Fundamentals of IP in Broadcast Production

Wes Simpson
Telecom Product Consulting
wes.simpson@gmail.com
+1 203 376 3372
https://www.telecompro.tv

Ed Calverley
Q3 Media Training
ed.calverley@q3media.co.uk
+44 20 3475 0250
https://q3mediatraining.co.uk

Agenda (90-minute Session)

- Ed • IP / Networking Basics
- Wes • Media Transport Over IP (ST 2110-10/20/30/40 Deep Dive)
- Ed • PTP: Timing & Synchronisation
- Wes • ST 2110-21 Traffic Shaping
- Wes • New parts of ST 2110 (ST 2110-22/23)
- Wes • ST 2022-7 Redundant Transport
- Ed • JT-NM TR-1001 / NMOS

IP / Networking Basics

Why IP?

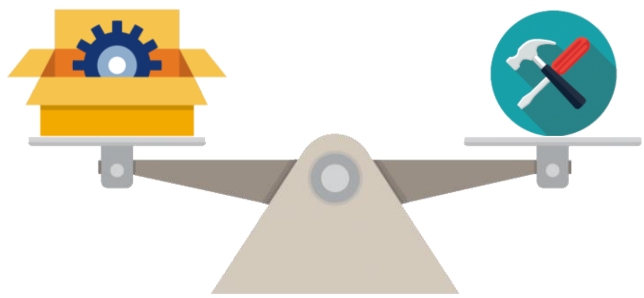
- We must start by recapping the obvious!
- 2 main drivers for switching to IP Infrastructure:
  - Flexibility
    - Reconfigurable & infrastructure not limited by resolution/formats
    - Operational functions easier to relocate and evolve over time
    - More efficient architectures (don't simply think about replacing SDI)
    - Software on generic IT servers rather than vendor-badged systems
    - may have to accept some compromises to change workflow
  - Costs > Use of more COTS hardware/software
    - minimise custom development and branched code makes systems easier to support
    - Up-front cost may not be lower (overall lifecycle costs may be lower)
    - Move to software-as-a-service (SaaS) – *pay only for what you use when you need it!*

IP SHOWCASE THEATRE

COTS Confusion

COTS:
Commercial Off-The-Shelf

- Defined Costs
- Standards based
- Choice *(interoperable)*
- Generic Features
- Stable
- Supported
- Upgradable



Proprietary /
Bespoke System

- Variable Costs
- Vendor lock-in
- Interfacing/Conversion
- Custom Features
- Higher risk of issues
- Fixed function
- Limited/Costly to evolve

However:

- Not all IP hardware is equal
- Networking for broadcast media production is specialist
- Good system architecture & workflow planning is essential

telecompro.tv
IP Video Training and Consulting
Q3 media Training
Tailored Technology Training
Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

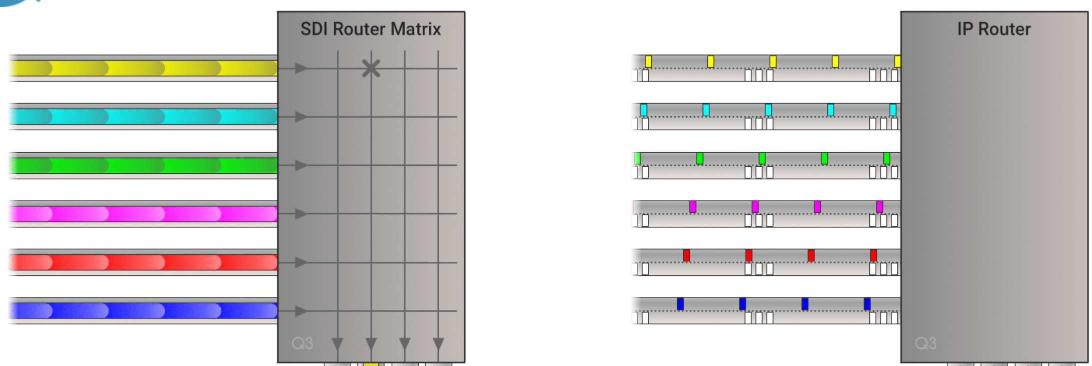
The Rise of Software

- Dedicated Hardware still strong in production or wherever real-time processing with low-latencies are important
- Media processing with Software is growing in capability
- Software enables new architectures that don't have equivalents in SDI
- Motivation for vendors is changing to create products which can be sold in scale
- IP Media Standards need to work for both software & hardware

telecompro.tv
IP Video Training and Consulting
Q3 media Training
Tailored Technology Training
Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

IP is all about Packets!



SDI Signal Routing

- Dedicated wire per signal
- Routed via crosspoint switching

IP Signal Routing

- Multiple signals per wire
- Packet-level switching
- Full-Duplex *(bi-directional)*

telecompro.tv *IP Video Training and Consulting*

Q3 media Training — Tailored Technology Training — *Q3MediaTraining.co.uk*

IP SHOWCASE THEATRE

IP is all about Packets!

SDI is a dedicated link
with constant data rate
SD-SDI: 270Mb/s
HD-SDI: 1.5Gb/s
3G-SDI: 3Gb/s

Ethernet links can have higher
data rate so more data can be
carried in the same time
10GE: 10Gb/s
25GE: 25Gb/s

40GE = 4x10GE
100GE = 4x25GE

Data is sent in packets.
Network Switches &
Routers manage the
sending of packets
across the network

telecompro.tv *IP Video Training and Consulting*

Q3 media Training — Tailored Technology Training — *Q3MediaTraining.co.uk*

IP SHOWCASE THEATRE

How do we send data in packets?

- **Prepare Data**
- Chose Protocol
  - UDP
  - TCP
- Address it
- Send It

SOME DATA TO BE SENT

SOME | DATA | TO BE | SENT

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

How do we send data in packets?

- Prepare Data
- **Chose Protocol**
  - **UDP**
  - **TCP**
- Address it
- Send It

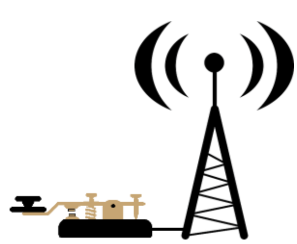
TCP Header

Source Port		Destination Port	
Sequence Number			
Acknowledgement Number			
Data Offset	Reser-ved	Flags (Control Bits)	Window Size
Checksum		Urgent Pointer	
Options			Padding

- Link Handshaking
- Transmission Acknowledgments
- Automatic resend on packet loss
- Perfect for FILES

UDP Header

Source Port	Destination Port
Length	Checksum



- 'Fire & Forget'
- Minimal Data Overhead
- Simple error detection
- Perfect for REAL-TIME STREAMS

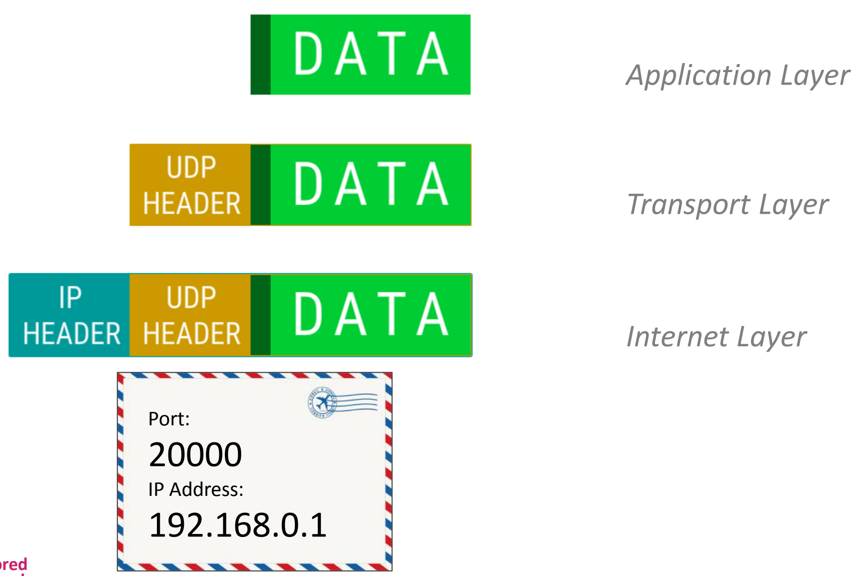
telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

How do we send data in packets?

- Prepare Data
- **Chose Protocol**
  - **UDP**
  - TCP
- Address it
- Send It

How do we send data in packets?

- Prepare Data
- Chose Protocol
  - UDP
  - TCP
- **Address it**
- Send It



IP SHOWCASE THEATRE

How do we send data in packets?

- Prepare Data
- Chose Protocol
  - UDP
  - TCP
- Address it
- **Send It**

			DATA		*Application Layer*
		UDP HEADER	DATA		*Transport Layer*
	IP HEADER	UDP HEADER	DATA		*Internet Layer*
FRAME HEADER	IP HEADER	UDP HEADER	DATA	FRAME FOOTER	*Link Layer* ETHERNET

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

Sending SDI Over an IP Network

Example:
SMPTE ST 2022-6

DATA

Not to scale!

UDP HEADER | DATA

IP HEADER | UDP HEADER | DATA

FRAME HEADER | IP HEADER | UDP HEADER | DATA | FRAME FOOTER

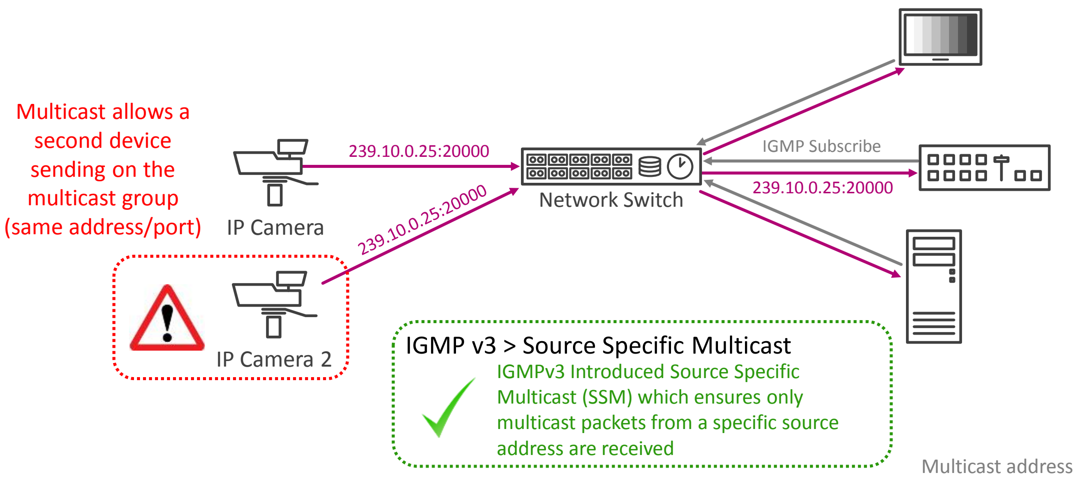
~6% Overhead

	Name	*Standard*	*Length*
Application Layer			
SDI	Serial Digital Interface	SMPTE 259M, 292M, 424M	1376 Bytes
HBRMT	High Bitrate Media Transport	SMPTE 2022-6	8-16 Bytes
RTP	Reat-Time Transport Protocol	RFC 3550	12 Bytes
Transport Layer			
UDP	User Datagram Protocol	RFC 768	8 Bytes
Internet Layer			
IP	Internet Protocol (v4/v6)	RFC 791 / RFC 2460	20 / 40 Bytes
Link Layer			
MAC	Media Access Control (e.g. Ethernet)	IEEE 802.3	42 Bytes

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

UDP Multicast



Multicast address range to use SSM may be limited to 232.0.0.1/8

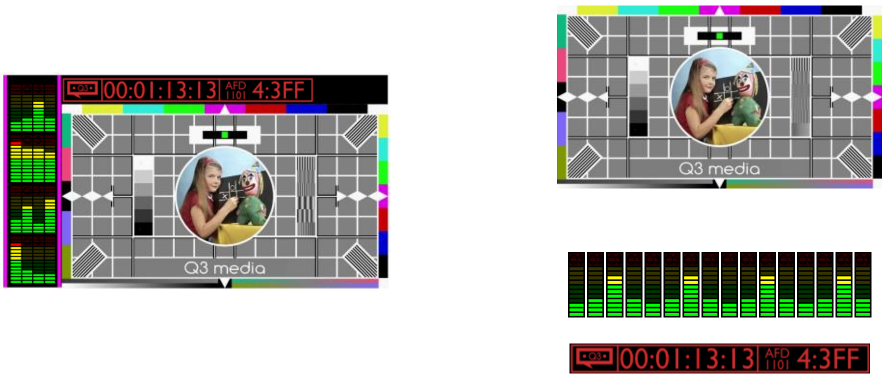
telecompro.tv *IP Video Training and Consulting*
Q3 media Training — Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

What are we sending?

