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TSN Time Sensitive Networking Powered by IEEE 802

DRIVING DIGITAL TRANSFORMATION THROUGH IEEE 802.1 TSN TECHNOLOGY

IEEE TIME-SENSITIVE NETWORKING WEBINAR SERIES:

AN INTRODUCTION TO AVB (AUDIO / VIDEO BRIDGING), THE 1ST TSN PROFILE

SPEAKER: DON PANNELL, FELLOW

AUTOMOTIVE ETHERNET NETWORKING, NXP SEMICONDUCTORS

MODERATED BY SRI CHANDRASEKARAN, SR DIRECTOR STANDARDS & TECHNOLOGY, IEEE SA

09 June 2022

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SPEAKER – DON PANNELL

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Fellow, Automotive Ethernet Networking, NXP Semiconductors

Don Pannell has architected Ethernet switches and networking solutions for over 25 years, focusing on Automotive Ethernet solutions for the last 15 years. He has been an active participant and contributor in both IEEE 802.3 and IEEE 802.1 for almost 25 years. Don organized the 802.3 Call for Interest (CFI) for RTPGE resulting in the 1000BASE-T1 Automotive PHY we have today, and he started the Time Aware Shaper project in 802.1, known as IEEE 802.1Qbv. More recently he helped start the new 802.1 TSN Automotive Profile project (P802.1DG) and the IEEE P802.1ASds amendment to add 10BASE-T1S support to gPTP. Don is currently Secretary of the IEEE 1722 working group and editor of the new IEEE 1722b standard (which standardizes end node protocols for AVB/TSN). He has been a lead architect for over 30 years at companies including Sierra Semiconductor, I-Cube, Marvell and now NXP. Don currently has over 95 patents granted, and he received his BSEE degree from Loyola University in California.

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AN INTRODUCTION TO AUDIO / VIDEO BRIDGING (AVB), THE 1ST TSN PROFILE

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OUTLINE

History of AVB (Audio Video Bridging)

Problems to solve & their Solutions

A Profile vs. a Base Standard

Lessons Learned & AVB's Future

Summary

HISTORY OF AVB (AUDIO VIDEO BRIDGING)

AVB'S HISTORY & TARGET GOALS

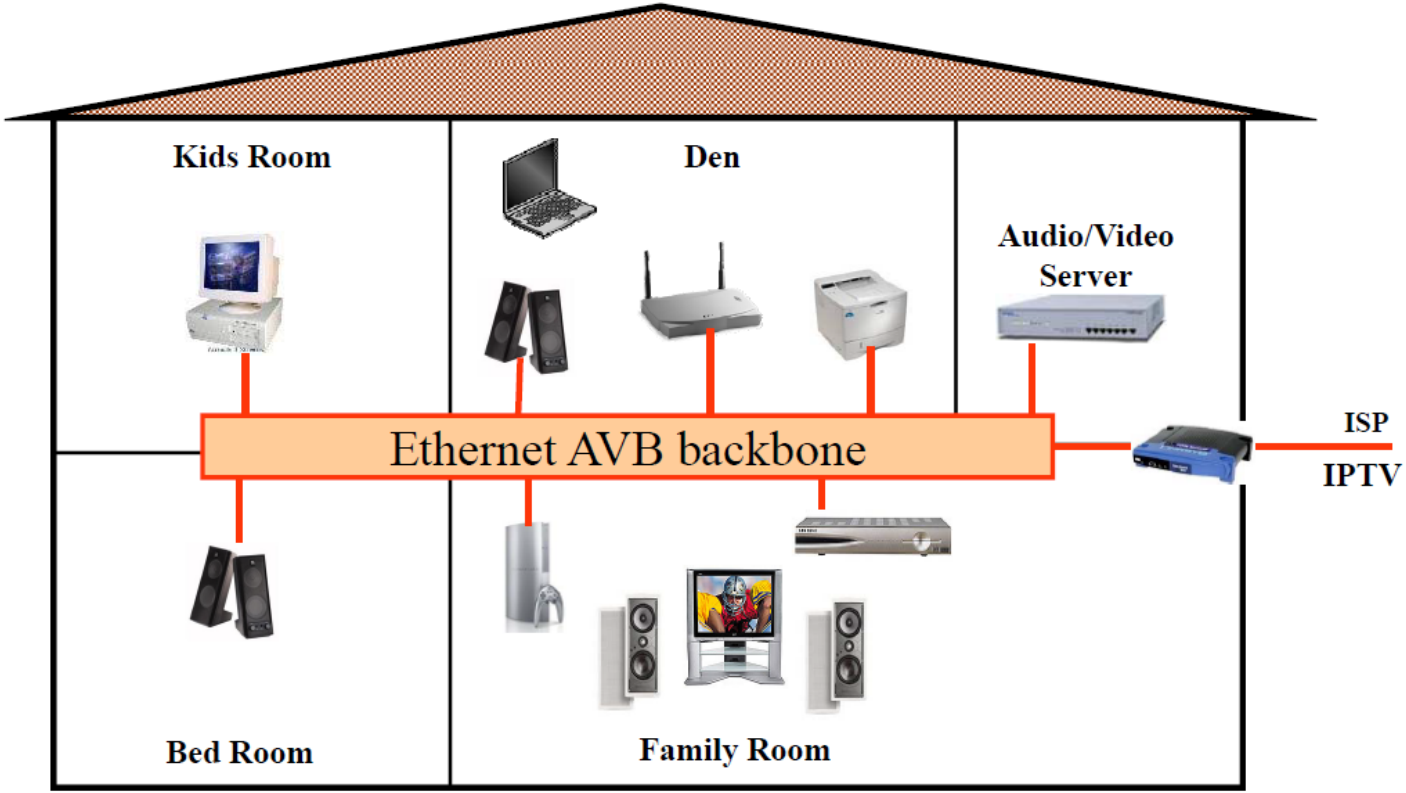
Audio Video Bridging (AVB) originally started as an IEEE 802.3 Study Group

- Called "Residential Ethernet"
- With the goal of **low-cost, plug-and-play, low-latency** audio & video transport
- The Study Group moved this work to 802.1 & the 802.1 AVB Task Group was formed

