A Study of In-Vehicular-Network by New IP

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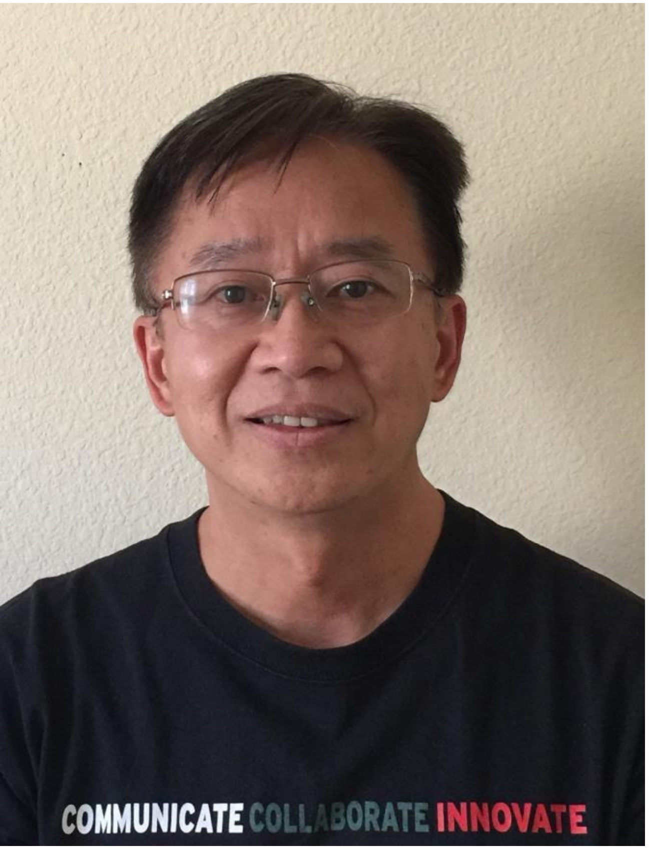


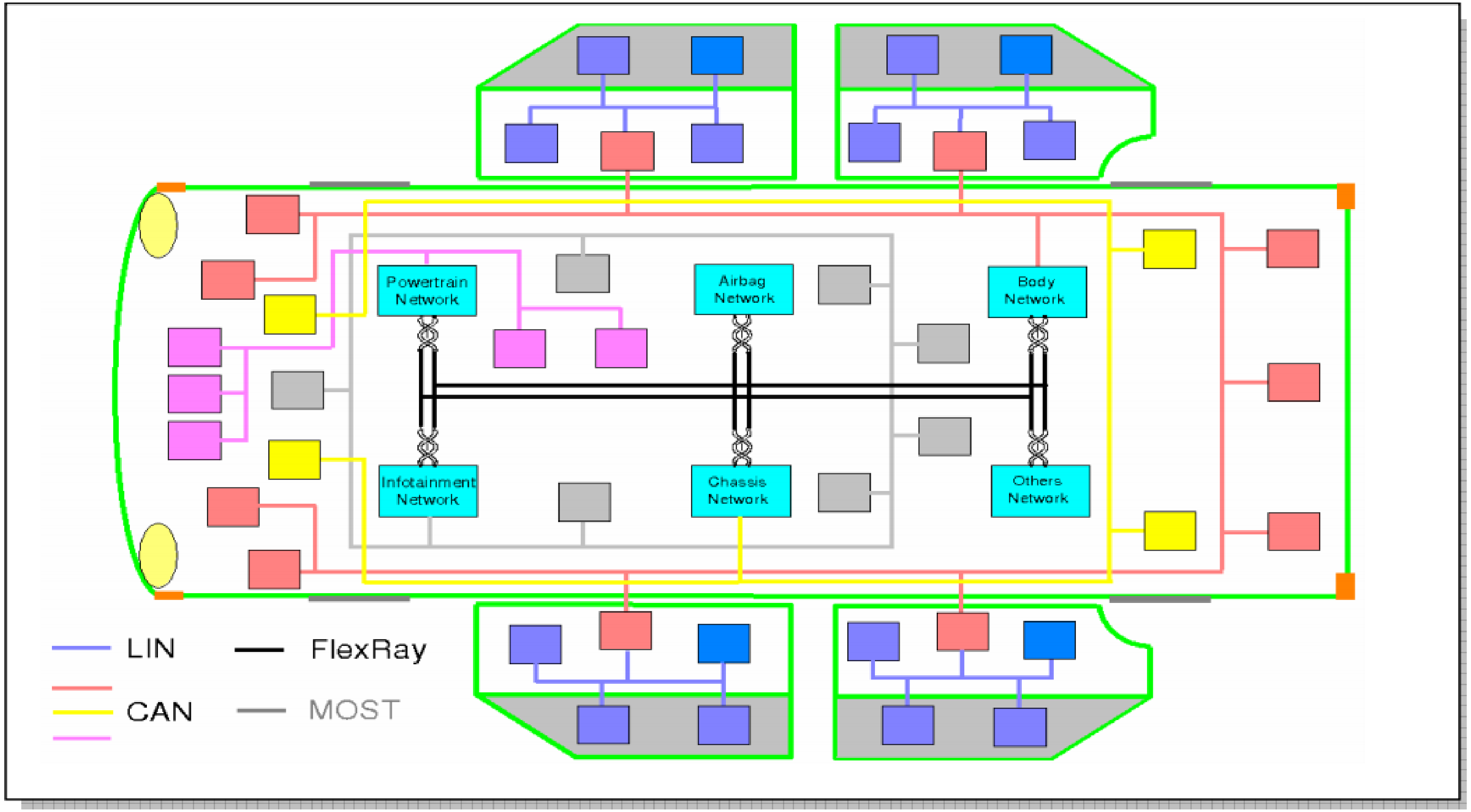
- Professional Experience
  - Distinguished Engineer, Futurewei Technologies (2019-Present)
  - Principal Engineer, Huawei U.S.A (2011-2019)
  - Technical Leader, Cisco Systems, U.S.A (1999-2011)
  - Software Engineer, Newbridge Network, Canada (1996-1999)
- Activities and publications
  - Work for “Focus Group on Technologies for Network 2030” in ITU, 2019
    - Member to write “Towards a New Internet for the Year 2030 and Beyond”
    - Member of SubG1: “Network 2030 Architecture Framework for FG-NET2030”,
  - Rapporteur of ETSI NGP “Network Layer Multi-Path” WI, 2018
  - Rapporteur of ETSI NGP “New Transport Technology” WI, 2017
  - IEEE WCNC 2020 - “New IP Enabled In-Band Signaling for Accurate Latency Guarantee Service”
  - EuCNC 2020 - “In-Network Knowledge Reasoning with New IP”,
  - IEEE INFOCOMM 2020 Workshop on NewIP – “A Framework for Bandwidth and Latency Guaranteed Service in New IP Network”,
  - “Support Precise Latency for Network Based AR/VR Applications with New IP”, Proceedings of the 13th EAI International Conference on Mobile Multimedia Communications, Mobimedia 2020,
  - IEEE WOCC 2018 – “Flow-Level QoS Assurance via IPv6 In-Band Signaling”
  - AFIN 2018, The Tenth International Conference on Advances in Future Internet – “A New Congestion Control Algorithm for Bandwidth Guaranteed Networks”
  - More than 20 USA Patents