SMPTE ST 2022-6

SMPTE ST 2110



2110-20 x 1

2110-30 x16 *(e.g.)*

2110-40 x3 *(e.g.)*

1 RTP flow

~20 RTP flows

telecompro.tv *IP Video Training and Consulting*
Q3 media Training — Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

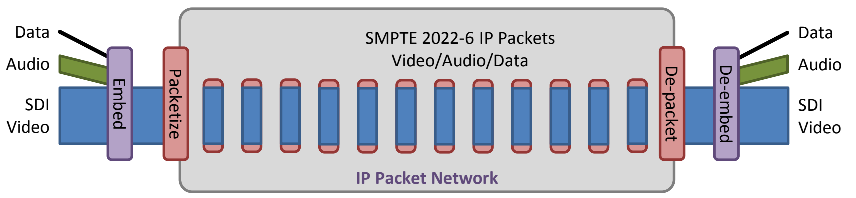
Media Transport Over IP
(2110-10/20/30/40 Deep Dive)

telecompro.tv *IP Video Training and Consulting*
Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

IP SHOWCASE THEATRE

Media Transport over IP
SMPTE ST 2022-6 ('SDI over IP')

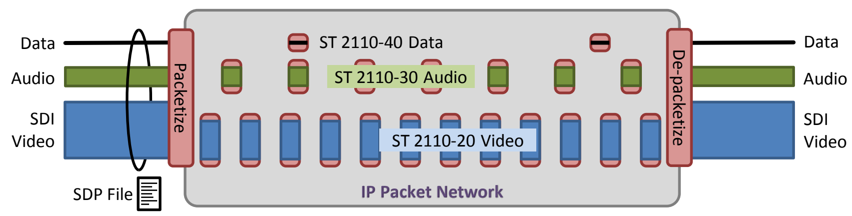
- Take entire SDI signal and encapsulate it in IP stream
  - Includes audio and embedded data signals
- Easy to maintain audio/video synchronization
  - Hard to process just one part of a stream



telecompro.tv *IP Video Training and Consulting*
Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

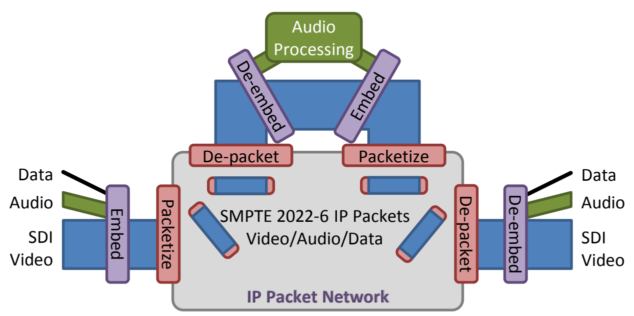
Media Transport over IP
SMPTE ST 2110

- Each media type in a separate packet stream
  - Easy to process individual components
  - Signals need to be resynchronized after processing
- PTP (Precision Time Protocol) used for packet timestamping

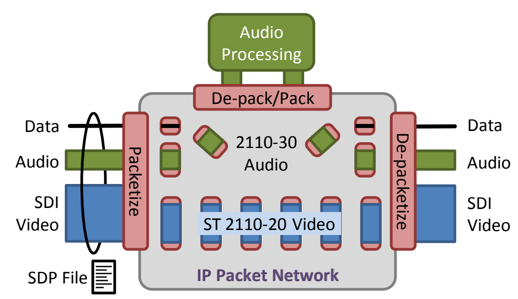


ST 2022-6 / ST 2110
Audio Processing Packet Flow

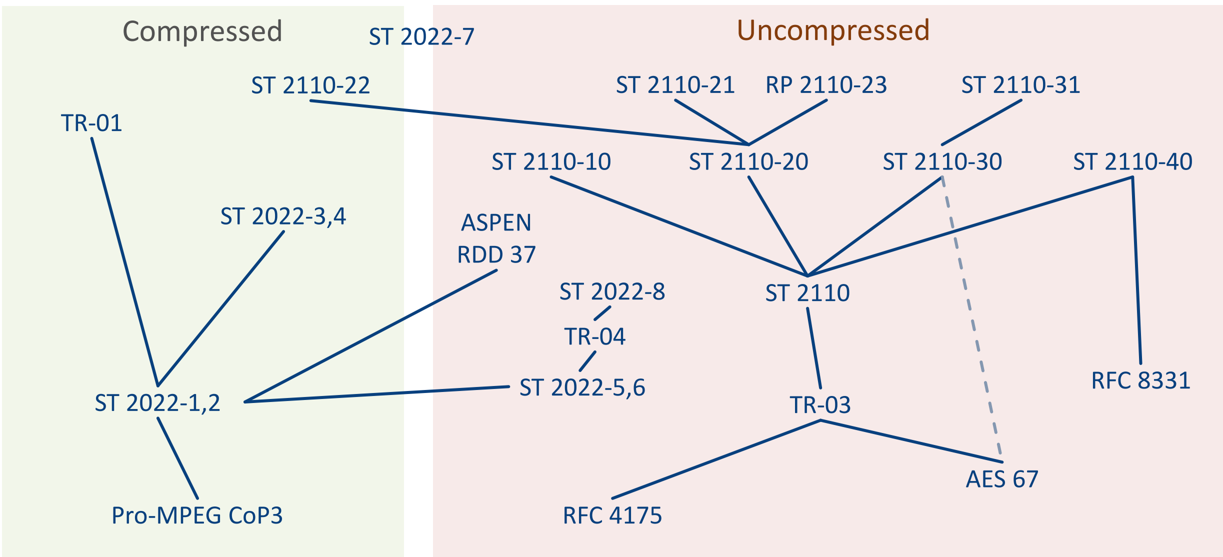
Using SDI/ST 2022-6



Using ST 2110



How Did We Get Here? – ST 2110 Evolution



SMPTE ST 2110 – Elements

- ST 2110-10 System and Timing
- ST 2110-20 Uncompressed Video
- ST 2110-21 Video Stream Packet Shaping

- ST 2110-30 Uncompressed Audio
- ST 2110-31 AES3 Audio Streams
- ST 2110-40 Ancillary Data

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

SMPTE ST 2110 – Elements (NEW!)

- OV 2110-0 Roadmap for the 2110 Document Suite
- ST 2110-10 System and Timing
- ST 2110-20 Uncompressed Video
- ST 2110-21 Video Stream Packet Shaping
- ST 2110-22 Constant Bit-Rate Compressed Video
- RP 2110-23 Single Video Essence Transport over Multiple ST 2110-20 Streams
- ST 2110-30 Uncompressed Audio
- ST 2110-31 AES3 Audio Streams
- ST 2110-40 Ancillary Data

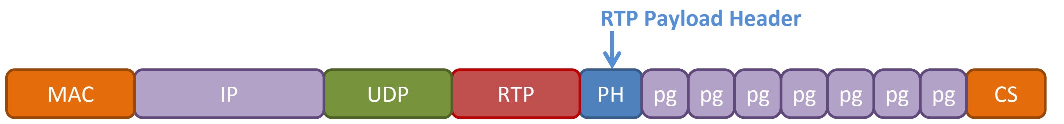
telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

ST 2110-10
System Timing and Definitions

- Maximum UDP datagram size: 1460 octets, including UDP header
  - Extended UDP datagram allowed with up to 8960 octets
- SMPTE ST 2059-2 PTP Profile of IEEE 1588-2008
  - If interchanging audio with AES67, then compatible parameters must be used
- RTP timestamps are tied to the media
  - For video, RTP timestamps of all packets for video frame are the same
  - For real-time sources, this should represent the Image Capture Time
  - For SDI converters, RTP timestamp is moment when video frame alignment point arrives at device input (SMPTE ST2059-1 defines alignment points)
- All media clocks must have an offset of zero
  - This makes it easier to recover from loss of signal or unexpected system restart

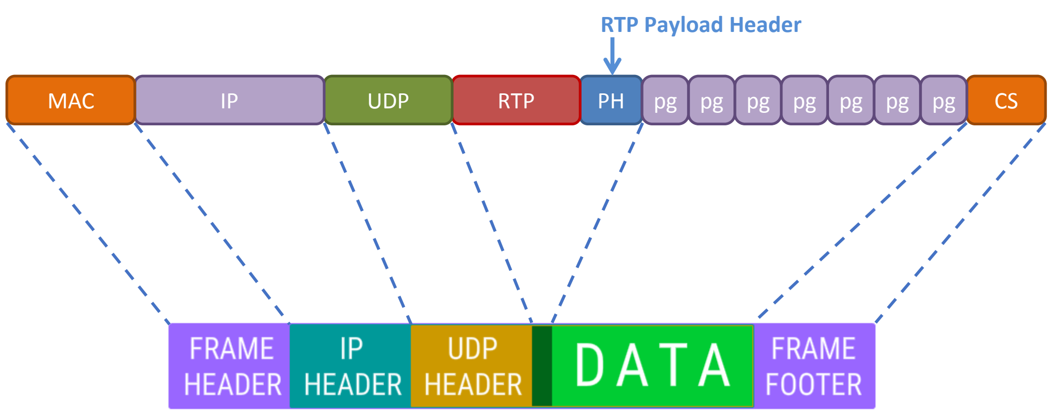
telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

ST 2110-20 Video Encapsulation



- Multiple video pixel groups (pgroups)
- RTP Payload Header applied
- Inserted into an RTP packet
- Placed into UDP packet
- IP packet header attached
- Wrapped into Ethernet Frame

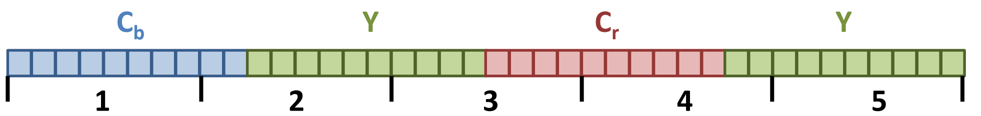
ST 2110-20 Video Encapsulation



- Same idea as before – just draw differently
  (and still not to scale!)