The work in the AVB Task Group

- Three target markets were seen: Residential, Pro Audio/Video, and Automotive
- Target AVB goals for a 7-hop (6 bridge spans) network using Fast Ethernet links were:
  - Synchronous play-back within 1 uSec between any two nodes (clock sync accuracy)
  - Source node to destination node maximum latency of 2 mSec (for Class A "real-time" flows)
    - Supports a musician/singer hearing the playback of their performance in "real-time"
  - Source node to destination node maximum latency of 50 mSec (for Class B "playback" flows)
    - Supports wireless speakers in a home entertainment system
  - Class A latency requires all Ethernet links, Class B supports up to two 802.11 WiFi link hops
  - Larger Network sizes are supported with graceful degradation of the target goals
    - Faster link speeds reduce latency or increase number of hops, & gets better sync accuracy
- AVB flows must work **without drops** while sharing same wires w/"best effort" flows

HOME NETWORK – AUDIO / VIDEO / GAMES – THE RESIDENTIAL VISION



Slide from: https://www.ieee802.org/1/files/public/docs2012/new-pannell-AVB-1722-for-8021-1205-v1.pdf

PRO AUDIO AND VIDEO

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See: ESPN Digital Center Ethernet AVB Case Study

Part 1:

https://www.digidescorp.com/espn-avb-case-study-part-1/

Part 2:

https://www.digidescorp.com/espn-avb-case-study-part-2/

And: https://avnu.org/specifications/ Avnu.org's Milan Spec

AUTOMOTIVE INFOTAINMENT NETWORK

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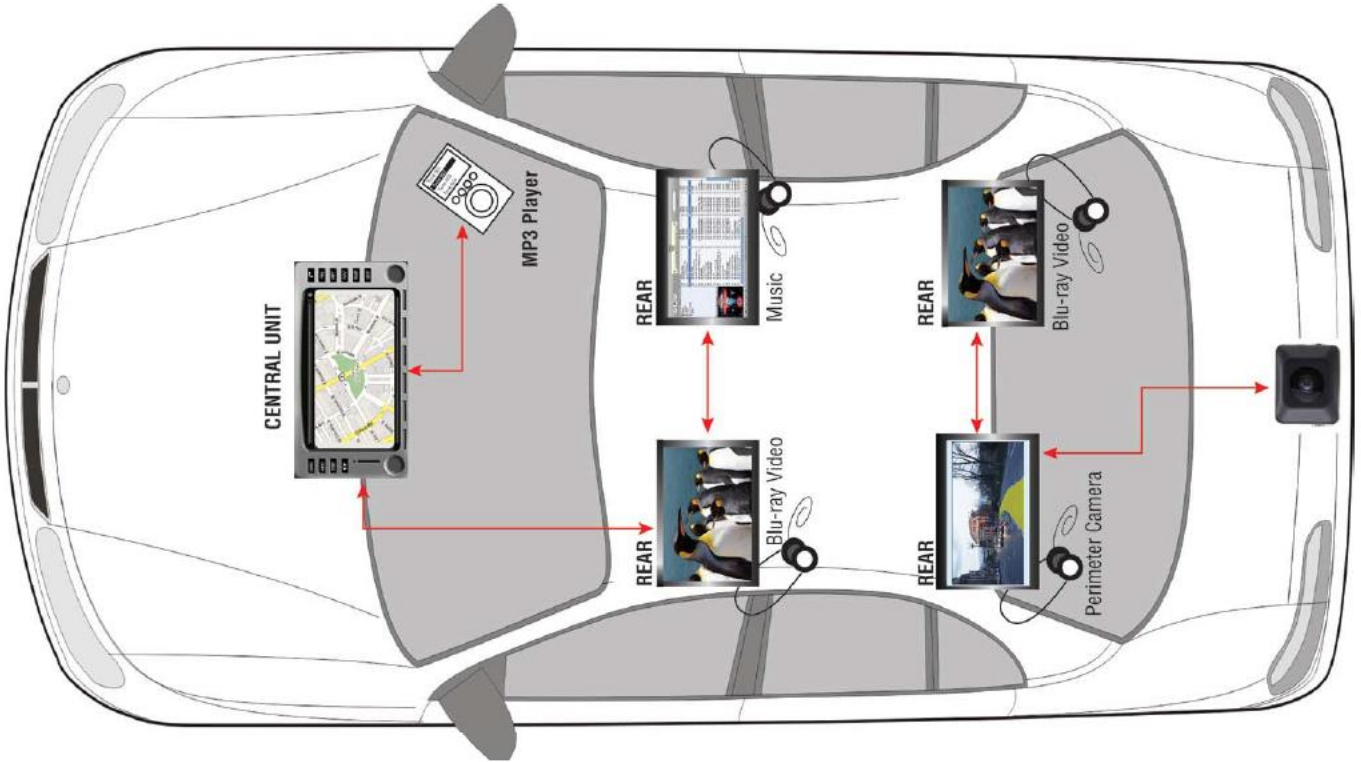

See: https://avnu.org/wp-content/uploads/2014/05/Auto-Ethernet-AVB-Func-Interop-Spec_v1.6.pdf

PROBLEMS TO SOLVE & THEIR SOLUTIONS

1: SYNCHRONIZED MEDIA CAPTURE AND/OR PLAYBACK

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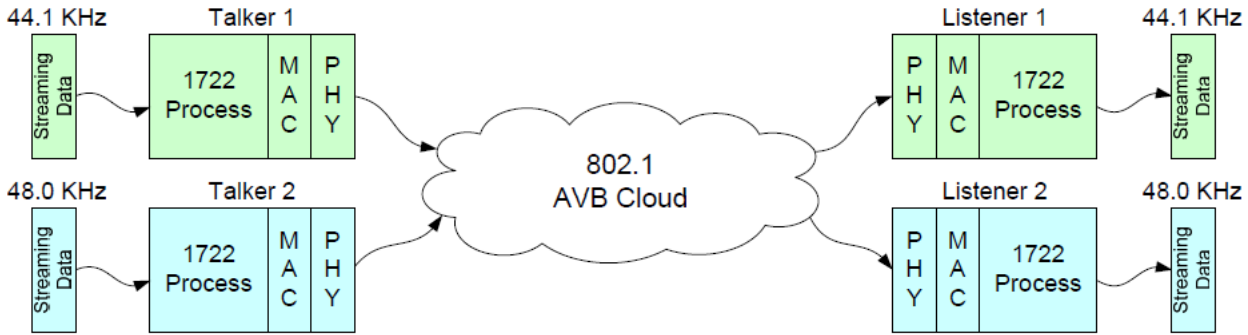
Benefits

