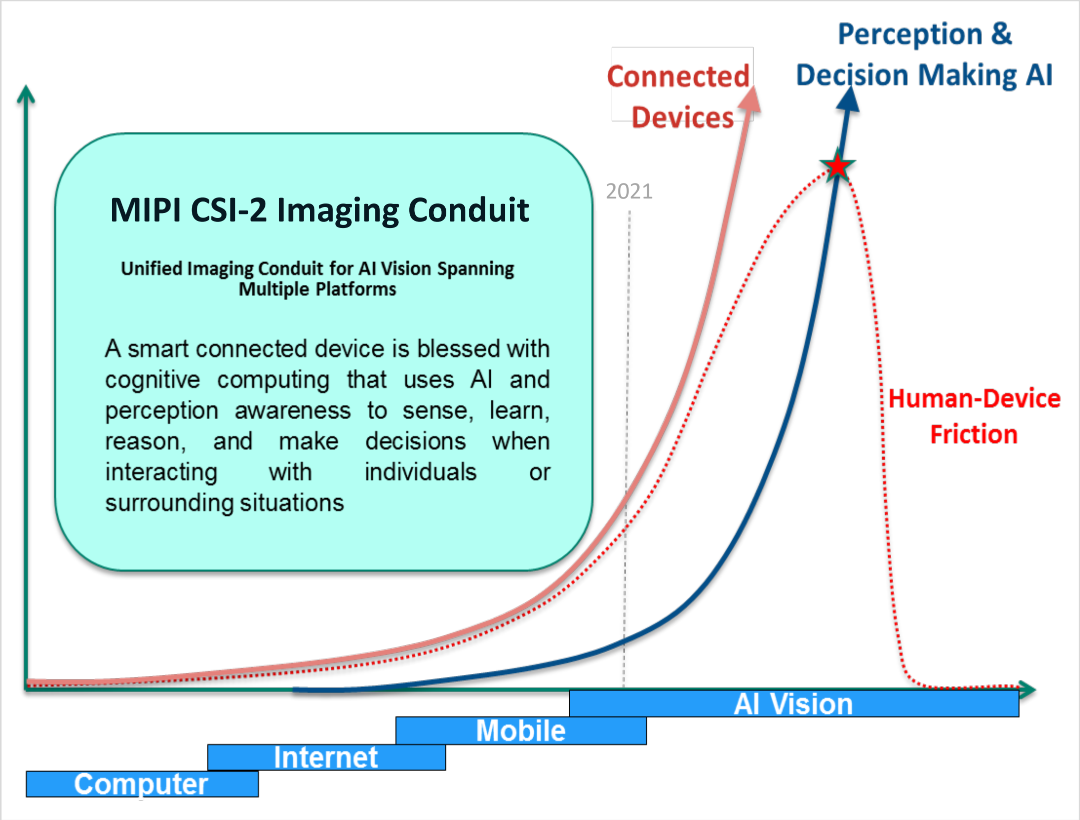
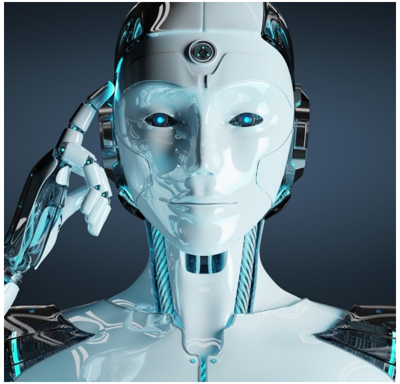
Evolution of Imaging Conduit

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

Evolution of MIPI Imaging Conduit Infrastructure

Ingredients
Photon Collectors, Transistors, Optics, Emitters, Algorithms

One World l One Imaging Conduit l MIPI CSI-2

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)