Agenda

- **Current Car vs Future Car**
- IVN Introduction and Requirement Analysis
- New IP Introduction
- New IP based New IVN Solution
- Latency Estimation
- Experiments

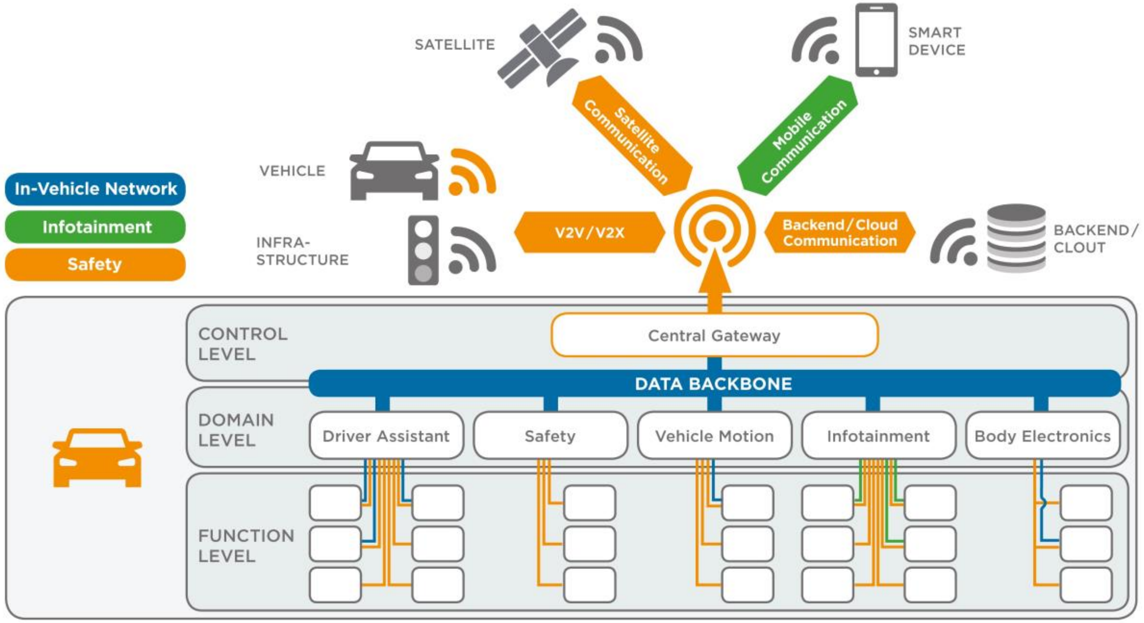
Current Car: ECU+IVN (LIN, CAN, FLexRay, MOST)

Tesla: 65 (Processors Analysis and Count – TeslaTap)
As of 2019, A single modern luxury vehicle now can integrate as many as 150 ECUs (https://www.eenewsautomotive.com/news/number-automotive-ecus-continues-rise)

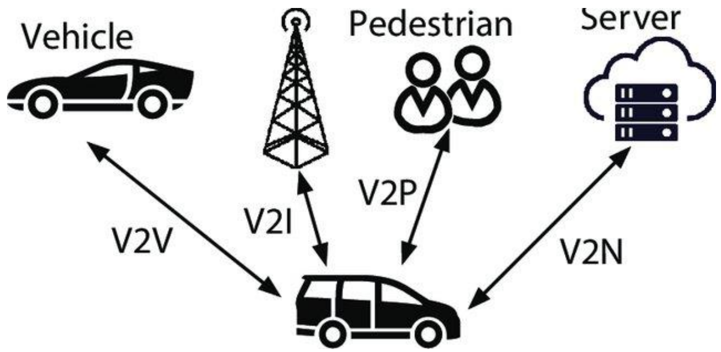


Future Car – Autonomous, Remote Control

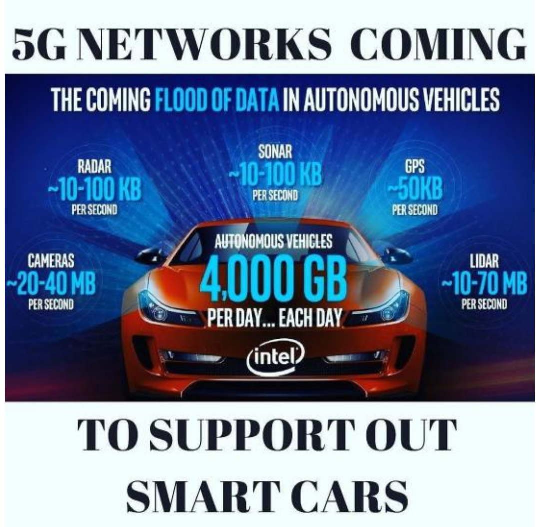
- Power (EV), Networking (V2X), Lidar, Radar, Many sensors
- Software Driven
- Huge data exchanging with cloud or internally



Source: "6 Key Connectivity Requirements of Autonomous Driving" https://spectrum.ieee.org/transportation/advanced-cars/6-key-connectivity-requirements-of-autonomous-driving



•**Source:** "An Overview of 3GPP Cellular Vehicle-to-Everything Standards". November 2017. GetMobile Mobile Computing and Communications 21(3):19-25



https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/#gs.3t5vyj

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Legacy Protocols Details

Table 1. Comparison of different communication protocols in the vehicle.