- Synchronous playback on all receiving end nodes all the time
  - Regardless of the number of hops an end node is away from the source (as close nodes will get their packets earlier)
  - Includes simultaneous starting of a play back on all nodes, and synchronous “join-in” of newly connected nodes
- Multiple flows can have independent and asynchronous media clocks since gPTP is not the media clock
  - A flow’s media playback clock is derived from IEEE 1722 media timestamps as these are aligned to gPTP time

Solution Part 1: IEEE 1722-2011 (Transport Protocol for Time-Sensitive Applications)

- In AVB networks, gPTP is used as a common “time of day” between all the network’s nodes
  - It is used as a “ruler” by which media (audio samples or video pixels) are measured against – it is not the media clock!
- IEEE 1722 standardizes a frame format to transport “samples” along with their associated timestamp



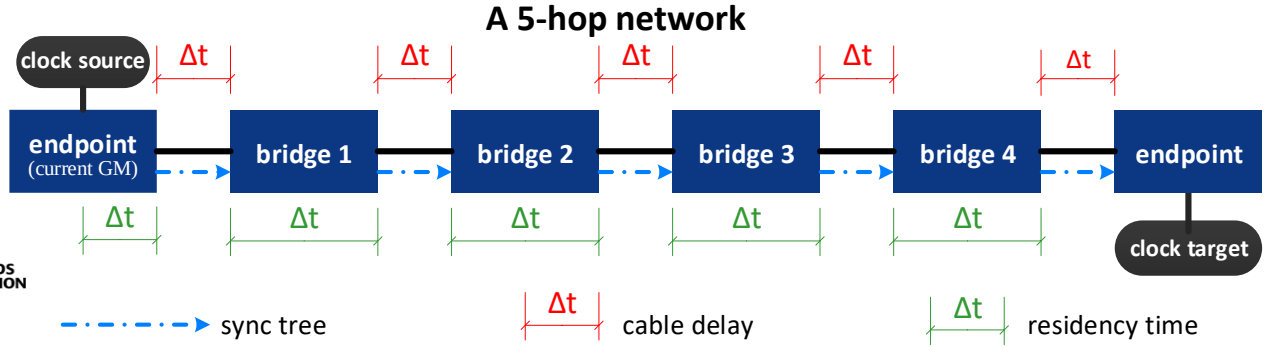
LOW-COST, PLUG-AND-PLAY NETWORK SYNCHRONIZATION - INCLUDING WIFI

Solution Part 2: IEEE 802.1AS-2011 (gPTP – generic Precise Timing Protocol)

- 802.1AS is the only profile of IEEE 1588 (PTP) that supports plug-and-play and supports 802.11 WiFi links
- Automatically finds the best network clock source (Grand Master or GM) and then builds the network's clock tree connecting the GM to all "time aware" nodes using its Best Master Clock Algorithm (BMCA)
- Corrects network clocks for PPM error and drift using software, so low-cost, non-temperature controlled, XTALs can be used – its Neighbor Rate Ratio is used to compensate for the PPM errors and drift

Performance

- Node to node accuracy was modeled with 7 hops of Fast Ethernet links with 40ns timestamp resolution
  - Gigabit links usually have 8ns timestamp resolution – 5 times better!
- The hop count is the distance away from the GM - with multiple branches off each bridge of the network, the network tree can support a huge number of "time aware" nodes - and added error is not linear w/more hops



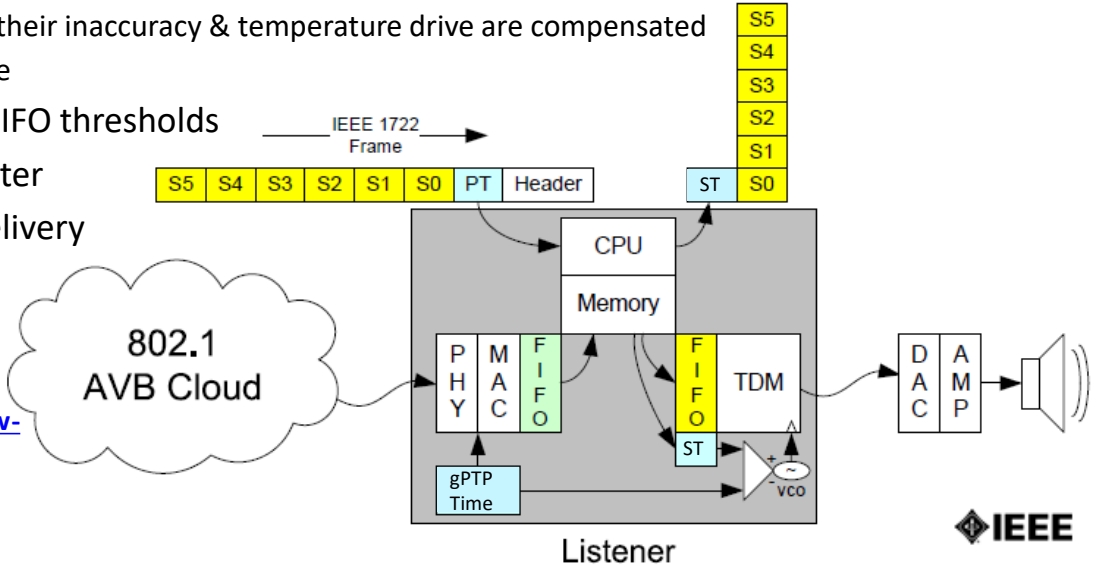
SYNCHRONIZED MEDIA CAPTURE AND/OR PLAYBACK – FUNCTIONAL MODEL

An IEEE 1722 frame contains a Presentation Time (PT) along with one or more samples