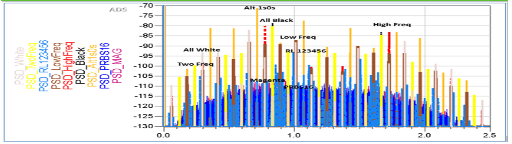
V. **Space Exploration**

2021

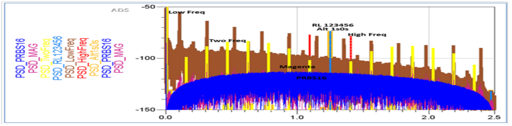
What's Done

PSD

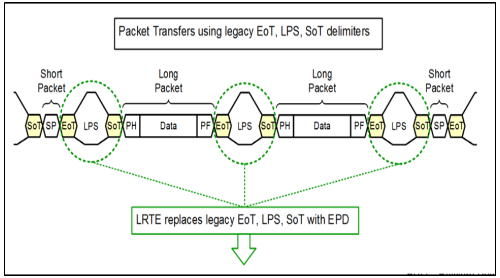
CSI-2 over C-PHY PSD emission reduction with scrambling (embedded clock and data)



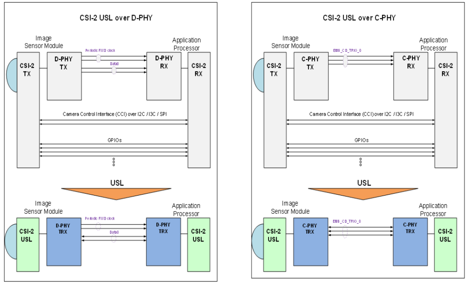
CSI-2 over D-PHY PSD emission reduction with scrambling (data lanes)



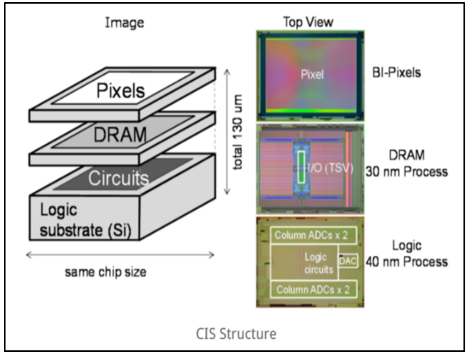
LRTE (PDQ, ALP)



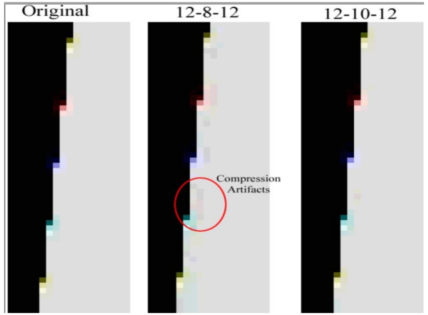
USL-Ph1 (ENCAP, REPL, OPT_WIRE)



SROI-Ph1

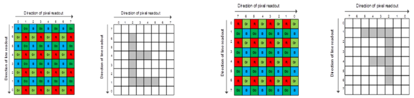


DPCM | RAW-24

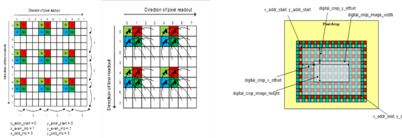


UNIFIED IMAGING DRIVER (CCS, DisCo*)

- Vertical Flip | Horizontal Mirroring



- Sub-Sampled Readout | Binning | Digital Crop



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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^{sm} / D-PHY^{sm} simultaneous transfers
  - Switch between AoSC and C-PHY^{sm} / D-PHY^{sm} transfers
- Benefits
  - Simple because no C-PHY^{sm} / D-PHY^{sm} 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)