ST 2110-20 Pixel Groups

- Pixels formed into pgroups
  - pgroup size depends on sampling format
  - Must be integer number of octets
  - Pixels that share samples must be in the same pgroup
- Example: 4:2:2 10-bit
  - 2 pixels in 5 octets



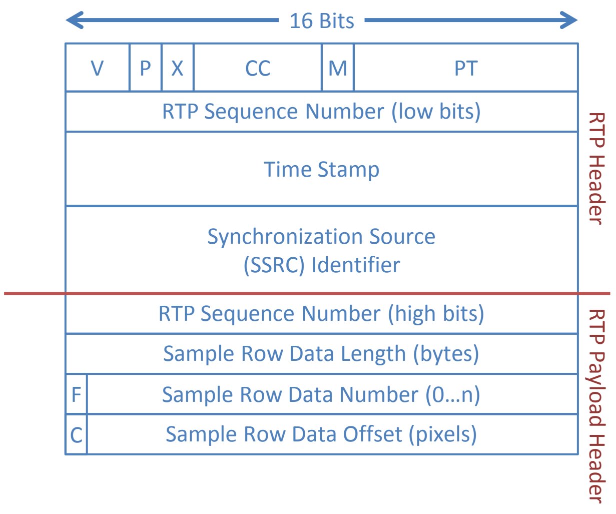
Pixel Group Sizes

- Every supported video format listed in ST 2110-20 tables
  - Tables also include order of samples within each pgroup

sampling	depth	pgroup size (octets)	pgroup coverage (pixels)	Sample Order
YCbCr-4:2:2 CLYCbCr-4:2:2	8	4	2	$C'_B,Y0',C'_R,Y1'$
	10	5	2	$C'_B,Y0',C'_R,Y1'$
	12	6	2	$C'_B,Y0',C'_R,Y1'$
	16, 16f	8	2	$C'_B,Y0',C'_R,Y1'$
ICtCp-4:2:2	8	4	2	$C'_T,I0',C'_P,I1'$
	10	5	2	$C'_T,I0',C'_P,I1'$
	12	6	2	$C'_T,I0',C'_P,I1'$
	16, 16f	8	2	$C'_T,I0',C'_P,I1'$

IP SHOWCASE THEATRE

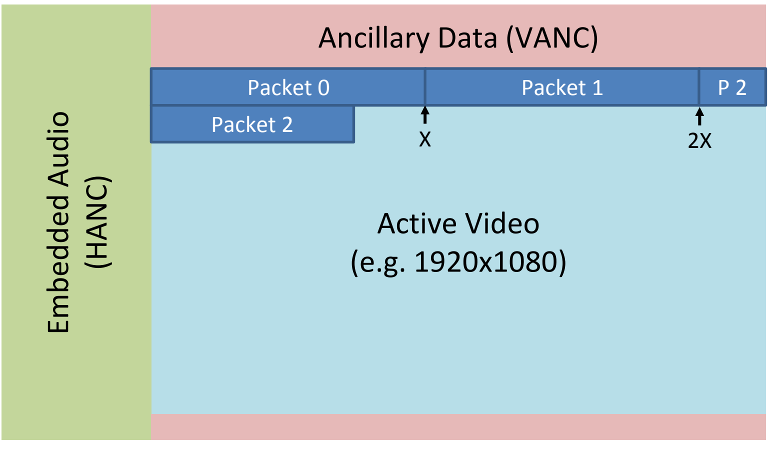
ST 2110-20 Video Packet Header



- 32-bit Sequence Number
  (16 bit Sequence number would wrap in less than half a second for Gigabit-class payloads)
- Length of Sample Row Data = Number of octets from scan line in this datagram. Must be multiple of pgroup
- F = 0 for progressive scan and first field in interlace video
- F = 1 for second field in interlace video
- Video Line Number = Video scan line number, starts at 0 for first active line of video (note difference from SDI line numbering)
- C = 1 if more than one line is in datagram, set to 0 for last line in each datagram
- Sample Row Data Offset
  = Location of first pixel of payload data within scan line
  = 0 if first pixel in scan line; counts by pixels

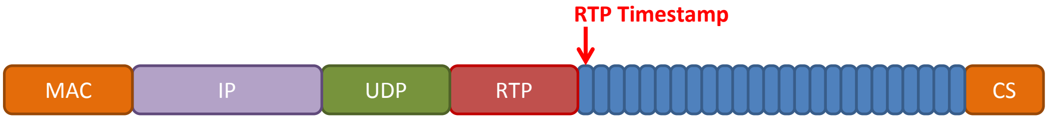
IP SHOWCASE THEATRE

ST 2110-20 Sample Row Data



- Packet 0
  - Sample Row 0
  - Offset 0
- Packet 1
  - Sample Row 0
  - Offset X
- Packet 2
  - Sample Row 0,1
  - Offset 2X, 0

ST 2110-30 Audio Encapsulation



- Multiple Audio Samples (16 or 24 bit)
- Grouped into one RTP packet
- Placed into UDP packet
- IP packet header attached
- Wrapped into Ethernet Frame

ST 2110-30 Audio

- Based on AES67
  - 48 kHz, 24-bit linear encoding must be supported in all devices
- Zero Offset Media Clock
  - Forces all media clocks to be tied to common time base
- Audio Channel Grouping
  - How audio channels relate to each other in a stream
- Receiver Classifications
  - Three levels of receiver performance
- Packet size limit 1440 = 1460 – (12 (RTP) + 8 (UDP))
- No need for SIP or other connection management

Importance of "ptime"

- Audio streams are divided into fixed duration packets
  - Common size is 1 msec, signaled using "**`a=ptime:1`**" attribute
- Number of samples from a channel depends on sampling rate
  - For example, 48 kHz has 48 samples in 1 msec
  - Each sample could be 2 bytes (16 bit audio) or 3 bytes (24 bit audio)
  - Thus, 1 msec of 48 kHz, 24-bit audio is 48 * 3 = 144 bytes
- Number of channels in a packet limited by payload size
  - Total RTP audio payload is 1440 bytes
  - Jumbo frames not allowed for audio

telecompro.tv *IP Video Training and Consulting* Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

ST 2110-30 Receiver Classifications

Required Sampling Rates and Packet Times	A	AX	B	BX	C	CX
48 KHz, 1 msec	8	8	8	8	8	8
48 KHz, 125 µsec			8	8	64	64
96 KHz, 1 msec		4		4		4
96 KHz, 125 µsec				8		32

telecompro.tv *IP Video Training and Consulting* Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

ST 2110-30 Audio Channel Grouping Symbols

Channel Grouping Symbol	Quantity of Audio Channels in group	Description of group	Order of Audio Channels in group
M	1	Mono	Mono
DM	2	Dual Mono	M1, M2
ST	2	Standard Stereo	Left, Right
LtRt	2	Matrix Stereo	Left Total, Right Total
51	6	5.1 Surround	L, R, C, LFE, Ls, Rs
71	8	7.1 Surround	L, R, C, LFE, Lss, Rss, Lrs, Rrs
222	24	22.2 Surround	Per SMPTE ST 2036-2, Table 1
U01…U64	Unn where nn is the number of channels in group	Undefined	Undefined

ST 2110-31 AES3 Audio Streams

- AES3 streams can be used for non-PCM audio applications
  - Dolby E Compressed Audio is one common application
  - Other signals defined in SMPTE ST 337/338 (e.g. AC-3 compressed audio)
  - Has also been used for non-linear audio, one-bit audio and SACD
  - Also know as AES/EBU Audio
- For these applications, transparent carriage across IP is a must
  - Cannot change any bits within the stream
  - Data cannot be interpreted as uncompressed linear audio signals
- ST 2110-31 should NOT be used for linear 16-bit or 24-bit audio
  - Those should be carried using ST 2110-30 packet streams

ST 2110-31 Packet Format

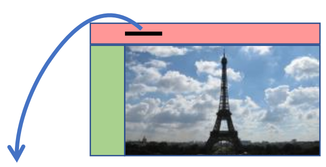
- Based on AM824 data format
  - 32 bit sub-frames, each with 8 bits of signaling and 24 bits of data
  - Can hold all data plus signaling bits from AES-3 (B, F, P, C, U, V)

V	P	X	CC	M	PT	RTP Sequence Number	
Time Stamp (32 bits)							RTP Header
Synchronization Source (SSRC) Identifier							
B,F,P,C,U,V data bits					AM824 sub-frame 0		
B,F,P,C,U,V data bits					AM824 sub-frame 1		
B,F,P,C,U,V data bits					AM824 sub-frame 2		

telecompro.tv *IP Video Training and Consulting* Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

ST 2110-40 Ancillary Data

- Extract ancillary data packets from VANC or HANC
  - Captions, time code, ad triggers, etc.
  - Place them into RTP packets with custom header
- Line numbers are based on SDI line numbering
  - Don't match 2110-20 line numbers



ANC Data Packet:

Ancillary Flag	DID	SDID	DC	User Data	CS
000 3FF 3FF	41	07	xx	SCTE 104	zz

RTP Datagram:

RTP Header	Payload Hdr.	Anc. Packet Header	DID	SDID	DC	User Data	CS
Seq. #, SSRC	01	Line #, Offset	41	07	xx	SCTE 104	zz

telecompro.tv *IP Video Training and Consulting* Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

ST 2110-40 ANC Packet Format

C	Line Number (11 bits)	Horizontal Offset (12 bits)	S	Stream Num (7)
DID (10 bits)	SDID (10 bits)	Data Count (10 bits)		
ANC Packet Payload				
ANC Packet Payload				
ANC Packet Payload	Checksum (10 bits)	Padding to 32 bits		

– Each ANC packet in the RTP payload has its own header
– Color channel flag: C=1 – ANC packet is from HD color difference channel. C=0 in all other cases
– Line Number and Horizontal Offset refer to SDI raster values
– S=1 Multiple streams comprise the format of the original video signal containing the ANC packets
– Stream number indicates where the ANC packets were located within a multi-stream signal
– DID, SDID, Data Count, Packet Payload and Checksum are exact 10-bit values from ANC packet
– For each ANC packet within the RTP payload, padding makes the total number of bits a multiple of 32

SDP – Session Description Protocol

- Standardized format for describing video and audio content
  - RFC 4566
- Provides key data needed to process content
  - Structural metadata for each type of media stream
  - Connection information for each stream
  - Clock and timing information
  - Stream associations for closely coupled streams (ST 2022-7 hitless and RP 2110-23 subdivided streams)
- Text file
  - Can be accessed through NMOS APIs, other means

Parts of a Session Description

Session Information

Timing Information

Media Information

Connection Information

SDP Example

```
v=0
o=wes 203763372 89 IN IP4 10.201.33.19
s=Example of a 1080i29.97 video signal
t=0 0
m=video 31008 RTP/AVP 101
c=IN IP4 239.201.33.11/32
a=source-filter: incl IN IP4 239.201.33.11 10.201.33.19
a=rtpmap:101 raw/90000
a=fmtp:101 sampling=YCbCr-4:2:2; width=1920; height=1080; interlace;
exactframerate=30000/1001; depth=10; TCS=SDR; colorimetry=BT709;
PM=2110GPM; SSN=ST2110-20:2017;
a=ts-refclk:ptp=IEEE1588-2008:39-A7-94-FF-FE-07-CB-D0:42
a=mediaclk:direct=0
```

IP SHOWCASE THEATRE

PTP
Timing & Synchronisation

telecompro.tv
IP Video Training and Consulting

Q3 media Training
Tailored Technology Training
Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

Time / Synchronisation

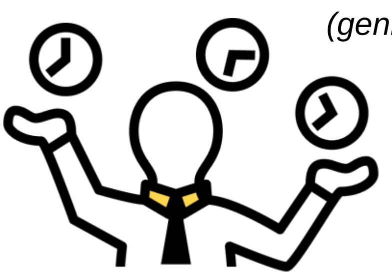
- Synchronous signals are essential for production to allow clean-switching/mixing and capture to a common timebase

Date <> Time-of-day <> Frequency <> Phase

SMPTE-309M *SMPTE-12M* *B&B/Tri-Level Sync*

'Offline' *'Real-time'*

(genlock)



telecompro.tv
IP Video Training and Consulting

Q3 media Training
Tailored Technology Training
Q3MediaTraining.co.uk

Time / Synchronisation

- **PTPv2 (IEEE 1588-2008)**
- Defines mechanism for accurately setting a local clock via exchange of a few simple messages
- PTP timestamps are 80-bits in size: **48 bits Seconds** : **32 bits nanoseconds**
- Can handle all our needs from Date/Time Timecode through to Frequency (Genlock)
- PTP Profiles defined by **AES67 / SMPTE 2059-2**