- The Presentation Time can be converted into a local Sample Time (ST) that the local logic understands

Samples with a Sample Time (ST) are compared to the current gPTP time at the interface (TDM) pins

- This comparison is used to start a new flow on all node at the same, designated time
- As the flow progresses, the observed error difference in this comparison is used to adjust the media clock
  - The local media clock adjustment compensates for source clock error and drift, and local clock error and drift
  - Low-cost clock sources can be used as their inaccuracy & temperature drive are compensated
  - The media clock is the VCO in the figure
- Media clock adjustments based on FIFO thresholds don't work with Ethernet's packet jitter
- This supports just-in-time sample delivery along with instantaneous delivery



See:
https://www.ieee802.org/1/files/public/docs2012/new-pannell-AVB-1722-for-8021-1205-v1.pdf

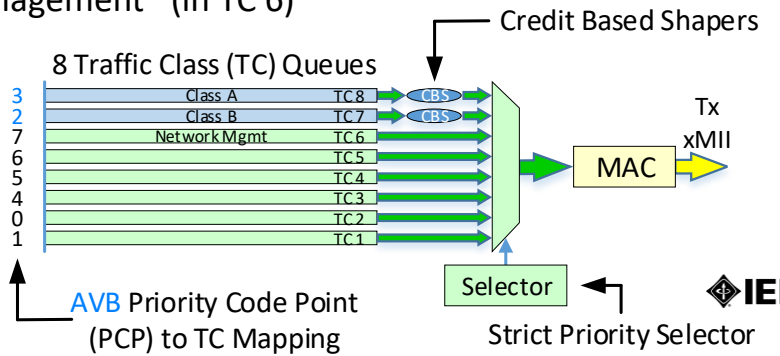
2: AVB FLOWS WITHOUT DROPS WHILE SHARING WIRES W/"BEST EFFORT"

Benefits

- End user experiences "instantaneous" / "real-time" start of new content
  - There is no need for 10+ second start-up delays for content buffering needed to support drops and re-transmission times
- Supports "real-time" applications as re-transmissions are not needed
  - This is the reason for the 2 mSec Class A plug-and-play Talker (source node) to Listener (destination node) network latency
  - Lower worst-case latencies below 2 mSec are possible for Engineered networks and/or with faster links (Gigabit or faster)
- Network wiring is saved if non-AVB traffic can use the same wires without upsetting the AVB flow
  - Sharing the wires between "real-time" and "best effort" flows was not possible with Ethernet before AVB

Solution Part 1: Strict Priorities – IEEE 802.1p-1998 and 802.1Q-2000

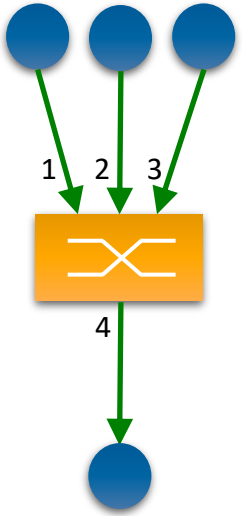
- Give AVB Class A & Class B traffic higher priority over non-AVB traffic flows (i.e., placed in Traffic Class 8 & 7)
- gPTP is NOT an AVB flow – it is part of "Network Management" (in TC 6)
- Ethernet Frame's Priority Code Points 3 & 2 are used
  - Shown mapped to TC8 and TC7 respectively
  - Allows previous priority-aware applications to co-exist
    - As PCP 3 & 2 were not being used



AVB FLOWS WITHOUT DROPS WHILE SHARING WIRES W/"BEST EFFORT"

Solution Part 2: Stream Reservation Protocol (SRP) – 802.1Qat-2010 (now 802.1Q clause 35)

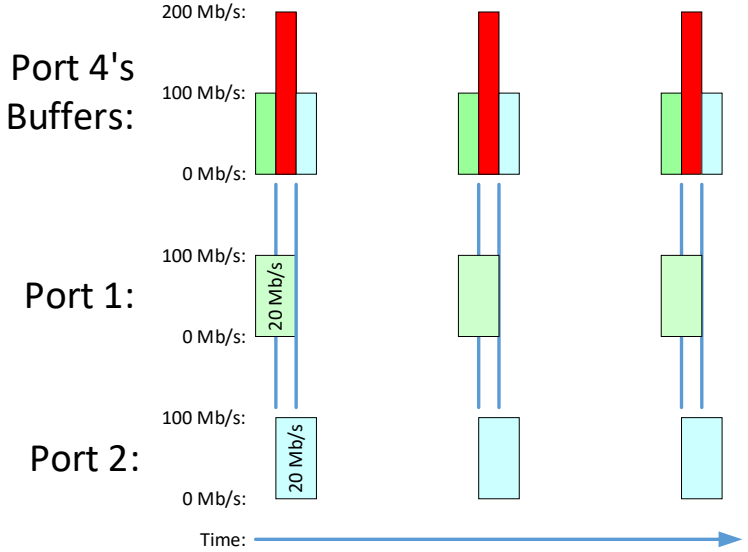
- Prevents packet drops for all "reserved" AVB flows
  - 99.99% of packet drops in Ethernet networks are due to congestion occurring on Bridges, as CRC errors are miniscule
- Congestion occurs when the flows going out a Bridge port exceed the capabilities of the Bridge port
  - For example: Three 40 Mb/s flows ingress Ports 1, 2 & 3 all trying to go out Port 4 which is 100 Mb/s
    - 3 x 40 = 120 Mb/s. This is a sustained oversubscription
  - SRP solves this for AVB flows by limiting their bandwidth to no more than 75% of any link's speed
    - Bandwidth allocated AVB flows are given a "reservation" and are allowed to start
    - AVB flow requests that exceed the limit are not given a "reservation" – like a telephone busy signal
  - Based upon these "reservations" Bridges also need to reserve enough Bridge memory for these flows
    - This "reserved" memory can only be used by flows that have a "reservation"
- Instantaneous congestion also occurs with slower flow rates – causing packet drops
  - For example: Three 20 Mb/s flows on Ports 1, 2 & 3 egressing out Port 4
    - 3 x 20 = 60 Mb/s. This "should" work and all flows will get an SRP "reservation"
    - But it doesn't work in practice, without another AVB standard, as Ports 1, 2 & 3 are also 100 Mb/s links
    - The solution for this case is discussed next…
- SRP does so much more than covered here – this is what SRP does to prevent packet drops