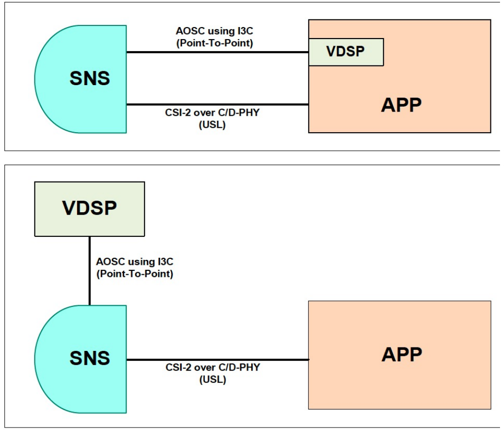


Figure 195 Point-To-Point AOSC Systems with USL Solutions

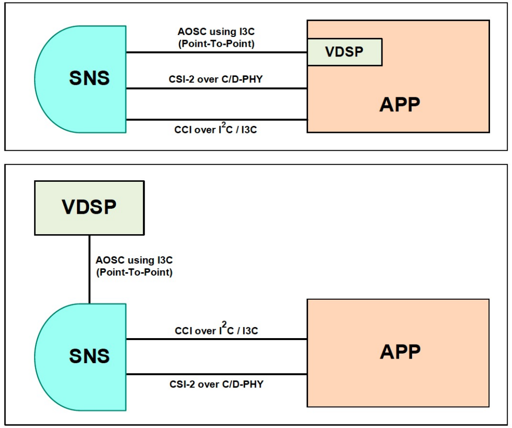


Figure 196 Point-To-Point AOSC Systems with Non-USL Solutions

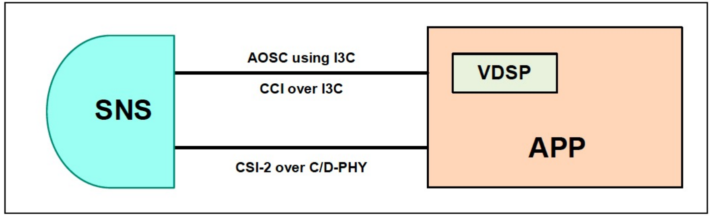


Figure 197 System Supporting AOSC and CCI Operations Over Multi-Drop I3C

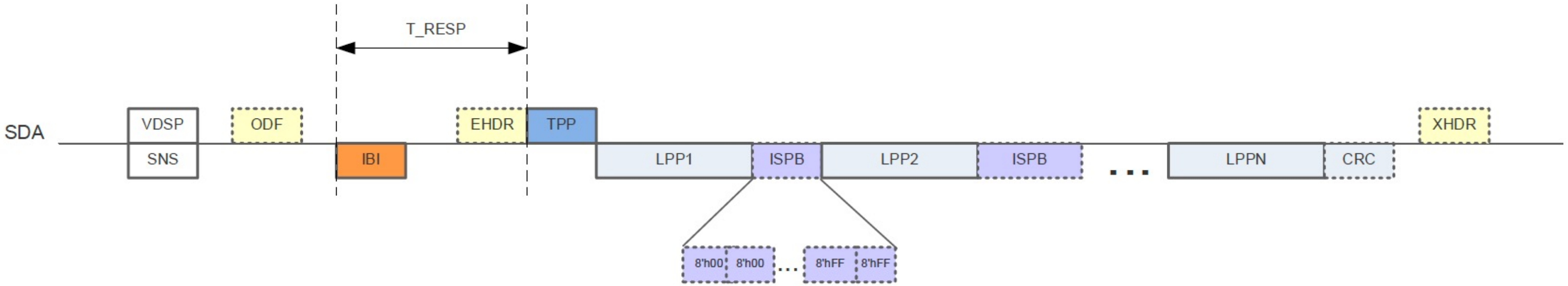
AOSC – OTM – Optimal Transport Mode

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.



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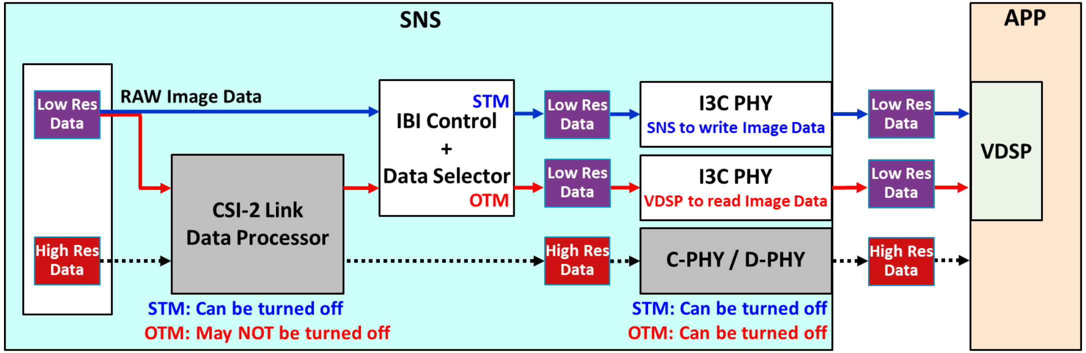
AOSC STM