*(see **AES-R-16-2016** for compatibility recommendations)*

- Epoc **1970-01-01 00:00:00**

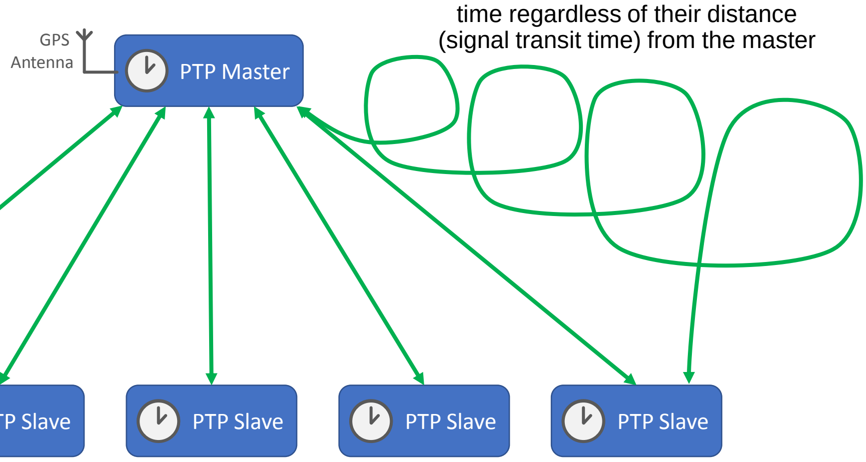
NTP – accuracy ~200 micro seconds
PTP – accuracy ~1 micro second

We learned from Y2K!
48bits is approx. 9 million years!

telecompro.tv *IP Video Training and Consulting*
Tailored Technology Training *Q3MediaTraining.co.uk*

PTP Architecture

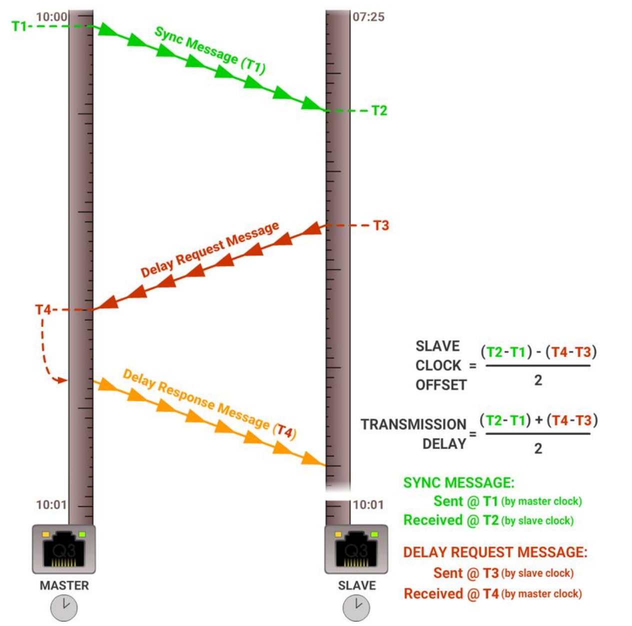
PTP ensures all slaves have the same time regardless of their distance (signal transit time) from the master



telecompro.tv *IP Video Training and Consulting*
Tailored Technology Training *Q3MediaTraining.co.uk*

1-Step Sync with End-to-End Delay

- Sync Message:
  - "The time now is XX:XX" (sec:nanosec.)
  - If slave immediately updated clock to be the time in the sync message (T1), it would still be offset equal to the time taken for the message to transit the link
- Delay Request & Response:
  - Measures time taken to transit network link
  - Assumes symmetrical delay



telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

PTP Implementation Options

Time-Stamping Mechanism

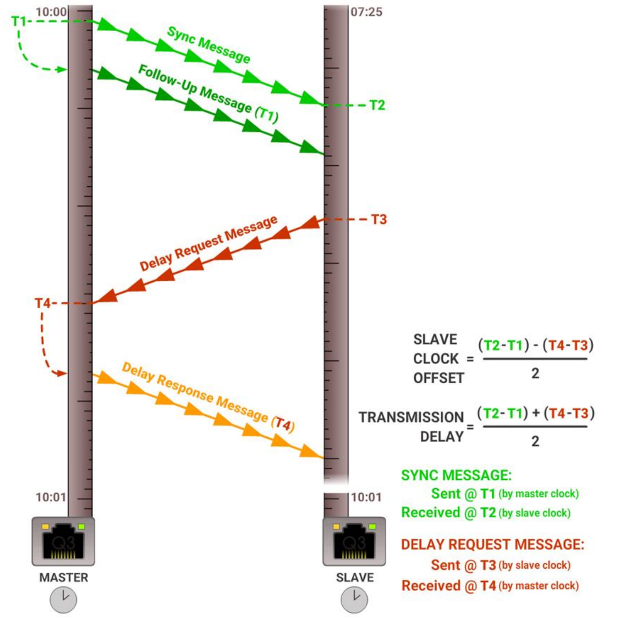
- **1-Step**
  - Accurate timestamp written into packet at the point of egress
  - Requires precision hardware implementation
- **2-step**
  - Message formed and passed to hardware for egress
  - Actual time of egress reported and inserted in a follow-up message
- Messages affected:
  - Sync Message
  - Peer Delay Response Message *(will cover later!)*

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

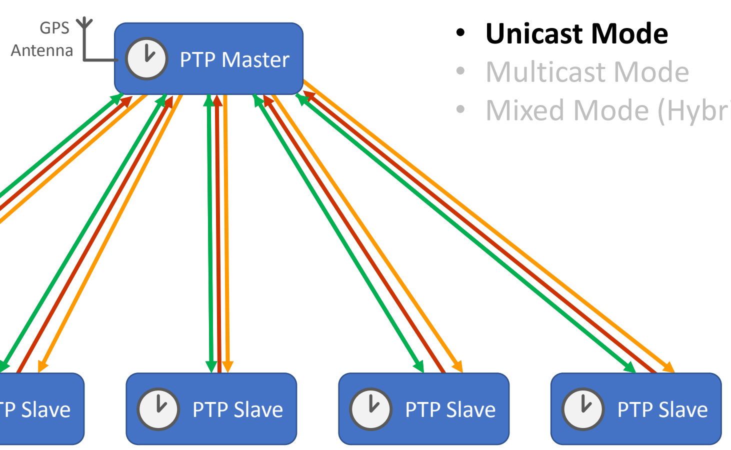
© 2019 telecompro.tv & Q3 Media Training – no part of this presentation can be reproduced or repurposed without permission of the authors

2-Step Sync with End-to-End Delay

- Sync Message:
  - "The time now is XX:XX" (sec:nanosec.)
  - If slave immediately updated clock to be the time in the sync message (T1), it would still be offset equal to the time taken for the message to transit the link
  - **Actual time of egress sent in a follow-up message**
- Delay Request & Response:
  - Measures time taken to transit network link
  - Assumes symmetrical delay



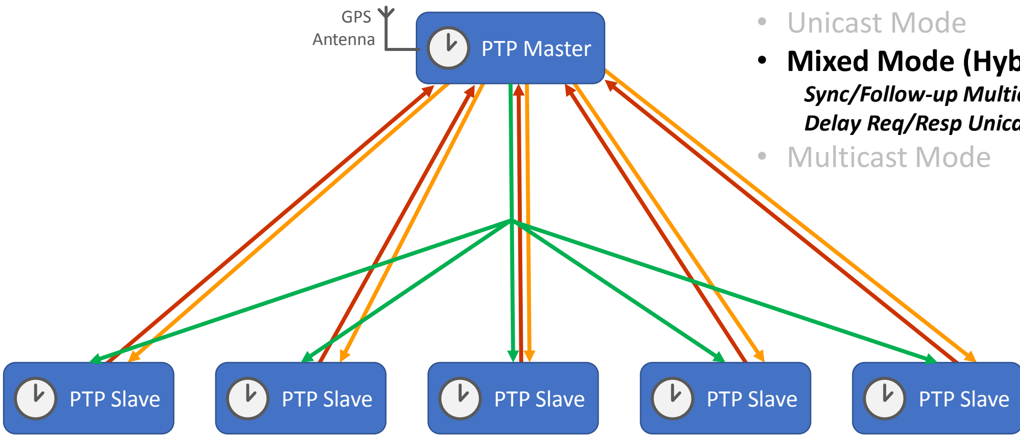
PTP Architecture



- **Unicast Mode**
- Multicast Mode
- Mixed Mode (Hybrid)

IP SHOWCASE THEATRE

PTP Architecture

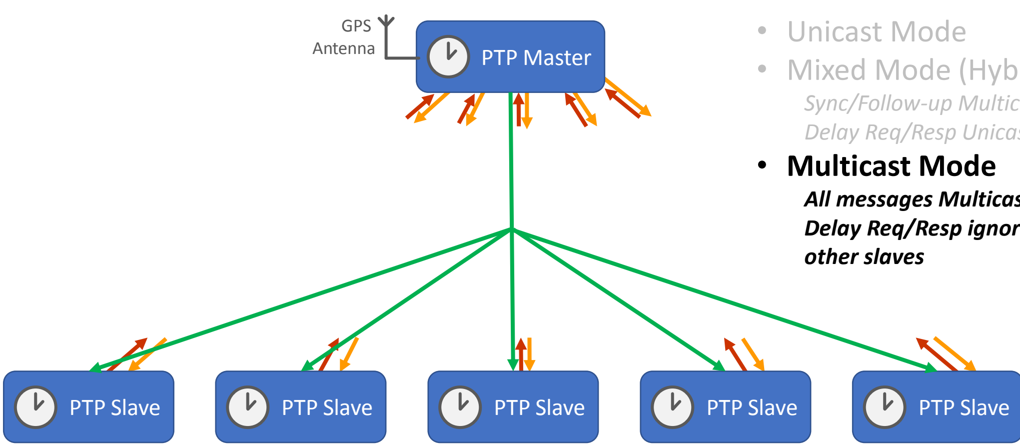


- Unicast Mode
- **Mixed Mode (Hybrid)**
  - ***Sync/Follow-up Multicast***
  - ***Delay Req/Resp Unicast***
- Multicast Mode

telecompro.tv *IP Video Training and Consulting*
Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

IP SHOWCASE THEATRE

PTP Architecture

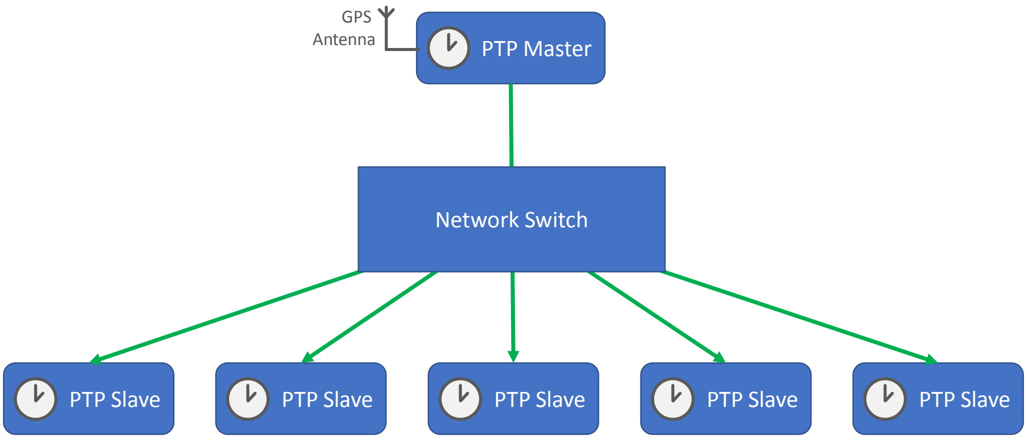


- Unicast Mode
- Mixed Mode (Hybrid)
  - *Sync/Follow-up Multicast*
  - *Delay Req/Resp Unicast*
- **Multicast Mode**
  - ***All messages Multicast***
  - ***Delay Req/Resp ignored by other slaves***

telecompro.tv *IP Video Training and Consulting*
Q3 media Training Tailored Technology Training *Q3MediaTraining.co.uk*