	LIN	CAN	ByteFlight	TTCAN	FlexRay	MOST	TTP/C
General Description	low-speed low-cost	low-cost simple twisted pair widely used	hybrid	low cost twisted pair hybrid	twister pair or optical fiber time/event triggered.	cost-effective data-efficient	time triggered twister pair or optical fiber
Type	class A	class B class C	class D	class C	class D	class D	Class D
Adapted for	low-level subnets	soft real-time	real-time	soft real-time x-by-wire	hard real-time x-by-wire	multimedia	soft real-time x-by-wire
Network bandwidth	20kbps	1Mbps	10Mbps	1Mbps	10Mbps	25Mbps	25Mbps
Architecture	single-master	multi-master		multi-master	multi-master	multi-master	
Transfer mode	synchronous	asynchronous		synchronous asynchronous	synchronous asynchronous	synchronous asynchronous	synchronous asynchronous
Access control	polling	CSMA	FTDMA	TDMA	TDMA		TDMA
Physical layer	single-wire	dual-wire	optical fiber	dual-wire	optical fiber dual-wire	optical fiber	optical fiber dual-wire
Network topology	bus	bus star	star	bus star	bus star	ring star	bus star

Example - FlexRay

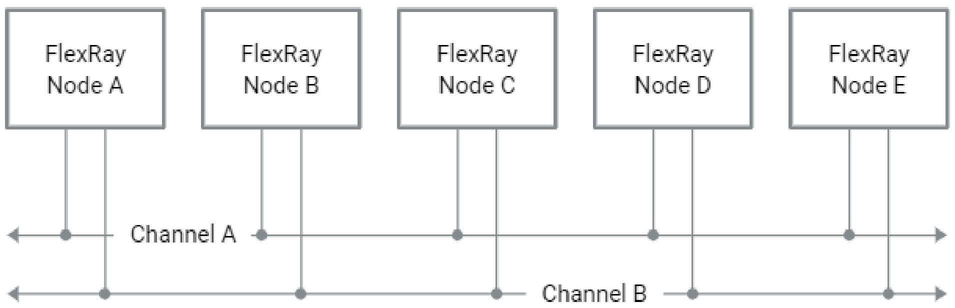
FlexRay Bus Access

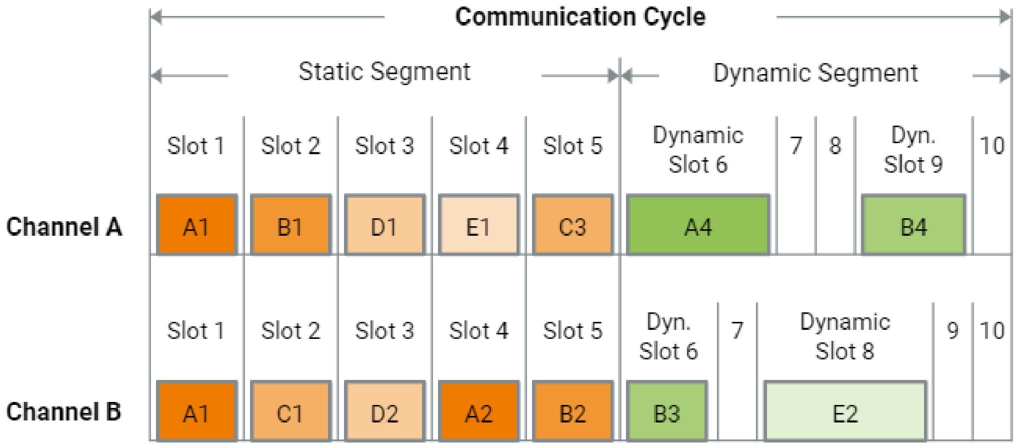
Demo Cluster

Communication Schedule

	Slot	Node	Frame	Channel	Event
Static Segment	1	Node A	A1	A	
			A1	B	
	2	Node B	B1	A	
		Node C	C1	B	
	3	Node D	D1	A	
			D2	B	
	4	Node E	E1	A	
		Node A	A2	B	
	5	Node C	C3	A	
		Node B	B2	B	
Dynamic Segment	6	Node A	A4	A	⚡
		Node B	B3	B	⚡
	7	Node C	C4	A	
		Node D	D3	B	
	8	Node D	D3	A	
		Node E	E2	B	⚡
	9	Node B	B4	A	⚡
		Node A	A5	B	
	10	Node E	E3	A	
		Node C	C5	B	