Yuichi Mizutani, Sony Corporation

AOSC – STM – Smart Transport Mode

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

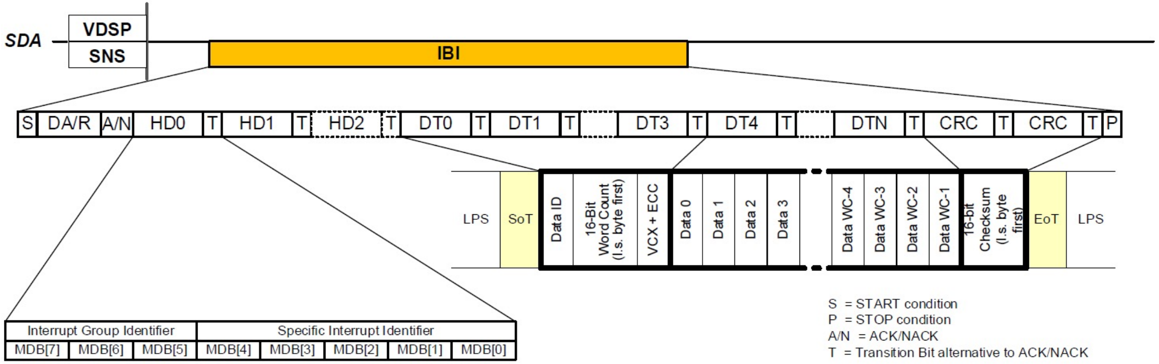


Figure 204 AOSC Smart Transport Mode (STM) Operation for the D-PHY Generic STM Types

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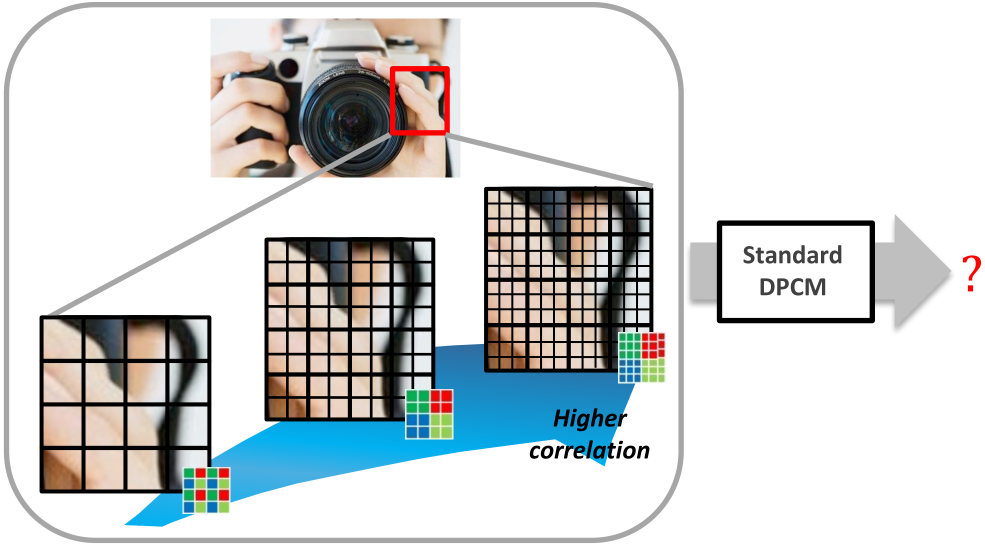
MPC

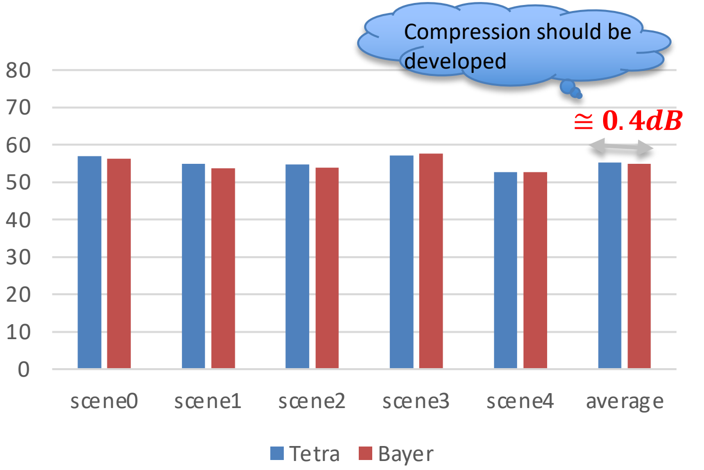
Wonseok Lee, Samsung Electronics, Co.