IP SHOWCASE THEATRE

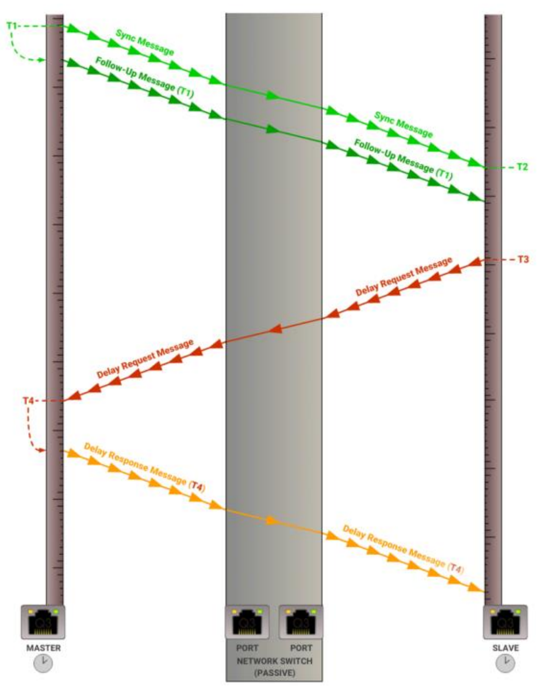
PTP Architecture



IP SHOWCASE THEATRE

Passive Network Switches

- Any network switch which is not 'PTP-Aware'
- Variable delay can be introduced as messages transit
- QoS can be used to improve performance
- The assumption of symmetry used in the End-2-End delay mechanism can result in clock jitter
- Passive switches can be used but their impact needs to be considered



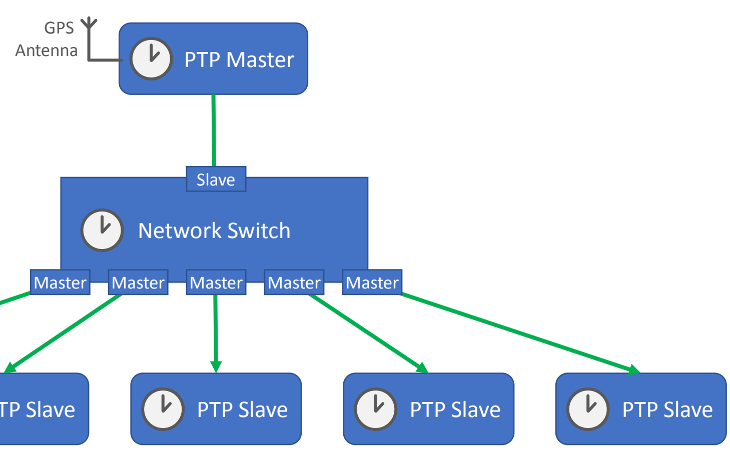
IEE 1598-2008 defines the following device Types

- **Ordinary Clock**
  - Device with a single PTP port, can be grandmaster-capable or can be slave-only
- **Boundary Clock**
  - has multiple PTP ports, synchronises network segments
- **End-to-End Transparent Clock**
  - has multiple PTP ports, modify timestamps in PTP messages
  - residence times measured/added to the correctionField of Sync / Delay_Req (one-step) or Follow_Up / Delay_Resp (two-step)
- **Peer-to-Peer Transparent Clock**
  - has multiple PTP ports, modify timestamps in PTP messages
  - residence times plus egress-link delays measured/added to the correctionField of Sync (one-step) or Follow_Up (two-step) messages
- **Management Node**

PTP Enabled Network Switches

telecompro.tv IP Video Training and Consulting
Tailored Technology Training Q3MediaTraining.co.uk

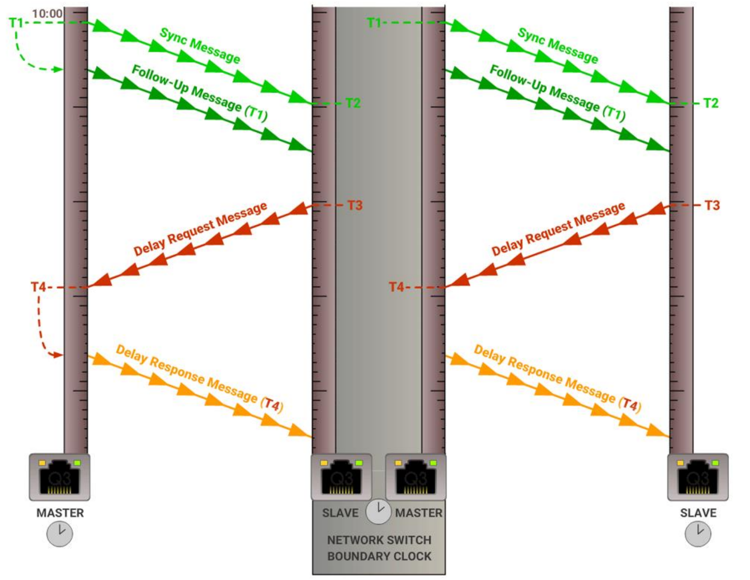
Boundary Clock Network Switch



telecompro.tv IP Video Training and Consulting
Tailored Technology Training Q3MediaTraining.co.uk

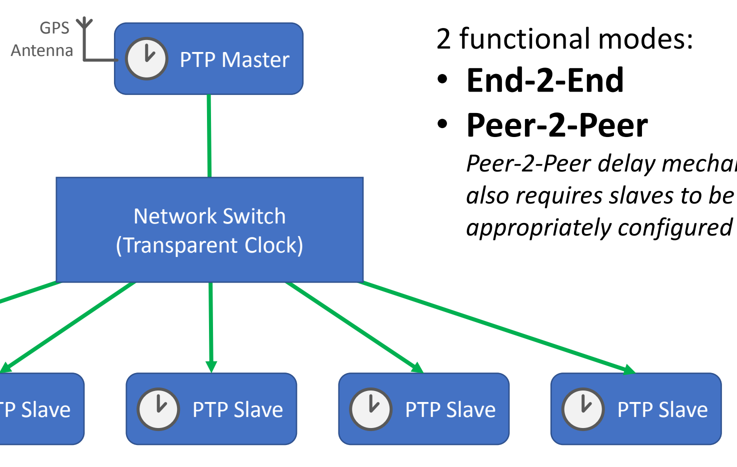
Boundary Clock Network Switch

- One port on the network switch will be a PTP Slave
- All other ports become PTP Master
- Provides independent links to downstream clocks
- Allows expansion through multiple tiers and with common grandmaster
- Individual links use End-to-End delay mechanism



telecompro.tv IP Video Training and Consulting
Q3 Media Training Tailored Technology Training Q3MediaTraining.co.uk

Transparent Clock Network Switch



2 functional modes:

- **End-2-End**
- **Peer-2-Peer**

  Peer-2-Peer delay mechanism also requires slaves to be appropriately configured

telecompro.tv IP Video Training and Consulting
Q3 Media Training Tailored Technology Training Q3MediaTraining.co.uk

PTP Implementation Options

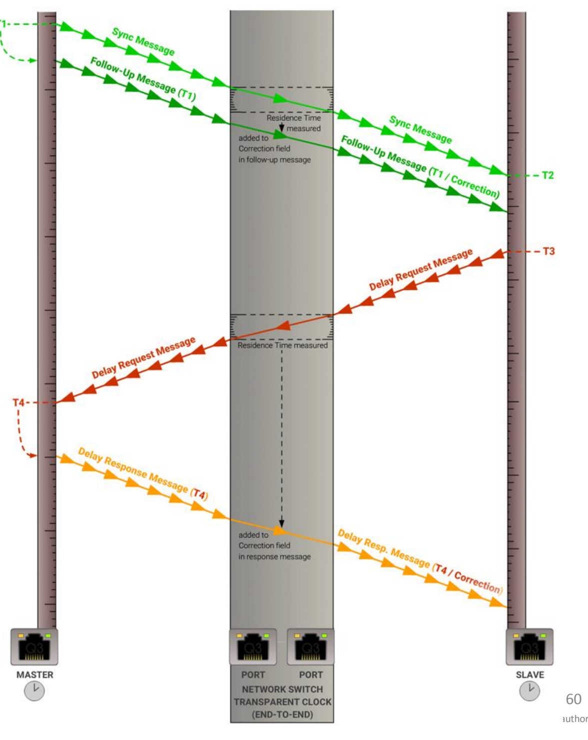
Delay Mechanism

- **End-to-End**
  - Slave measures the delay between itself and the master
  - Messages: Delay_Req / Delay_Resp
- **Peer-to-Peer**
  - Each network element measures the delay between its port and the device on the other end of the link
  - Measured delays for each network element added to SYNC message as it transits between master and slave
  - Messages: Pdelay_Req / Pdelay_Resp (+Follow-up for 2-step)

telecompro.tv IP Video Training and Consulting
Tailored Technology Training Q3MediaTraining.co.uk

Transparent Clock (TC) Network Switch (E2E)

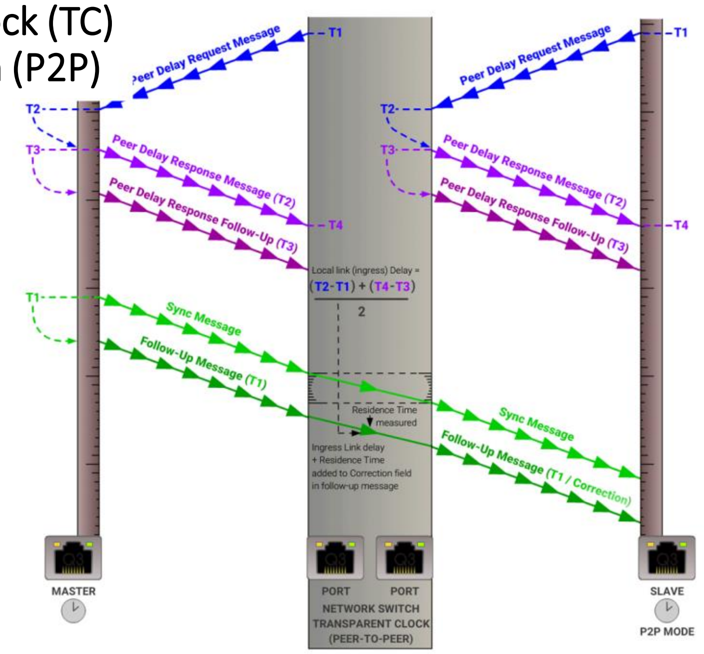
- PTP messages can be modified on the way through the switch
- '**Residence Time**'
  (the time spent in the switch)
  is measured and added to the correction field in PTP message:
  - 1 Step: Sync / Delay_Req
  - 2-Step: Follow_up / Delay Resp
- Each TC **adds** its measured value to correction field value
  (i.e. tracks the cumulative delay)



telecompro.tv IP Video Training and Consulting
Tailored Technology Training Q3MediaTraining.co.uk