FlexRay Cluster





Latest Industry proposals - TSN

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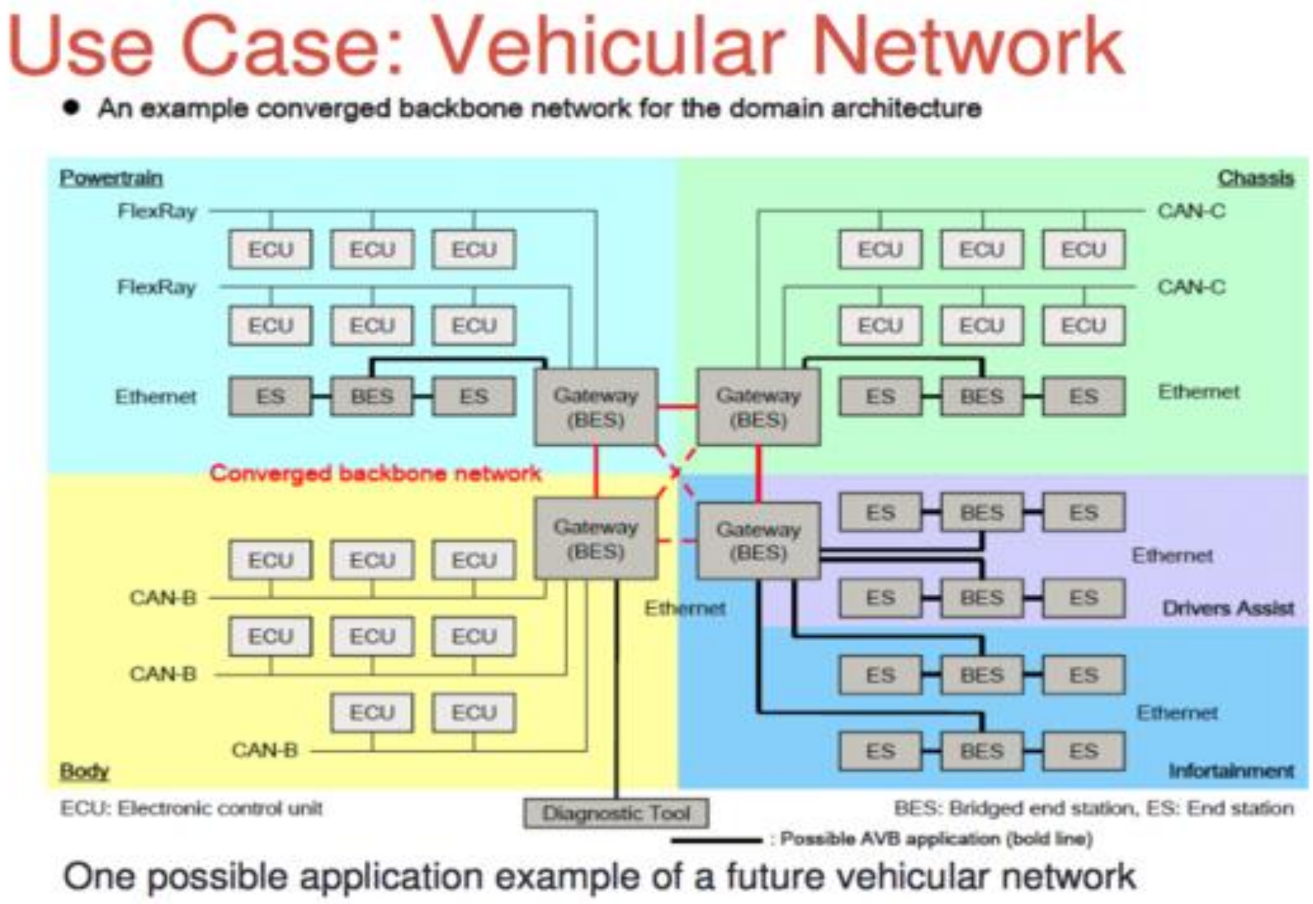
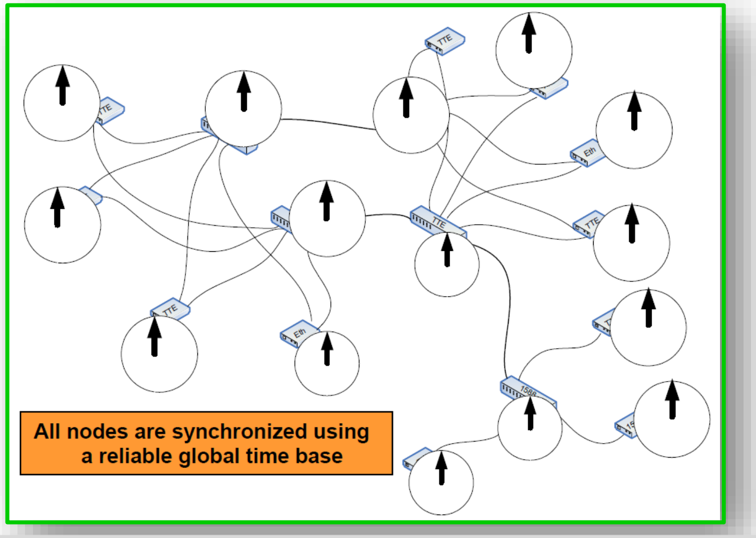
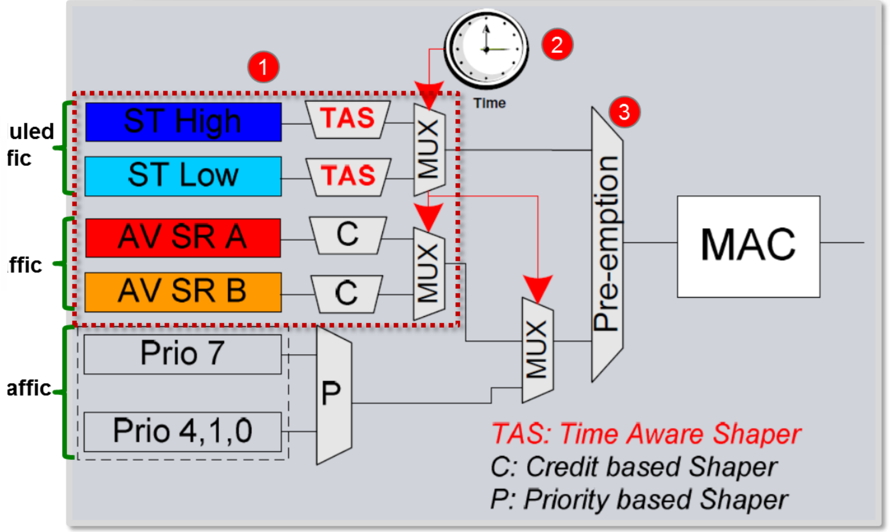