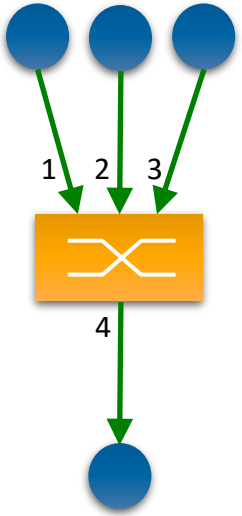


AVB FLOWS WITHOUT DROPS WHILE SHARING WIRES W/"BEST EFFORT"

Solution Part 3: Credit Based Shaper (CBS) – 802.1Qav-2009 (now 802.1Q clause 34)

- Talkers (CPUs) and Bridges like to burst accumulated packets out an Ethernet port as fast as they can
- So, a 20 Mb/s flow is instantaneously a 100 Mb/s burst of back-to-back packets on 100 Mb/s links
- Depending upon the size of the burst and the size of its overlap with another flow's burst, packets will drop
  - When bursts overlap, the bandwidth in vs. the bandwidth out is 2 to 1 or more
  - It doesn't take much overlap for all the buffers in the Bridge to be used up causing drops
  - This situation gets worse with increasing numbers of ingress ports mapped to the same egress port

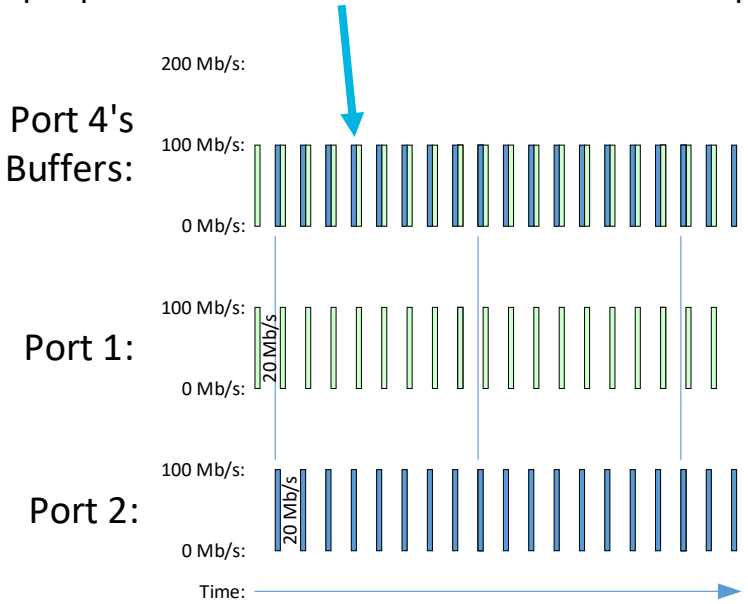


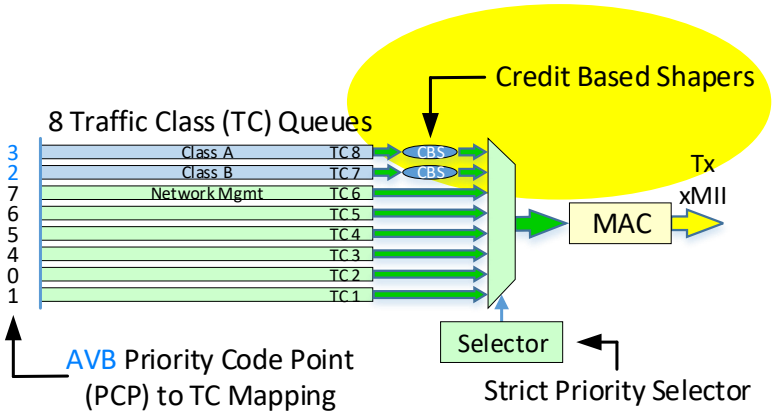


AVB FLOWS WITHOUT DROPS WHILE SHARING WIRES W/"BEST EFFORT"

Solution Part 3: Credit Based Shaper (CBS) – 802.1Qav-2009 (now 802.1Q clause 34)

- The Credit Based Shaper de-bursts back-to-back packets egressing Talkers and Bridges
  - This reduces the size of the possible overlaps such that Bridge buffers are not exhausted
- The figure below shows that Port 4's Buffers to do not expand and in fact are empty quite often
- The Credit Based Shaper is essential in Talkers (more on this next)
- In Bridges it helps space out the small burst that it receives helping the next Bridge