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



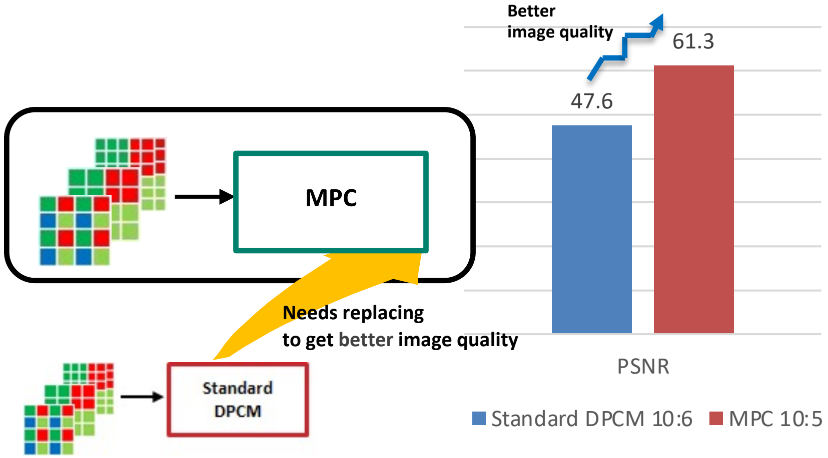


PSNR of Standard DPCM for Bayer and Tetra

Multi-Pixel Compression (MPC) for multi-pixel sensors

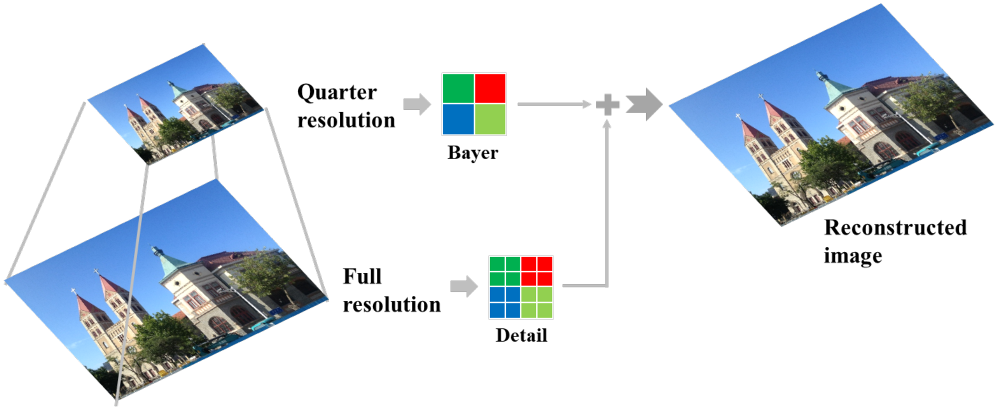
High correlation of color channel

- MPC can utilize a higher correlation neighboring pixels from multi-pixel sensors



Apply multi-resolution scheme

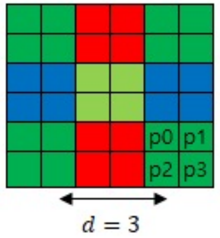
- MPC encodes detail which is information of 2x2 multi-pixel
- MPC simultaneously supports multi-resolution in 1-frame of Tetra-cell image
- Tetra-cell, sensor can simultaneously output full resolution and quarter resolution image for Tetra and Bayer image, respectively.