Source: IEEE 802.1 AVB TG presentation

Clock Synchronized Network



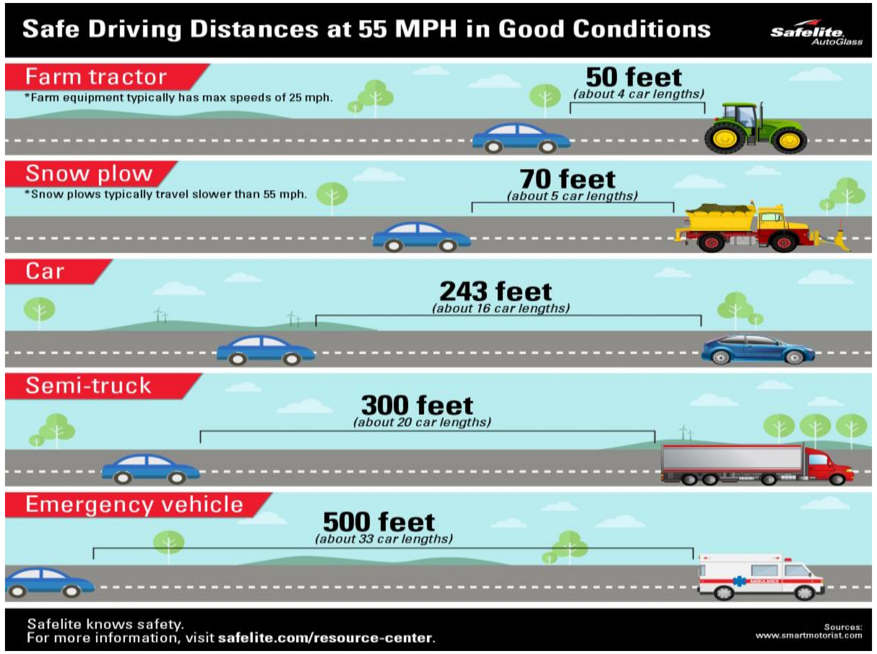


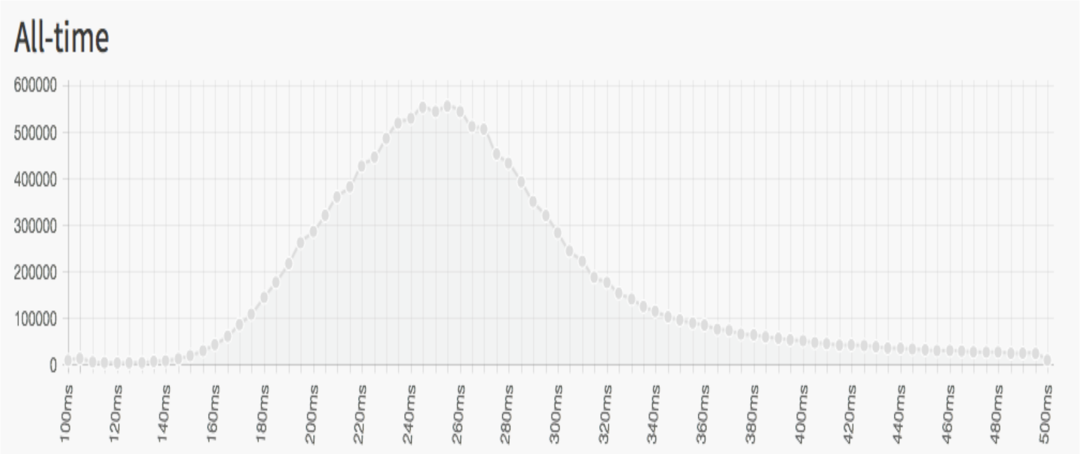
Latency requirement for IVN

- No standard yet
- From the driving safety distance:
  - 55MPH/50FT: 0.613s; 110MPH/50FT: 0.306s
- From Human reaction time: 250ms
- 10us was mentioned in paper: https://ieeexplore.ieee.org/document/8315204, but it does not define it. It should be E2E latency for network perspective;
- Use the fastest FlexRay as example,
  - For minimum FlexRay pack size (9bytes), the serialization latency is 9*8/10M = 7.2us;
  - For max Flexray pack size (262bytes), the serialization latency is 262*8/10M = 209us
- Also use FlexRay's cycle to predict, For real-time perspective, if there is any sporadic msg needs to be sent over FlexRay, the max delay by FlexRay is one cycle (about 1ms)
- On paper: https://ieeexplore.ieee.org/document/5981915

Table 2: Application constraints [9]

Priority Value	Traffic Type	Max. End-to-End Delay [ms]
3	Control	≤ 10 [16, 5]
2	Driver Assistance CAM	≤ 45 [5, 17]
1	Navigation	≤ 100
0	Multimedia	≤ 150 [18]





So, 1ms E2E delay for any p2p IVN communication is good enough!

https://www.pubnub.com/blog/how-fast-is-realtime-human-perception-and-technology/

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New IP – New Internet Protocol

- For the future Internet

NewIP Addr	NewIP Contract	User Payload

Variable length and heterogeneous address

New Features
- Service oriented routing
- Interconnect heterogeneous network
- Dynamic and auditable anonymous IP and ID
- Decentralized ID-based Key
- Authenticity based on minimum trust model
- Joint Inter-AS auditing and attack prevent

Advantages
- No more address type and size issue in the future
- Balanced privacy and security
- Balanced network sovereignty and openness
- Guaranteed integrity and confidentiality
- Guaranteed E2E security
- Routing is more than achievability

Contract and Meta Data

New Features
- Guaranteed E2E service for different QoS Metrics
- Improved user-network interface
- User-defined network behavior
- Ultra-high network throughput
- Concurrent multipath network support
- Network coding-based flow control
- New transport protocol stack

Advantages
- More service directly access-able to end user APP
- APP is aware the network state and service and select on-demand
- True E2E uRLLC for 5G and beyond
- Industry control can be over Internet
- Congestion free and lossless to critical communication

New IP for network side ≈ 5G NR for radio side
Similar approach to solve similar problem

	5G	Future Internet (5G and beyond)
Purpose and Requirements	eMBB mMTC uRLLC	Ultra high through put All things connected High Precision Communication
Solutions	New Radio (5G NR) + (SBA)	New IP
Technologies	New spectrum, MIMO New protocol stack at UE 5G NR QoS Grant Free Dynamic Scheduling	Flexible addressing Network Layer Multiple path New protocol stack at host and UE In-band signaling New queuing and scheduling Qualitative communication Network programmability Intrinsic Security Automation and autonomous networking

True E2E uRLLC = 5G+New IP

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Our Proposals – New IP based In-Vehicle Network

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- Visions:
  - The number of sensors, MCU and bandwidth grow fast
  - All APP are IP based
  - More and more in-vehicle data exchange:
    - control, monitoring, entertainments
  - More and more communication between vehicles, between vehicle and cloud
    - Tele-driving, Self-driving
  - The services are different,
    - Control data requires stringent or very short latency
    - Control data not only in vehicle, but also from cloud
- Why New IP
  - Advantages over Legacy protocol and Ethernet in different aspects: Topology, Link Efficiency, End device, etc
  - Easier APP development
  - Easier V2X integration
  - Backward compatible
  - Provide different service for different scenarios.
    - In-Vehicle
    - X-car
    - Car and cloud
    - End-to-End

Four types of services for IVN

Service Type	Bandwidth	Latency	Jitter	Packet Loss	Use case
On-time (for Scheduled Traffic)	CIR Provided by APP is guaranteed by network	Most precise, Network guarantees E2E bounded latency	Approximately zero	Approximately Zero • m-path to prevent drop due to physical failure • Congestion-free • Lossless (due to queuing)	Synchronous communication: Critical sensor and control data
In-time (for Real-time Traffic)	CIR Provided by APP is guaranteed by network	Minimized, Network guarantees E2E bounded latency	½ of E2E bounded latency	Minimized • Congestion-free • Lossless (due to queuing) • Only drop due to physical failure	Asynchronous communication: Critical sensor and control data
Bandwidth Guaranteed (Bandwidth sensitive, but not time critical)	CIR Provided by APP is guaranteed by network Could reach PIR	Less important	Less important	Don't care	Un-critical data Some Infotainment data
Best Effort	Don't care	Don't care	Don't care	Don't care	Other data

Scheduled Traffic: Data size, data start time, data rate are fixed, used for critical sensor data and control in polling mechanism
Real-Time Traffic: Data size and rate are fixed, but when the data starts is unknow, used for urgent sensor data change that polling mechanism did not catch.