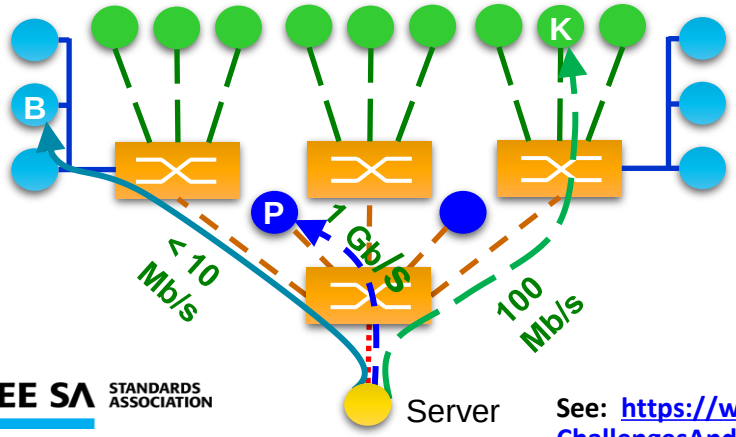


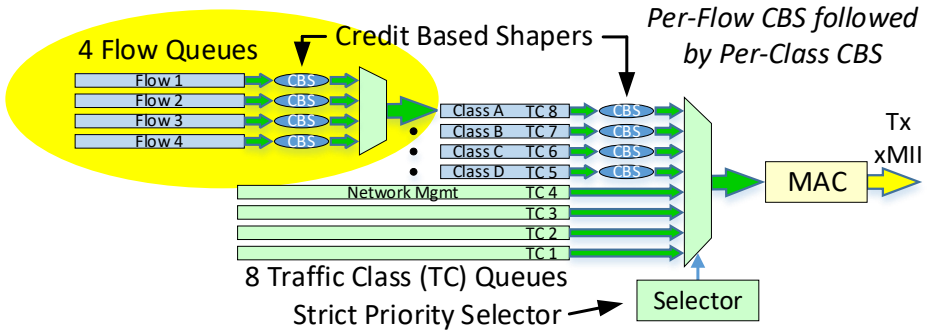


AVB FLOWS WITHOUT DROPS WHILE SHARING WIRES W/"BEST EFFORT"

Solution Part 4: Credit Based Shaper (CBS) in Talkers (required for fast to slow link data paths)

- The Credit Based Shaper adds specific requirements for end station Talkers:
  - Clause 5.20 b) of IEEE 802.1Q-2018: "Support the operation of the credit-based shaper algorithm (8.6.8.2) as the transmission selection algorithm used for frames transmitted for each stream associated with the SR class."
    - i.e., Talkers need to support per-flow egress shaping
  - This additional requirement for Talkers over Bridges, performs per-flow shaping (to limit each flow's transmission rate independently like TCP/IP does) followed by a per-class shaper (to de-burst each class's data – a common requirement for both Bridges & Talkers)
    - Note: CBS does not require network-wide time awareness, meaning it works without gPTP (IEEE 802.1AS)





See: https://www.ieee802.org/1/files/public/docs2021/dg-pannell-ChallengesAndSolutionsOfMixedDataRateEthernetNetworks-1221-v02.pdf

3: PLUG-AND-PLAY OPERATION

Benefits

- It just works – without the need to call IT or Network experts
  - Clearly this is a requirement for the Residential use case
  - But it also is a Pro Audio/Video use case, especially for traveling concert setups
  - Automotive is Engineered today, but some plug-and-play options are possible if needed in the future

Solutions:

- gPTP (IEEE 802.1AS) supports automatic plug-and-play operation – that was the only mode for AS-2011
- Stream Reservation Protocol (SRP) also supports automatic plug-and-play operation – but it needs some help
  - SRP will connect a Listener to a Talker reserving bandwidth & buffers, and configuring shapers, along the stream's path
  - But what Listener, Talker and stream? SRP needs to be told what to do
- IEEE 1722.1 completes the plug-and-play system, and it is called the AVB/TSN Discovery, Enumeration, Connection management & Control protocol (or ATDECC)
  - Discovery: Finds all the Talkers and Listeners on the network
  - Enumeration: Understands their capabilities (Audio/Video/Control – Source and/or Sync – Content)
  - Connection management: Operates on user input – For example: play a specific song on a specific set of speakers
    - This portion triggers SRP in the correct Talker and Listener(s)
  - Control: Operates on user input – For example: raise or lower the volume of the song

A PROFILE VS. A BASE STANDARD

AVB'S BASE STANDARDS VS. PROFILES

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IEEE 802.1's Base Standards and their Amendments are intended to support multiple use cases

- Thus, Base Standards have required functions ("shall") and optional functions ("may")

IEEE 802.1's Profiles and their Amendments are intended to support a specific use case

- Thus, Profiles can require functions that are optional in the Base Standards
- But Profiles cannot make a required functions in a Base Standard optional!

AVB is the 1st TSN Profile, and it is specified in IEEE 802.1BA

- In fact, the 802.1 TSN Task Group at the time was called the AVB Task Group
- But after AVB was completed and it was clear more use cases needed to be supported, the group changed its name to the TSN (Time Sensitive Networking) Task Group

AVB's Base Standards are:

- IEEE 802.1Qav: Forwarding & Queuing Enhancements for Time Sensitive Streams (Credit Based Shaper)
- IEEE 802.1Qat: Stream Reservation Protocol (SRP)
- IEEE 802.1AS: Timing and Synchronization (gPTP)
- IEEE 1722: Audio Video Transport Protocol (AVTP) – not an IEEE 802.1 standard but really a necessary part
- IEEE 1722.1: ATDECC – not an IEEE 802.1 standard but a necessary part if plug-and-play is needed

LESSONS LEARNED & AVB'S FUTURE

LESSONS LEARNED – MY OPINION

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IEEE 802.1AS's Low Cost, but accurate gPTP is a universal requirement for most use cases

- A lot of use cases see the value of the features & solutions 802.1 added in gPTP – seen in many TSN Profiles

AVB placed some requirements in the Base Standards that really needed to be Profile specific

- These are few, and are being worked on
  - These changes must be migrated first to the Profile(s) before they can be made optional in the Base Standard

IEEE 1722 and IEEE 1722.1 probably should have been done in 802.1

- At the time end-node only standards were not done in 802.1
  - It turns out 1722.1 is not just an end-node standard as it needs more information about the network
- In process, a portion of IEEE 1722 is being looked at to be "moved" to IEEE 802.1CQ

It was a good idea to get AVB "working" and then add features like redundancy, etc.