Multi-Pixel Compression(MPC) for multi-pixel sensors

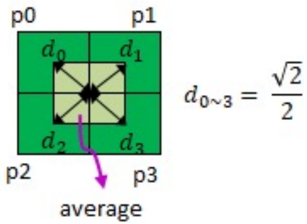
Distance geometry

- 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

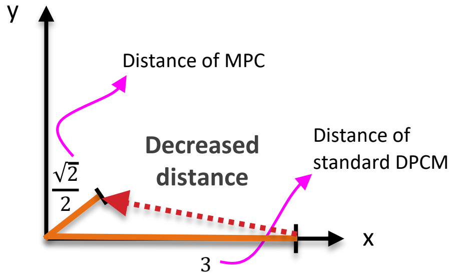


Distance of prediction pixel for conventional method

VS



Distance of prediction pixel for MPC

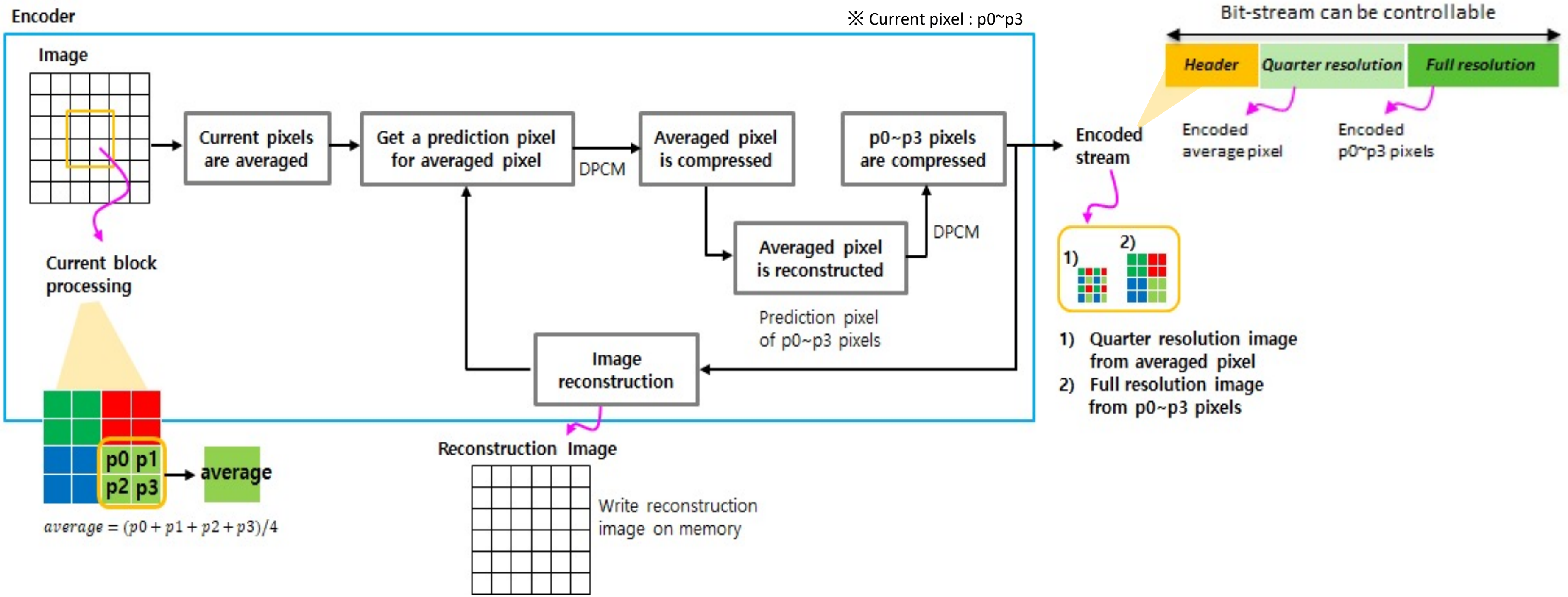