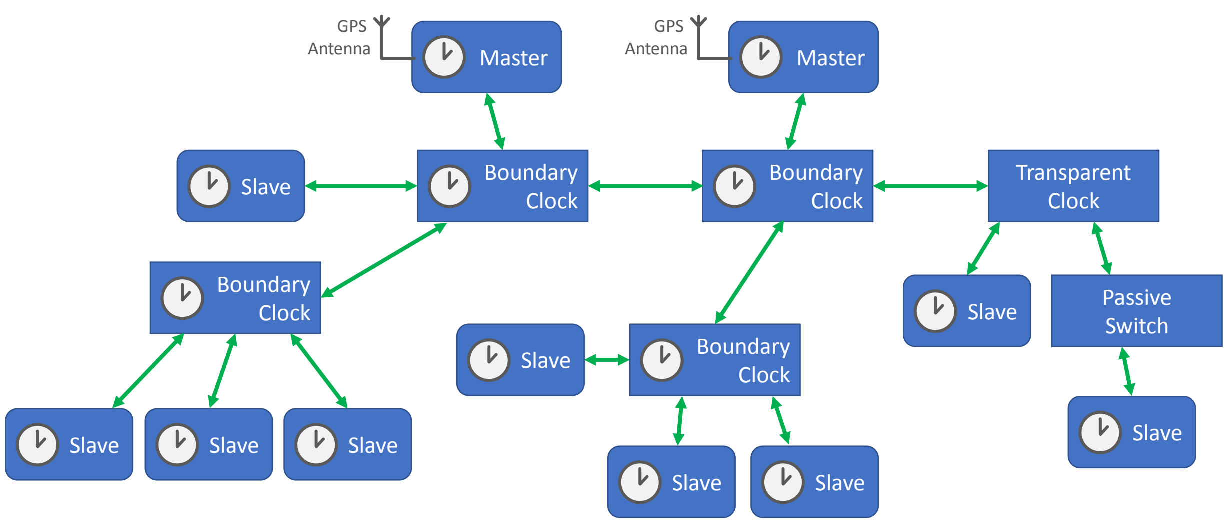
Transparent Clock (TC) Network Switch (P2P)

- Peer-2-Peer Delay Mechanism
- Sends/responds to Peer Delay Request messages on each port to asses delay on local link
- Residence Time + Peer Delay on Ingress Link added to Correction Field



telecompro.tv *IP Video Training and Consulting*
Q3 media Training — Tailored Technology Training — *Q3MediaTraining.co.uk*

Real Networks

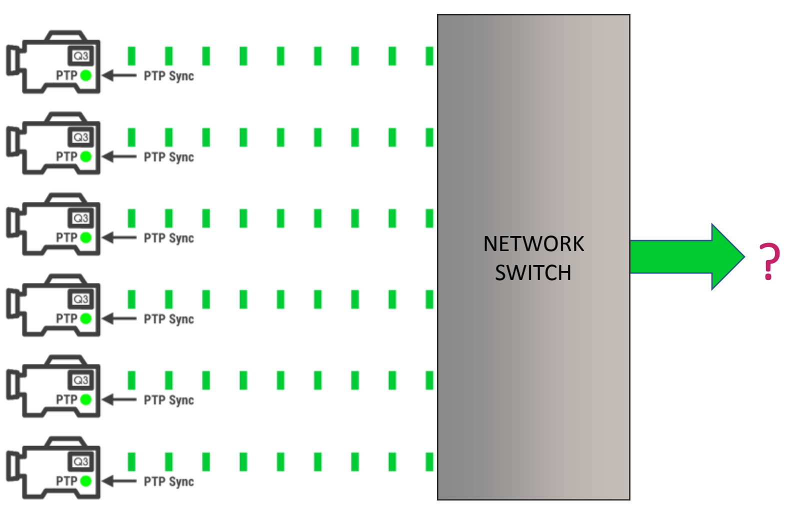


telecompro.tv *IP Video Training and Consulting*
Q3 media Training — Tailored Technology Training — *Q3MediaTraining.co.uk*

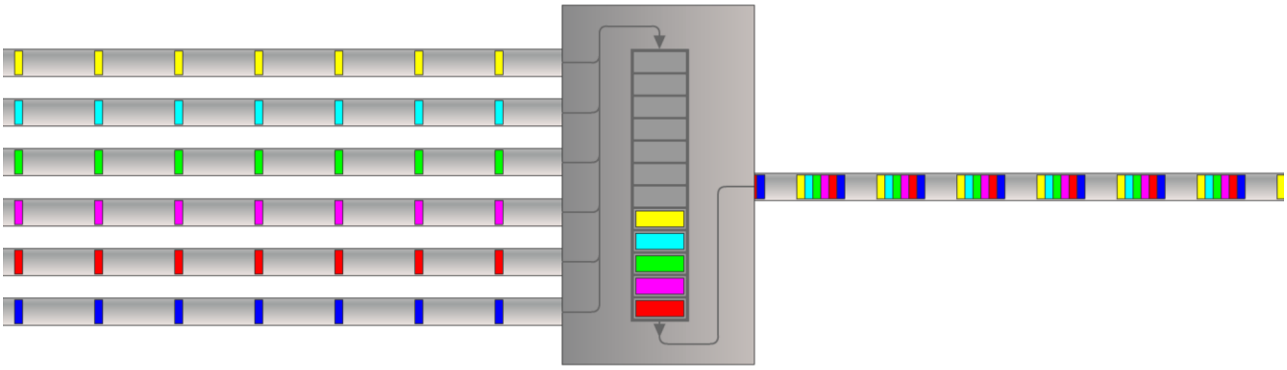
Electing a Grandmaster

- Best Master Clock Algorithm (**BMCA**) is used to elect a Grandmaster
- attributes are evaluated in the following order:
  - Priority 1 (lowest number wins)
  - Clock Class (GPS, free-run, etc)
  - Clock Accuracy (accuracy to UTC)
  - Clock Variance (jitter and wander)
  - Priority 2 (lowest number wins)
  - GMID (similar to mac address)
- These attributes are advertised in the PTP Announce Message *(typically 1 - 4 per second depending on config)*
- *NB: all other equipment should be set to be PTP Slave only to prevent accidental election of inappropriate masters*

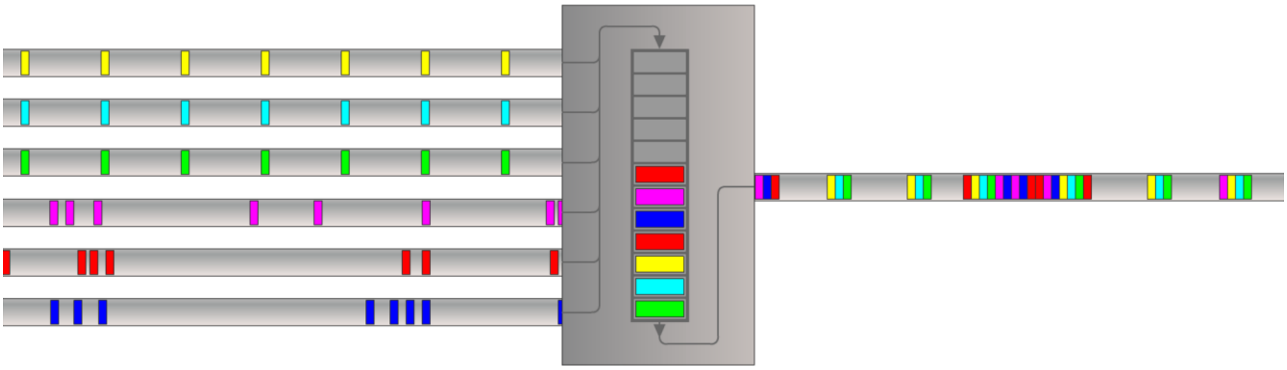
Equipment Reference with PTP



Switching Packets Requires Buffering



Switching Packets Requires Buffering



Wireshark captures showing some 2110-20 flows from different hardware devices

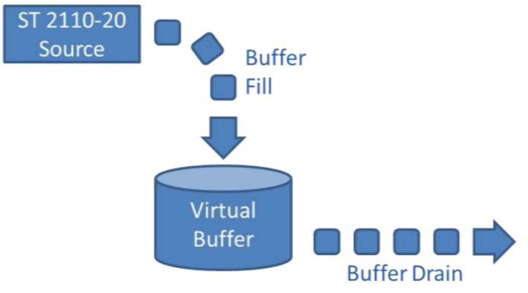
Software processes typically work with frame buffers so this could get a lot worse!

67

2110-21 Traffic Shaping

Networking Detail
ST 2110-21 Timing Models

- Senders can't burst out all of their data at once
  - Overloads receivers and network switch buffers
- Some variability is necessary
  - HANC/VANC gaps, software-based senders



Two Constraints for ST 2110-20
Senders

- Network Compatibility Model
  - Ensures streams will not overflow buffers inside network devices
  - Scaling factor β of 1.1 means buffers drain 10% faster than they fill
- Virtual Receiver Buffer Model
  - Buffer is modelled as input of every receiver device
    - Note: Must be included in end-to-end system delay
  - Packets read from buffer perfectly, based on video format
  - Buffer not allowed to overflow or underflow
- All senders must comply with both models

ST 2110-21 Gapped, Linear Packet Schedules

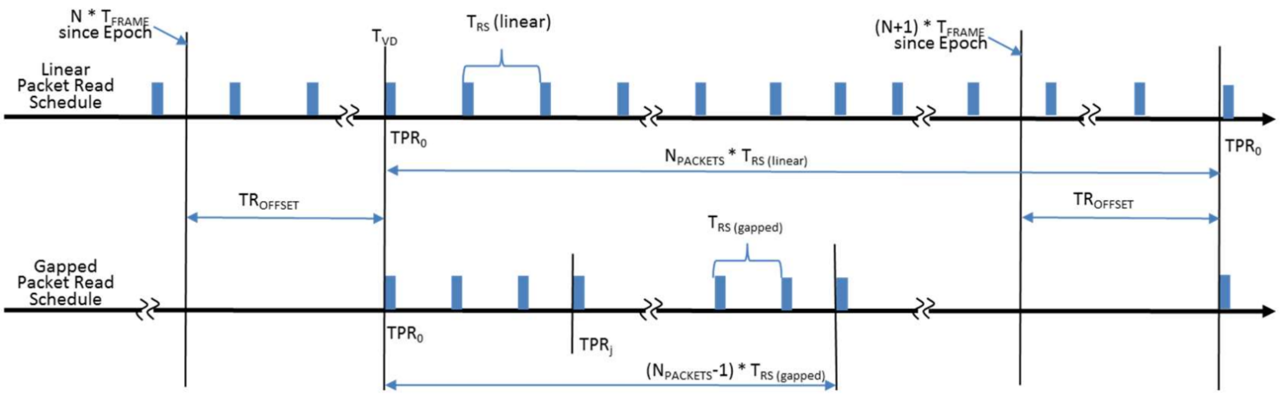


Image Source: SMPTE ST 2110-21 Traffic Shaping and Delivery Timing for Video

ST 2110-21 Sender Types

- Three Sender Types: N = Narrow, NL = Narrow Linear, W = Wide

Type N (Narrow)	– designed for real-time capture and processing – Maximum required receiver buffer is about 9 packets in gapped mode – Model assumes TR_{OFFSET} of a couple of video lines from SMPTE Epoch – Small buffer means limited delay passing through each device in systems – Pixels inside packets “roughly” in sync with pixels in SDI
Type NL (Narrow Linear)	– linear version of N – no gaps corresponding to SDI VANC
Type W (Wide)	– designed to support software-based video sources – Maximum receive buffer is 720 packets in some popular formats – Larger buffer can handle packet bursts more easily – Bursty transmission is more common to software-based senders

ST 2110-21 Sender/Receiver Compatibility

Receiver Type	Type N Sender	Type NL Sender	Type W Sender
Type N Synchronous Narrow	Mandatory	Optional	No
Type W Synchronous Wide	Mandatory	Mandatory	Mandatory
Type A Asynchronous	Mandatory	Mandatory	Mandatory

- Synchronous Receivers must have clock locked to Sender
- Synchronous Narrow Receivers are only required to work with Senders that use the default TR_{OFFSET}

New parts of 2110

Forthcoming: SMPTE ST 2110-22

- Current Title:
  "Professional Media over Managed IP Networks:
- Constant Bit-Rate Compressed Video"
  - Supports CBR compression formats such as VC2
  - Must be a registered RTP media type as per RFC 4855
  - RTP Clock rate of 90 kHz
  - Must conform to either "NL" or "W" network compatibility model of ST 2110-21; virtual receiver buffer model does not apply