- We need to keep breaking down the work into small portions as progress is made faster this way
- Since "redundancy is in the eyes of the user" many new work items/improvements are expected

Should have translated the network use case requirement into per-hop parameters

- It was not clear to people that AVB can work over more than 7 hops – per hop #'s would have helped

AVB'S FUTURE

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Redundancy was added to IEEE 802.1AS-2020 (gPTP) and IEEE 802.1CB (for flows)

- IEEE 802.1AS-2020 was enhanced to better support Engineered (non-plug-and-play) applications
- IEEE 802.1ASdm is currently defining Hot Standby for gPTP

IEEE 1722-2011 was updated to IEEE 1722-2016 supporting command & control formats

- This is the Audio/Video/Control Transport Protocol
- Making this protocol's support truly TSN (i.e., more than just Audio & Video)
- IEEE 1722b is being worked on to add more video and control formats and expanded headers

IEEE 1722.1-2012 was updated to IEEE 1722.1-2021

- This is the Discovery/Enumeration/Connection & Control Protocol
- This work along with IEEE 1722b's work clearly shows there is continuing support for these AVB standards

New TSN Shapers beyond the Initial Credit Based Shaper

- The Credit Based Shaper is clearly working for users of AVB – including large installations
- And CBS's per-flow requirements for Talkers is needed regardless if alternate shapers are used in Bridges
  - For Fast to Slow data path links (see "Solution Part 4: Credit Base Shaper (CBS) in Talkers", above)

AVB'S FUTURE

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The Stream Reservation Protocol was enhanced to support non-plug-and-play applications

- Allows the concept of "SR" (Stream Reservation) without the "P" (the Protocol part)
- As shown, the "SR" portion is needed to support the configuration of "reservations"
- This work (IEEE 802.1Qcc-2018) supports boot-up ROM based reservations, so the Protocol is not needed
- Some improvement is still needed to support more SRP flows for large stream flow applications

IEEE 802.1Qci-2017 adds Policing

- A very useful feature for any use case

IEEE 802.1 Security

- Security is also a very useful feature for many use cases and this area too has had many enhancements

IEEE 802.1BA-2011 was updated to IEEE 802.1BA-2021

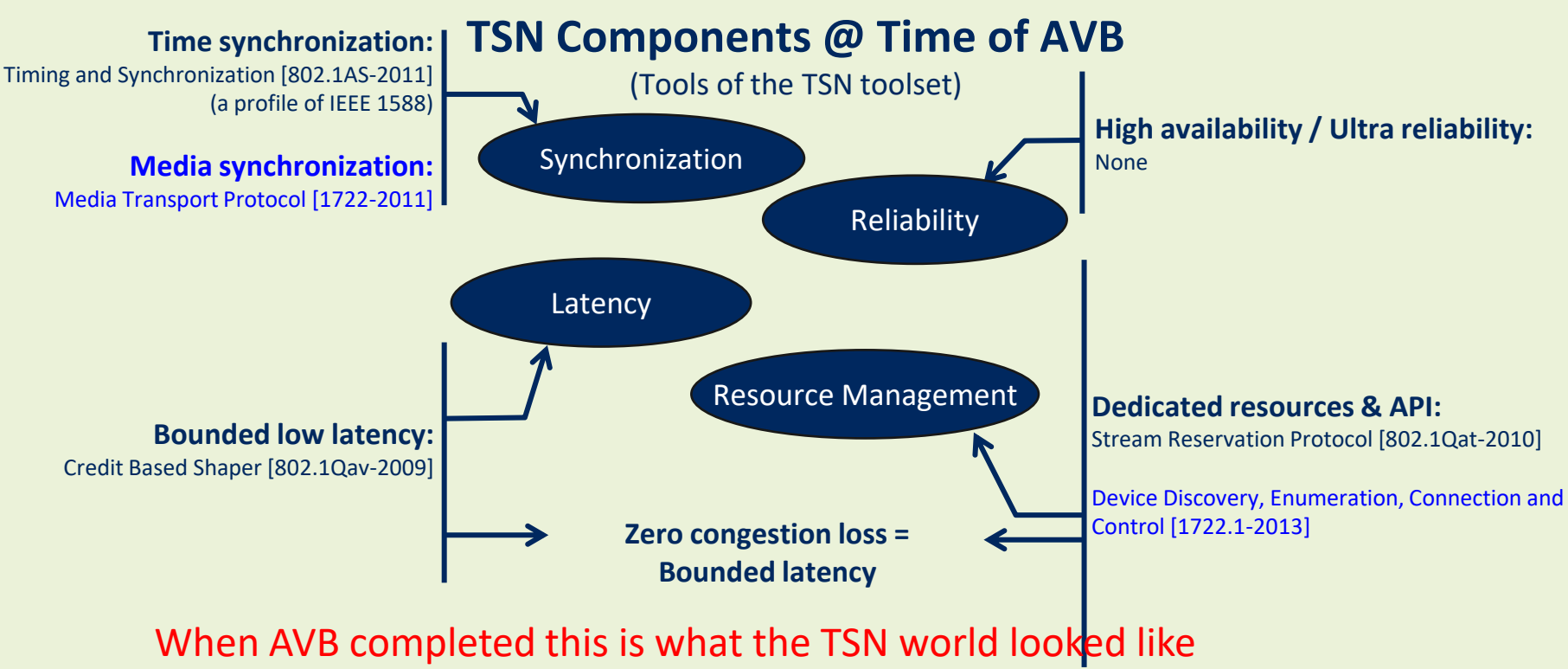
- This is the AVB Profile Specification
- There are discussions to start an amendment to this Profile to take advantage of the listed improvements

Clearly there are many more features AVB can support a future Profile Amendment!

SUMMARY

The AVB Time-Sensitive Networking (TSN) Profile

Audio Video Bridging
[802.1BA-2011 plus 1722]



When AVB completed this is what the TSN world looked like

TSN PROFILES

Now there are many TSN Profiles

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TSN Time-Sensitive Networking Powered by IL

Wide breadth of choices in IEEE 802 standards

Profiles define options in base standards as mandatory

A TSN Profile

- Narrows the focus ➔ ease interoperability and deployment
- Selects features, options, defaults, protocols, and procedures
- Describes how to build a network for a particular use
- Provides configuration guideline if needed