NewIP Based In-Vehicle Network

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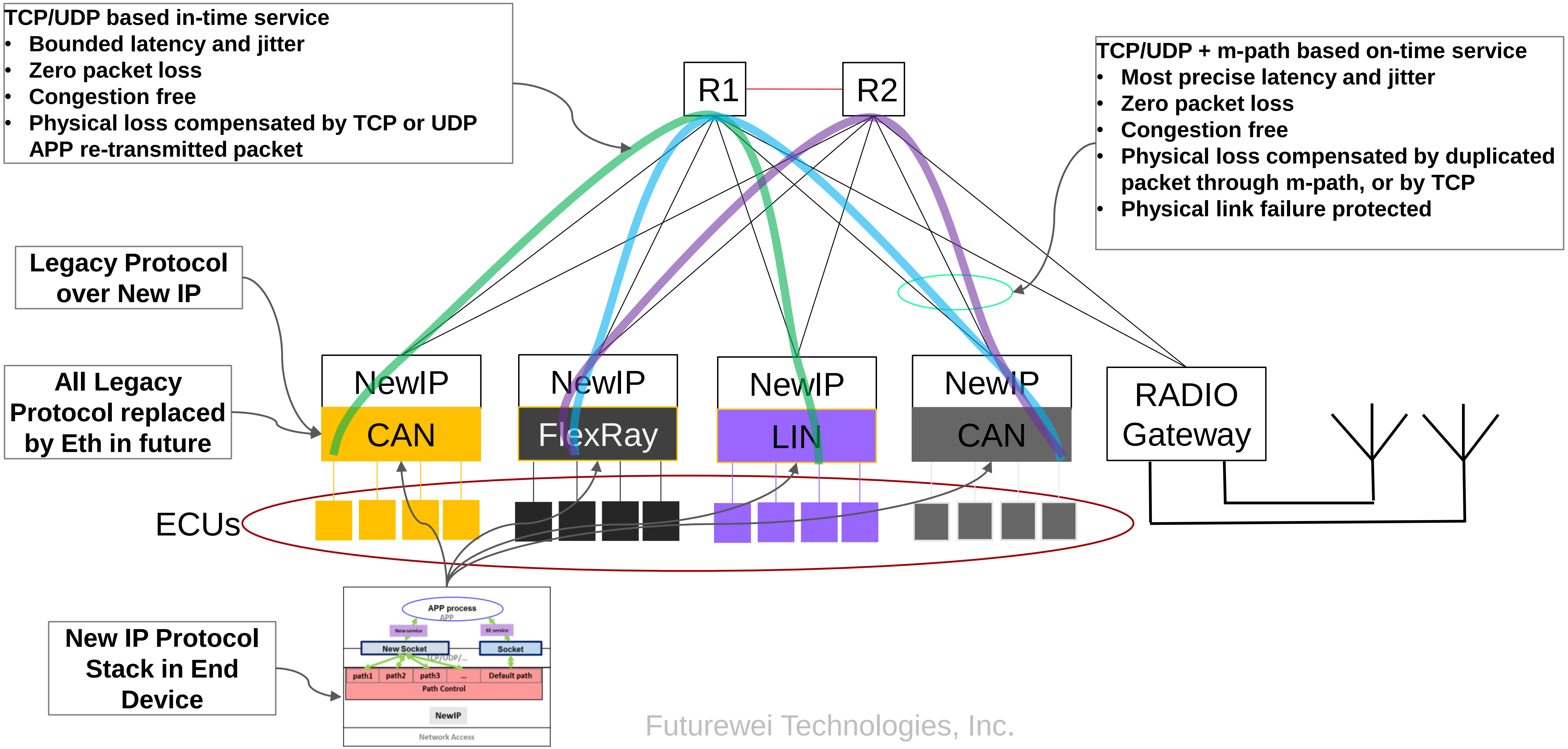
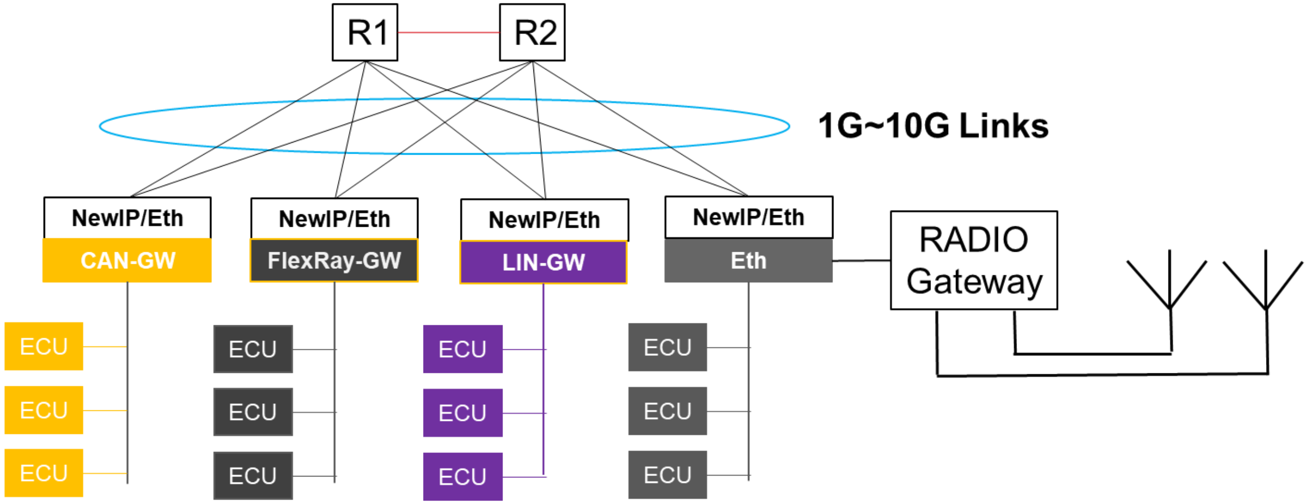
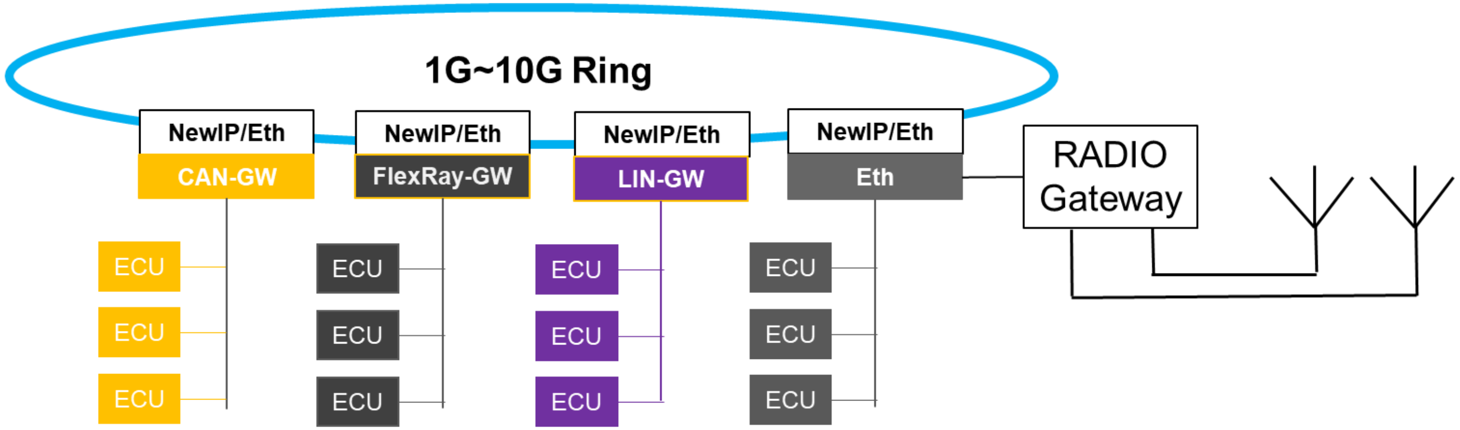