Distance geometry between current pixel and prediction pixel

Overview of MPC algorithm

Algorithm chain

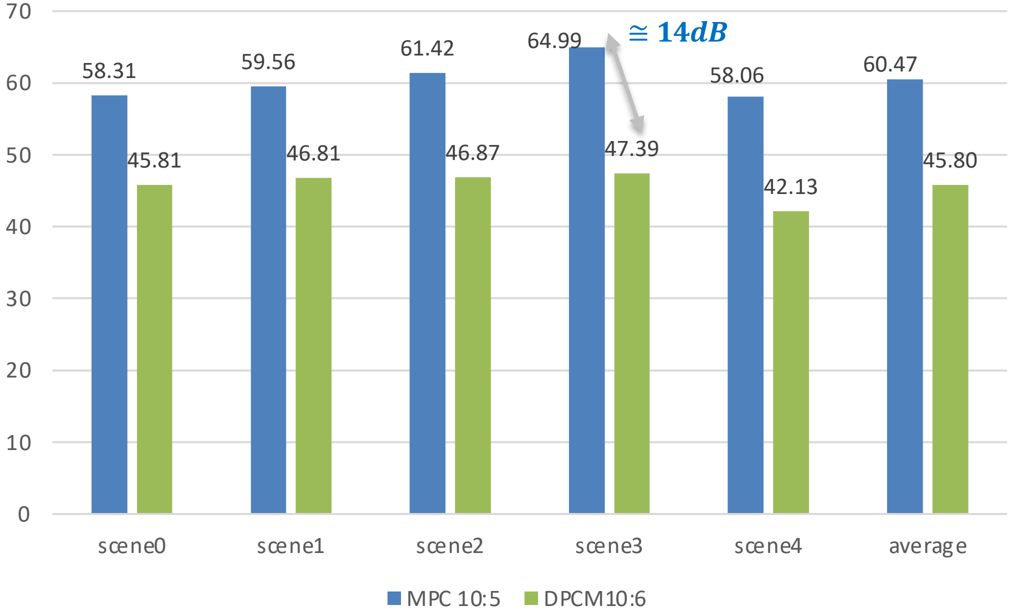
- Each pixel, p0~p3 and averaged pixel are simultaneously compressed
- Encoded stream includes dual-resolution images (full and quarter resolution)



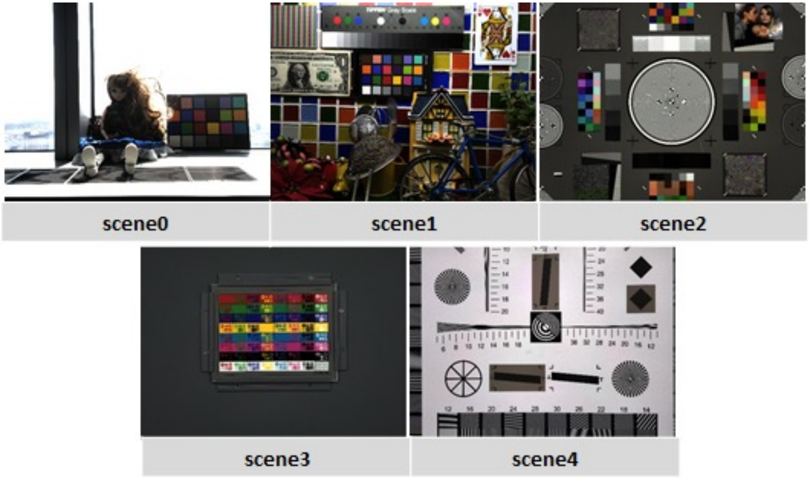
Experimental results (1/3)