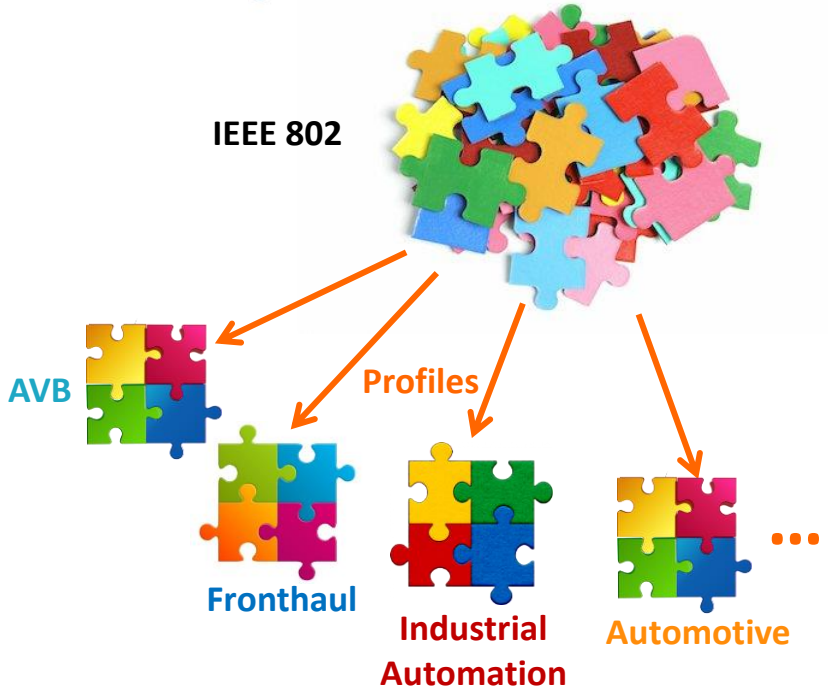
TSN profile standards:

AVB being the 1st

- IEEE Std 802.1BA Audio-Video Bridging (AVB) networks
- IEEE Std 802.1CM TSN for Fronthaul
- IEEE Std 802.1CMde Amendment on Sync enhancements

Ongoing TSN profile projects:

- IEC/IEEE P60802 TSN Profile for Industrial Automation
- IEEE P802.1DG TSN Profile for Automotive In-Vehicle Ethernet
- IEEE P802.1DF TSN Profile for Service Provider Networks
- IEEE P802.1DP TSN Profile for Aerospace



And more still in process

Time-Sensitive Networking (TSN) Profiles (Selection and Use of TSN tools)

Audio Video Bridging [802.1BA/Revision]	Fronthaul [802.1CM/de]	Industrial Automation [IEC/IEEE 60802]	Automotive In-Vehicle [P802.1DG]	Service Provider [P802.1DF]	Aerospace Onboard [IEEE P802.1DP / SAE AS6675]

TSN Components Today

(Tools of the TSN toolset)

Time synchronization:
Timing and Synchronization [802.1AS-2020]
(a profile of IEEE 1588)
Hot Standby [P802.1ASdm]
YANG [P802.1ASdn]
Inclusive Terminology [P802.1ASdr]
Support for 10BASE-T1S Links[P802.1ASds]

Media synchronization:
Media Transport Protocol [1722-2016]

Bounded low latency:
Credit Based Shaper [802.1Qav]
Frame Preemption [802.1Qbu & 802.3br]
Scheduled Traffic [802.1Qbv]
Cyclic Queuing and Forwarding [802.1Qch]
Asynchronous Traffic Shaping [802.1Qcr]
Shaper Parameter Settings [P802.1Qdq]
QoS Provisions [P802.1DC]

Synchronization

Reliability

Latency

Resource Management

Zero congestion loss = Bounded latency

High availability / Ultra reliability:
Frame Replication and Elimination [802.1CB]
Path Control and Reservation [802.1Qca]
Per-Stream Filtering and Policing [802.1Qci]
Reliability for Time Sync [802.1AS-2020]

Dedicated resources & API:
Stream Reservation Protocol [802.1Qat]
Link-local Registration Protocol [802.1CS]
TSN Configuration [802.1Qcc]
Foundational Bridge YANG [802.1Qcp]
YANG for CFM [P802.1Qcx]
YANG for LLDP [P802.1ABcu]
YANG for 802.1Qbv/Qbu/Qci [P802.1Qcw]
YANG & MIB for FRER [P802.1CBcv]
Extended Stream Identification [P802.1CBdb]
Resource Allocation Protocol [P802.1Qdd]
TSN Configuration Enhancements [P802.1Qdj]
LLDPv2 for Multiframe Data Units [P802.1ABdh]
Multicast and Local Address Assignment [P802.1CQ]
Device Discovery, Enumeration, Connection and Control [1722.1-2021]

Note: A 'P' in front of '802.1' indicates an ongoing Project.

The TSN world today!

SUMMARY OF AVB

FOUNDATIONAL TECHNOLOGIES

AVB Started Time Sensitive Networking (TSN)

- And just because AVB is “old” (over 10 years!) does not mean it is outdated
- Is Ethernet is outdated because it is over 40 years old – I don’t think so
- The foundation work and techniques of AVB are just are relevant today as in AVB’s beginning

While the AVB Profile is a plug-and-play use case, Engineered audio/video can be parts of other Profiles

- Using the same concepts, but replacing some components like using “SR” instead of “SRP”

AVB, TSN, Bridging and Ethernet work will never be done

- “Good standards get added to, bad standards die”
- All of the original AVB’s standards have been “added to” and many quite recently

Is a Profile or Base Standard missing something you need?

- Come help by attending IEEE 802.1
- IEEE standards are created by people like you, where IEEE is not their “day job”

UPCOMING WEBINARS

Fronthaul – IEEE Std 802.1CM (8 September 2022)
Industrial Automation – IEC/IEEE 60802
Automotive Ethernet – IEEE P802.1DG
Aerospace Ethernet – IEEE P802.1DP / SAE AS6675

THANK YOU

DON PANNELL

Fellow
Automotive Ethernet Networking
NXP Semiconductors
ieee.donp@gmail.com

SRI CHANDRASEKARAN

Senior Director | Standards & Technology
Practice Lead | Foundational Technology Practice
IEEE Standards Association
sri.chandra@ieee.org

IEEE 802.1: http://www.ieee802.org/1

Foundational Technologies: https://standards.ieee.org/practices/foundational/index.html

Standards Home Page: standards.ieee.org

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