NewIP Based In-Vehicle Network topo

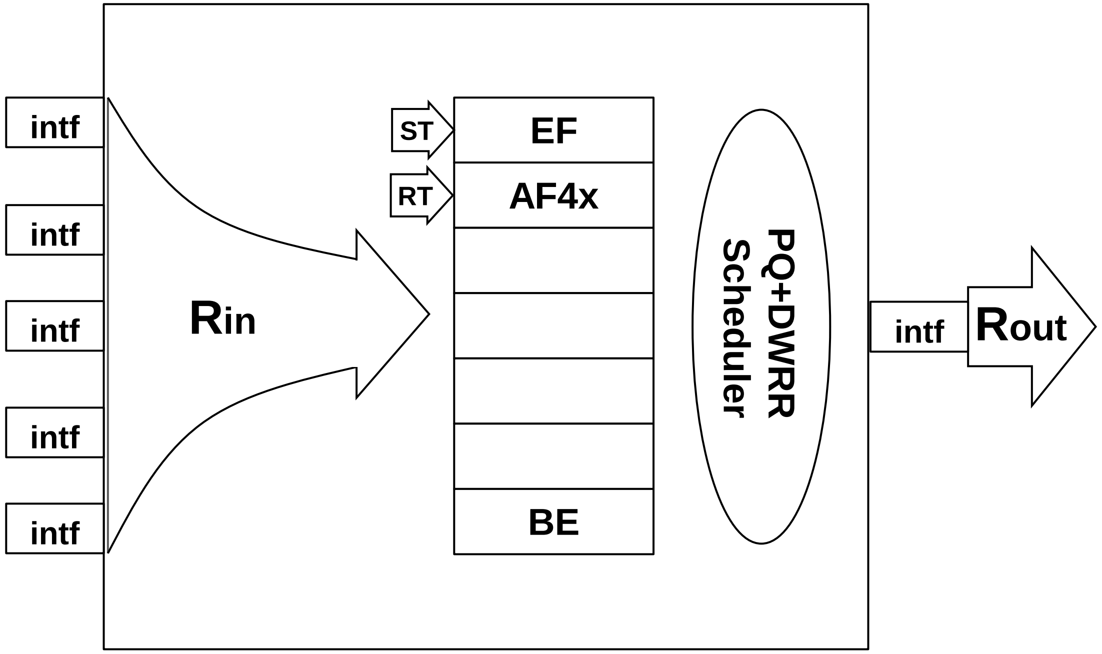


There will be at most two hops between IP and any other protocol communication

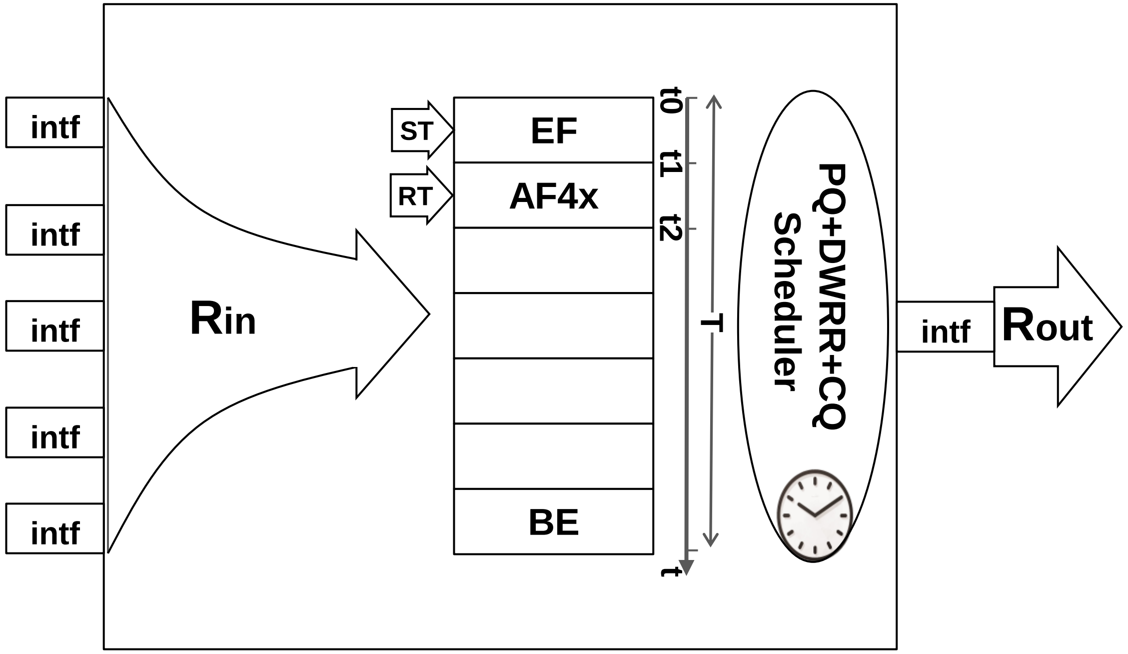


There will be at most two hops between IP and any other protocol communication

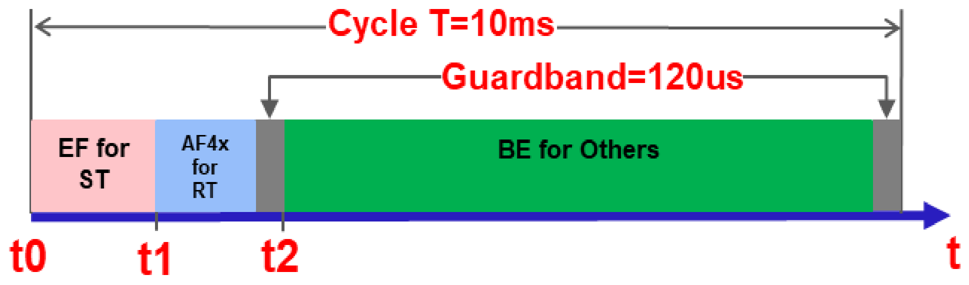
Class Based PQ and its Variation



Asynchronous Solution



Synchronous Solution



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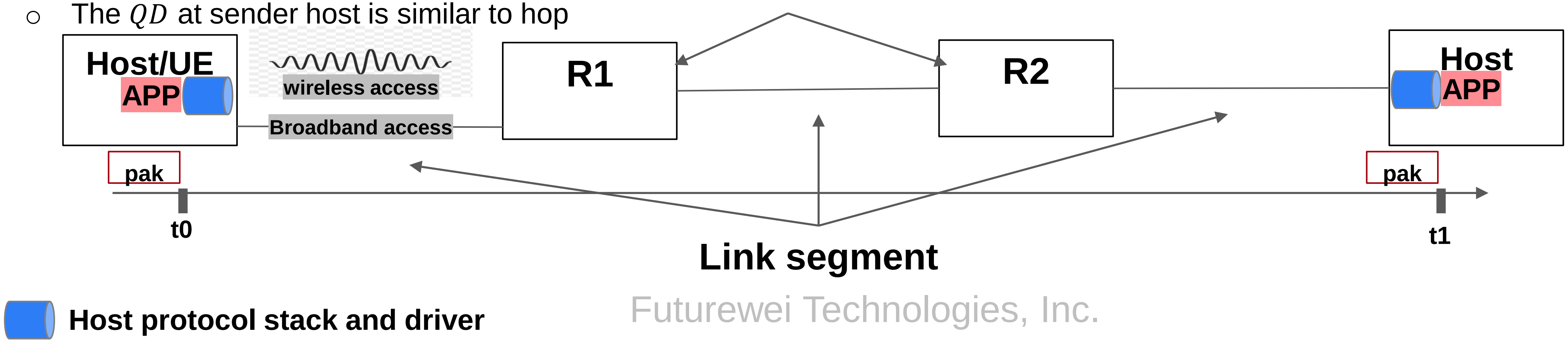
E2E Delay Estimation

- APP E2E delay $D_{e2e}^{LGS} = RD + PD + \sum_{i=1}^{n}(OD_i^{LGS} + QD_i^{LGS}) + \sum_{s=1}^{m} SD_s^{LGS} + RTD = t1 - t0$
    - t0: the time a pack is starting to be leaving the sender's APP process
    - t1: the time a pack is starting to be received at receiver's APP process
    - RD: Radio delay occurred in radio access, or Air Latency
    - PD: Propagation delay
    - ODi : The other delays (pack process, deque, decap, lookup, switch, L2-rewrite, encap, etc) at the i-th hop and host. If underlayer uses bus, hub, extra L2 delay should be considered as other delay.
    - QDi: The queuing delay at the i-th hop and sender host (UE)
    - SDs: The serialization delay at the s-th link segment (apply to both fixed and radio links), it is related to the packet size and link rate: $SD_S^{LGS} = L^{LGS}/R_S$
    - RTD: Retransmission Delay when there is packet loss, Caused by packet loss 1) physical fault or failure in media 2) congestion and queue overflow