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

Forthcoming: SMPTE ST 2110-22

- Visually lossless compression cannot be seen by observer
  - Some data must always be removed
  - Done so as to be invisible to human viewer
  - Can have very low latency – using slice-based compression
- Popular codecs available
  - VC-2 DIRAC from BBC – RFC 8450
  - Also JPEG XS – draft-lugan-payload-rtp-jpegxs-01
- 2:1 to 8:1 compression ratios
  - 3Gbit/s SDI compressed to 1.5 to 0.5 Gbit/s

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

© 2019 telecompro.tv & Q3 Media Training – no part of this presentation can be reproduced or repurposed without permission of the authors

Forthcoming: SMPTE ST 2110-22 SDP for ST 2110-22

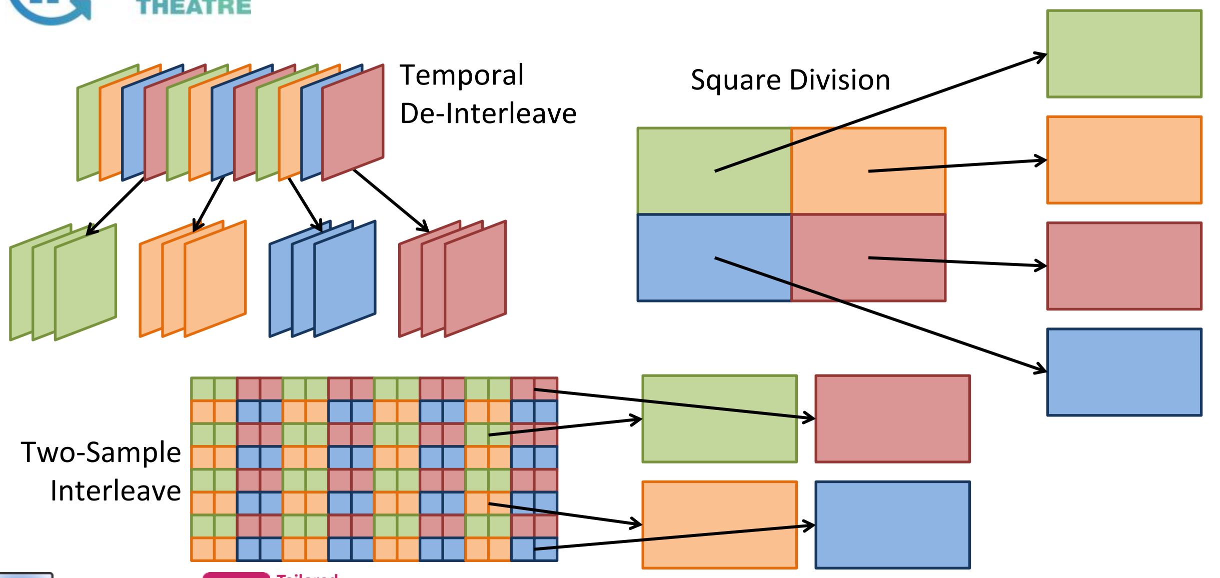
- Format parameters (**`a=fmtp`**) statement must include
  - Image height in lines
  - Image width in pixels
  - TP of either 2110TPNL or 2110TPW
  - Optional value of CMAX if different from default
- Bit rate parameter "**`b=AS:<bandwidth>`**" must be included
  - Bandwidth is in kilobits/second calculated over one frame period
- SDP must include a frame rate statement, either
  - **`a=framerate xx.yy`** (as a decimal number)
  - **`exactframerate=M/N`** (as a ratio of two integers) in "fmtp"

Forthcoming: SMPTE RP 2110-23

Recommended Practice

- Working Title:
  "Single Video Essence Transport over Multiple ST 2110-20 Streams"
- Idea is to have a system where multiple low-bandwidth streams can be used to transport one high-bandwidth signal
  - High resolution streams, such as UHD1/4K or UHD2/8K
  - High frame rate streams, such as those over 100 fps
  - Also known as "multiport"
- Each sub-stream is a valid ST 2110-20/2110-21 stream
  - Timestamps tied to original frames
  - Comply with timing models

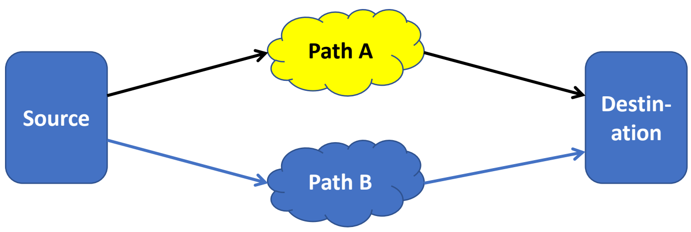
RP 2110-23 – Three Methods to Split Stream



2022-7 Redundant Transport

2022-7 Hitless Protection Switching

- Send identical signal on two separate paths
  - Identical packet timestamps, sequence numbers
  - Receiver aligns packets using buffer
  - Transit time equal to delay of longest path
- SMPTE 2022-7 Standard
  - "Seamless Protection Switching of SMPTE ST 2022 IP datagrams"
  - Published 2013

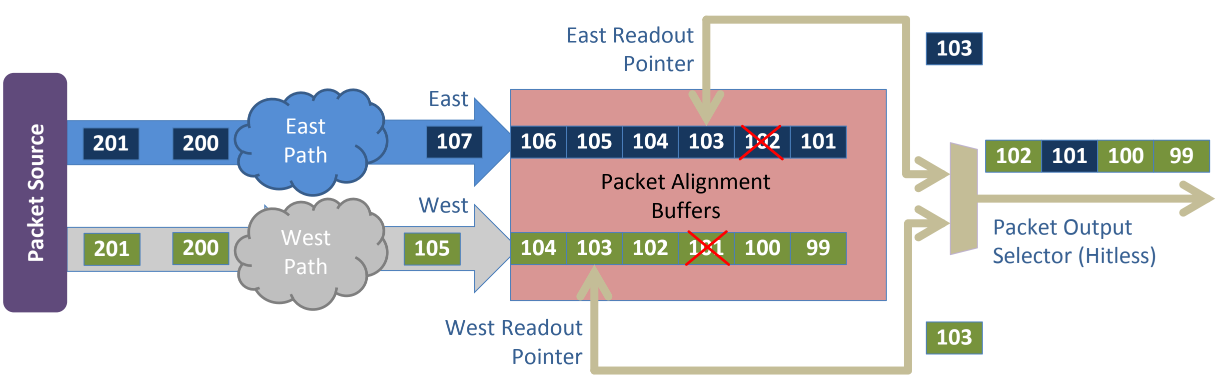


telecompro.tv
IP Video Training and Consulting
Tailored Technology Training
Q3MediaTraining.co.uk

IP SHOWCASE THEATRE AT IBC2019 : 13–17 SEPT 2019 81

Route Diversity using ST 2022-7

- Diverse routes with SMPTE ST 2022-7 Hitless Protection Switching



telecompro.tv
IP Video Training and Consulting
Tailored Technology Training
Q3MediaTraining.co.uk

IP SHOWCASE THEATRE AT IBC2019 : 13–17 SEPT 2019 82

IP SHOWCASE THEATRE

JT-NM TR-1001 / NMOS

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE

Standards & Bodies (Related to 2110)

Industry Bodies
Marketing & Education
AIMS Alliance for IP Media Solutions
NAB National Association of Broadcasters
IBC
iabm

Industry Bodies
with working groups defining specifications
EBU *European Broadcasting Union*
AMWA *Advanced Media Workflow Association*
VSF *Video Services Forum*
JT-NM Joint Task Force on Networked Media

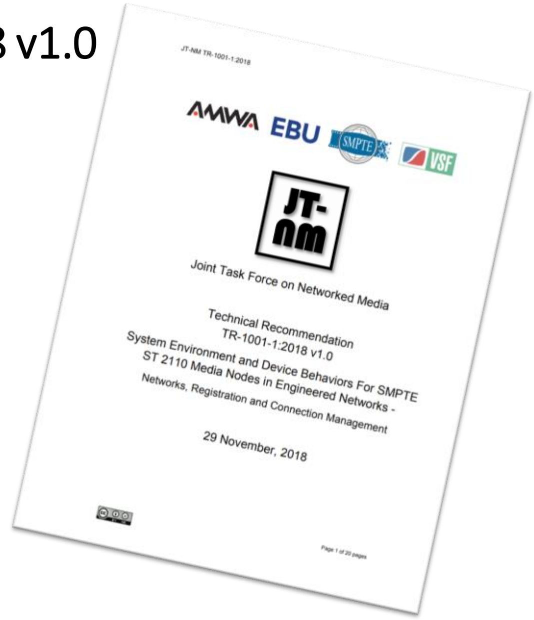
Standards
Industry Specific
SMPTE *Society of Motion Picture & Television Engineers*
AES *Audio Engineering Society*

Standards
General
IETF *Internet Engineering Task Force*
IEEE *Institute of Electrical and Electronics Engineers*

JT-NM TR-1001-1:2018 v1.0

"System Environment and Device Behaviours for ST 2110 Media Nodes in Engineered Networks – Networks, Registration, and Connection Management"

- *The goal of this document is to enable the creation of network environments where an end-user can take delivery of new equipment, connect it to their network, and configure it for use, with a minimum amount of human interaction.*


JT-NM TR-1001-1:2018

AMWA EBU SMPTE VSF

JT-NM

Joint Task Force on Networked Media

Technical Recommendation
TR-1001-1:2018 v1.0
System Environment and Device Behaviors For SMPTE ST 2110 Media Nodes in Engineered Networks - Networks, Registration and Connection Management

29 November, 2018

Page 1 of 20 pages

http://www.jt-nm.org/documents/JT-NM_TR-1001-1:2018_v1.0.pdf

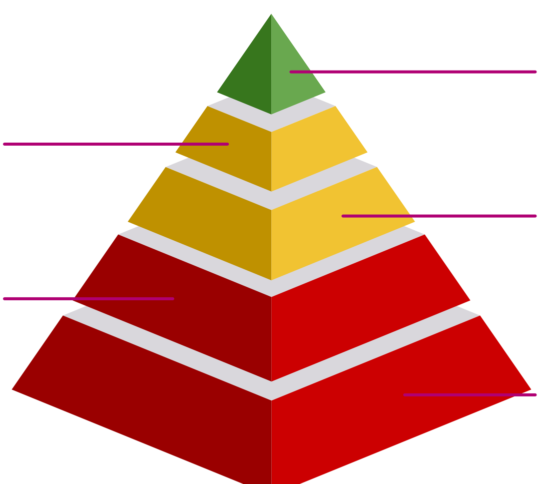
telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IP SHOWCASE THEATRE AT IBC2019 : 13–17 SEPT 2019 85

EBU: "The Technology Pyramid for Media Nodes"

The minimum stack of endpoint technologies to build an IP-based media facility

Widely Available	Partially Available	Rarely Available



https://tech.ebu.ch/docs/tech/tech3371.pdf (Dec 2018) EBU

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

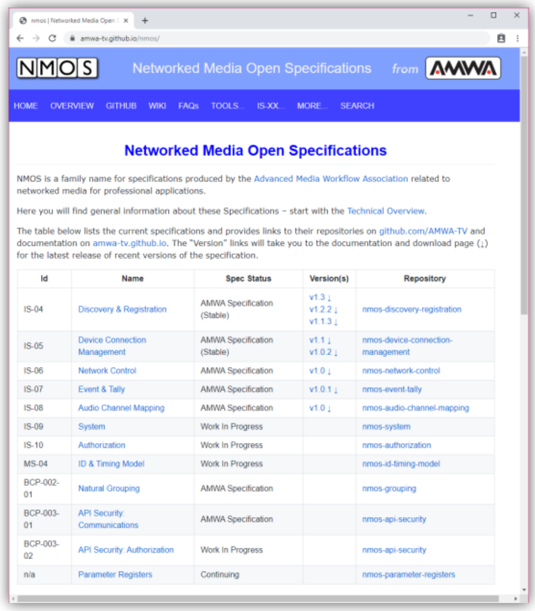
IP SHOWCASE THEATRE AT IBC2019 : 13–17 SEPT 2019 86

NMOS

networked media NMOS open specifications

AMWA Advanced Media Workflow Association

- A set of specifications/protocols created by AMWA's Network Media Incubator working group
- Developed since 2015 alongside standardisation of SMPTE ST-2110
  (which evolved out of VSF's TR-03 format)
- Modelled around concepts outlined in JT-NM's Reference Architecture document published at IBC 2015 (http://jt-nm.org/RA-1.0/)



NMOS Networked Media Open Specifications from AMWA

HOME OVERVIEW GITHUB WIKI FAQs TOOLS... IS-XX... MORE... SEARCH

Networked Media Open Specifications

NMOS is a family name for specifications produced by the Advanced Media Workflow Association related to networked media for professional applications.