Against existing standard DPCM for Tetra-Cell

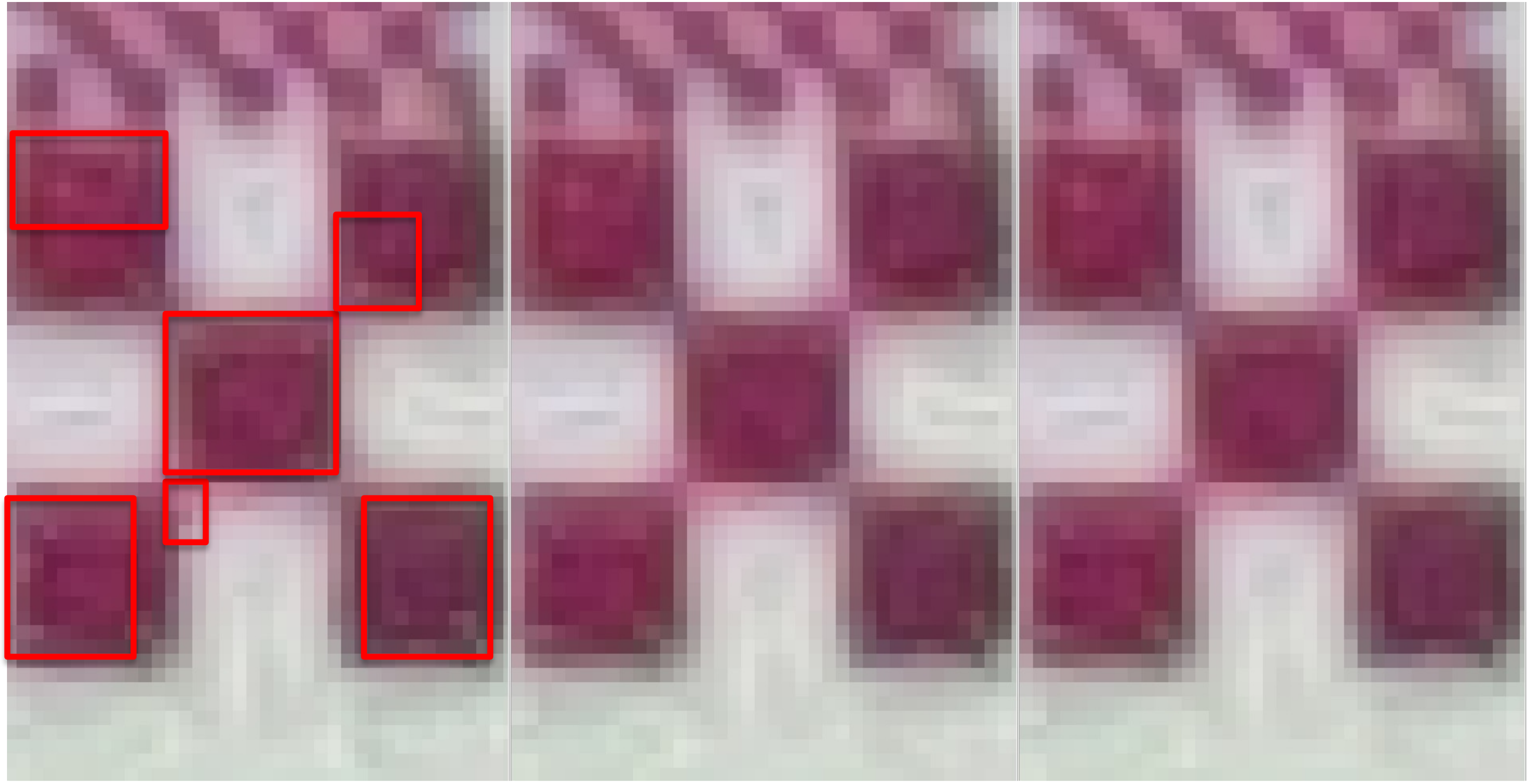
- PSNR of MPC 10:5 is ~14dB higher than standard DPCM
- Compression ratio of MPC is 20% higher than standard DPCM
  (comp. ratio 2:1 vs 1.67:1)



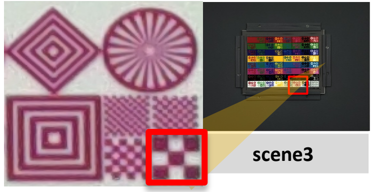
Difference of PSNR	
average	+14 dB



Experimental results (2/3)



Standard DPCM 10:6 | Original | MPC 10:5

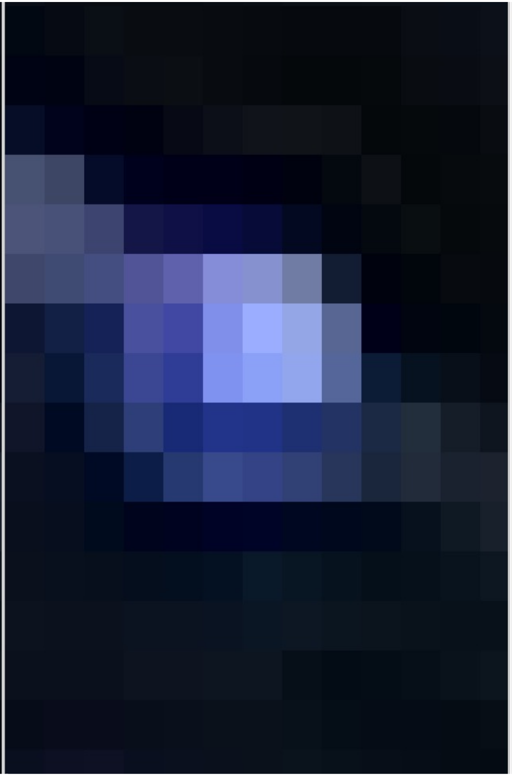


MPC compresses pixel data while maintaining the image quality

Experimental results (3/3)

Standard DPCM 10:6

Original



MPC 10:5

scene0

MPC compresses pixel data while maintaining the image quality

ADDITIONAL RESOURCES

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

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THANK YOU!