Here you will find general information about these Specifications – start with the Technical Overview.

The table below lists the current specifications and provides links to their repositories on github.com/AMWA-TV and documentation on amwa-tv.github.io. The "Version" links will take you to the documentation and download page (↓) for the latest release of recent versions of the specification.

Id	Name	Spec Status	Version(s)	Repository
IS-04	Discovery & Registration	AMWA Specification (Stable)	v1.3 ↓ v1.2.2 ↓ v1.1.3 ↓	nmos-discovery-registration
IS-05	Device Connection Management	AMWA Specification (Stable)	v1.1 ↓ v1.0.2 ↓	nmos-device-connection-management
IS-06	Network Control	AMWA Specification	v1.0 ↓	nmos-network-control
IS-07	Event & Tally	AMWA Specification	v1.0.1 ↓	nmos-event-tally
IS-08	Audio Channel Mapping	AMWA Specification	v1.0 ↓	nmos-audio-channel-mapping
IS-09	System	Work In Progress		nmos-system
IS-10	Authorization	Work In Progress		nmos-authorization
MS-04	ID & Timing Model	Work In Progress		nmos-id-timing-model
BCP-002-01	Natural Grouping	AMWA Specification		nmos-grouping
BCP-003-01	API Security: Communications	AMWA Specification		nmos-api-security
BCP-003-02	API Security: Authorization	Work In Progress		nmos-api-security
n/a	Parameter Registers	Continuing		nmos-parameter-registers

https://amwa-tv.github.io/nmos/

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IS-04 Discovery & Registration

NMOS

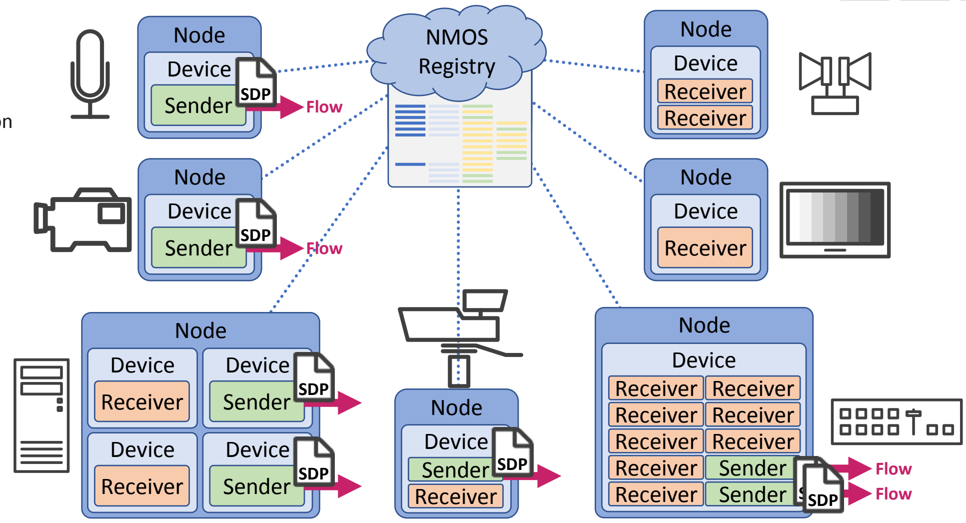
- Keeping track of all the flows, what is generating them, and what can consume them
- Protocols defined for both Peer-to-Peer discovery and discovery via central Registry
- mDNS discovery (within subnet)
- HTTP-based protocols for Node/Registration/Query API's (JSON payload)
- Flow properties/parameters via SDP file (RFC 4566)

telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IS-04 Discovery & Registration

NMOS

- API's defined by IS-04
  - Node
  - Registration
  - Query
- All devices should be PTP locked

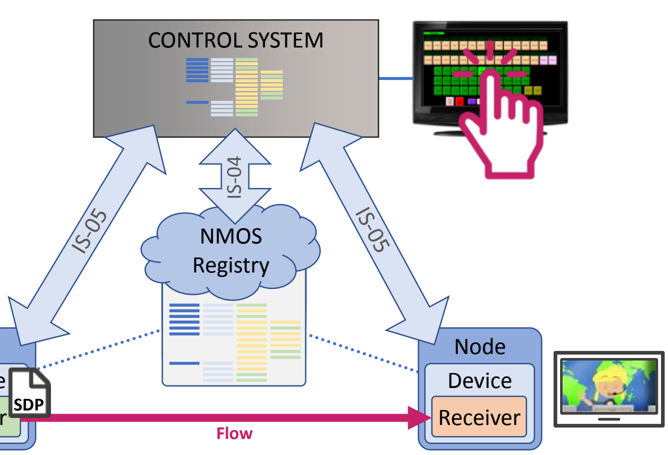


telecompro.tv *IP Video Training and Consulting*
Q3 Training Tailored Technology Training Q3MediaTraining.co.uk

IS-04 Discovery & Registration
IS-05 Device Connection Management

NMOS

- IS-05 works alongside IS-04 to provide mechanism to configure senders & receivers
- Commands can be 'staged' before making 'active' *(e.g. to allow validation)*
- Support for applying immediately or with time offset
- Single / Bulk mechanism *(e.g. Salvo routing)*

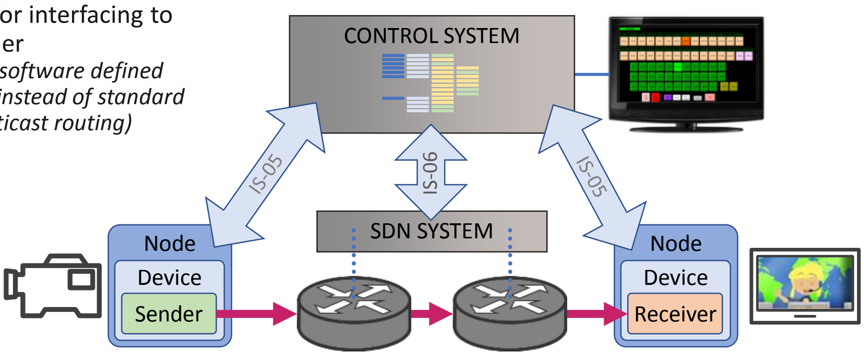


telecompro.tv *IP Video Training and Consulting*
Q3 Training Tailored Technology Training Q3MediaTraining.co.uk

IS-06 Network Control

NMOS

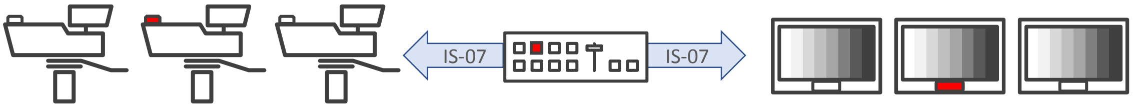
- IS-06 is an API for interfacing to an SDN controller
  (e.g. when using software defined network routing instead of standard IGMP-based multicast routing)



telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

IS-07 Event & Tally

NMOS



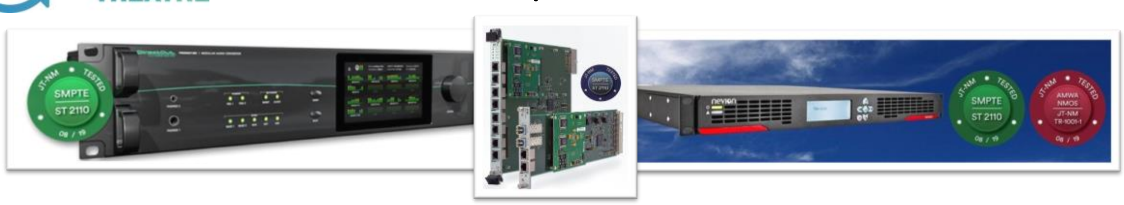
- Mechanism to emit and consume states and state changes issued by sources
- 'GPI for IP' – *General purpose interfacing for buttons/knobs/sliders/displays/lights*
- Extensible to carry additional data/values *(potentially much more than triggers & tallies!)*
- Clients subscribe to message queues (MQTT / Websockets)
- Small message size with very low-latency
- Multiple option timestamps for tracking action/effect times
- Signalling device reboot/shutdown *(in addition to general purpose state messages)*

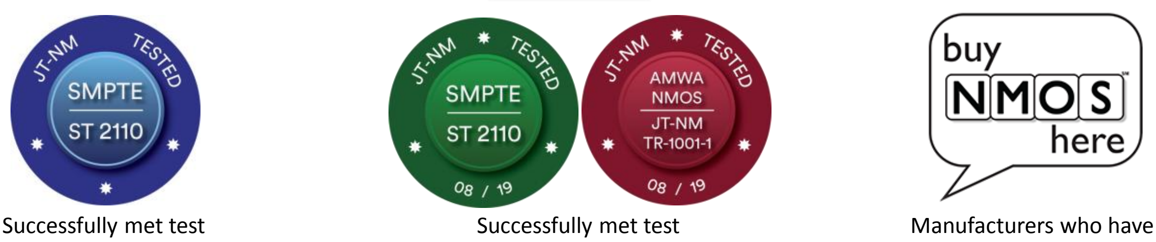
telecompro.tv IP Video Training and Consulting
Q3 media Training Tailored Technology Training Q3MediaTraining.co.uk

Network Media Open Specifications NMOS

Id	Name	Spec Status	Version(s)	Repository
IS-04	Discovery & Registration	AMWA Specification (Stable)	v1.3 / v1.2.2 / v1.1.3	nmos-discovery-registration
IS-05	Device Connection Management	AMWA Specification (Stable)	v1.1 / v1.0.2	nmos-device-connection-management
IS-06	Network Control	AMWA Specification	v1.0	nmos-network-control
IS-07	Event & Tally	AMWA Specification	v1.0.1	nmos-event-tally
IS-08	Audio Channel Mapping	AMWA Specification	v1.0	nmos-audio-channel-mapping
IS-09	System	Work In Progress		nmos-system
IS-10	Authorization	Work In Progress		nmos-authorization
MS-04	ID & Timing Model	Work In Progress		nmos-id-timing-model
BCP-002-01	Natural Grouping	AMWA Specification		nmos-grouping
BCP-003-01	API Security: Communications	AMWA Specification		nmos-api-security
BCP-003-02	API Security: Authorization	Work In Progress		nmos-api-security
n/a	Parameter Registers	Continuing		nmos-parameter-registers

JT-NM TR-1001 / NMOS at IBC 2019





Successfully met test criteria at interop event held prior to NAB 2019

Successfully met test criteria at interop event held prior to IBC 2019

Manufacturers who have implemented NMOS ('Self-certified')

Full list of both tests and successful participants here: http://jt-nm.org/jt-nm_tested/

Thank you

Wes Simpson
Telecom Product Consulting
wes.simpson@gmail.com
+1 203 376 3372
https://www.telecompro.tv

Ed Calverley
Q3 Media Training
ed.calverley@q3media.co.uk
+44 20 3475 0250
https://q3mediatraining.co.uk

Thank you to our Media Partners

IP SHOWCASE THEATRE AT IBC2019 : 13–17 SEPT 2019 95