- Note
    - The OD are usually and relatively fixed, it is dependent on HW; OD at host are delays caused by pack process, task switch, etc
    - The QD at sender host is similar to hop



Per Queue Delay Estimation for different solutions

- APP E2E delay $D_{e2e}^{LGS} = RD + PD + \sum_{i=1}^{n}(OD_i^{LGS} + QD_i^{LGS}) + \sum_{s=1}^{m} SD_s^{LGS} + RTD = t1 - t0$
- Asynchronous Solution:

The maximum packet number in EF Q: $N_{max}^{EF} = \lceil R_{in}^{EF} / R_{out} * (L_{max}^{LOW} / L_{max}^{EF} + 1) + 1 \rceil$

The maximum latency for EF Q: $D_{max}^{EF} = N_{max}^{EF} * L^{EF} * 8 / R_{out}$

The maximum packet number in $AF4x$ Q:

$$N_{max}^{AF4x} = \lceil R_{in}^{EF} / R_{out} * (L_{max}^{LOW} / L_{max}^{EF} + 1) + 1 \rceil + \lceil (R_{in}^{AF4x} / R_{out} * (L_{max}^{LOW} / L_{max}^{AF4x} + 1) + 1) * (R_{in}^{AF4x} / R_{out}) \rceil$$

The maximum latency for $AF4x$ Q: $D_{max}^{AF4x} = N_{max}^{AF4x} * L^{AF4x} * 8 / R_{out}$

The aggregated ingress rate for EF Q: $R_{in}^{EF} = r_{EF} \sum_{i=1}^{m} cir_i^{EF}$

The aggregated ingress rate for for $AF4x$ Q: $R_{in}^{AF4x} = r_{AF4x} \sum_{i=1}^{n} cir_i^{AF4x}$

- Synchronous Solution:

The maximum packet number in EF Q: $N_{max}^{EF} = \lceil R_{in}^{EF} / R_{out} + 1 \rceil$

The maximum packet number in $AF4x$ Q: $N_{max}^{AF4x} = \lceil R_{in}^{AF4x} / R_{out} + 1 \rceil$

The maximum latency for both Q: $D_{max}^{EF} = D_{max}^{AF4x} = T$

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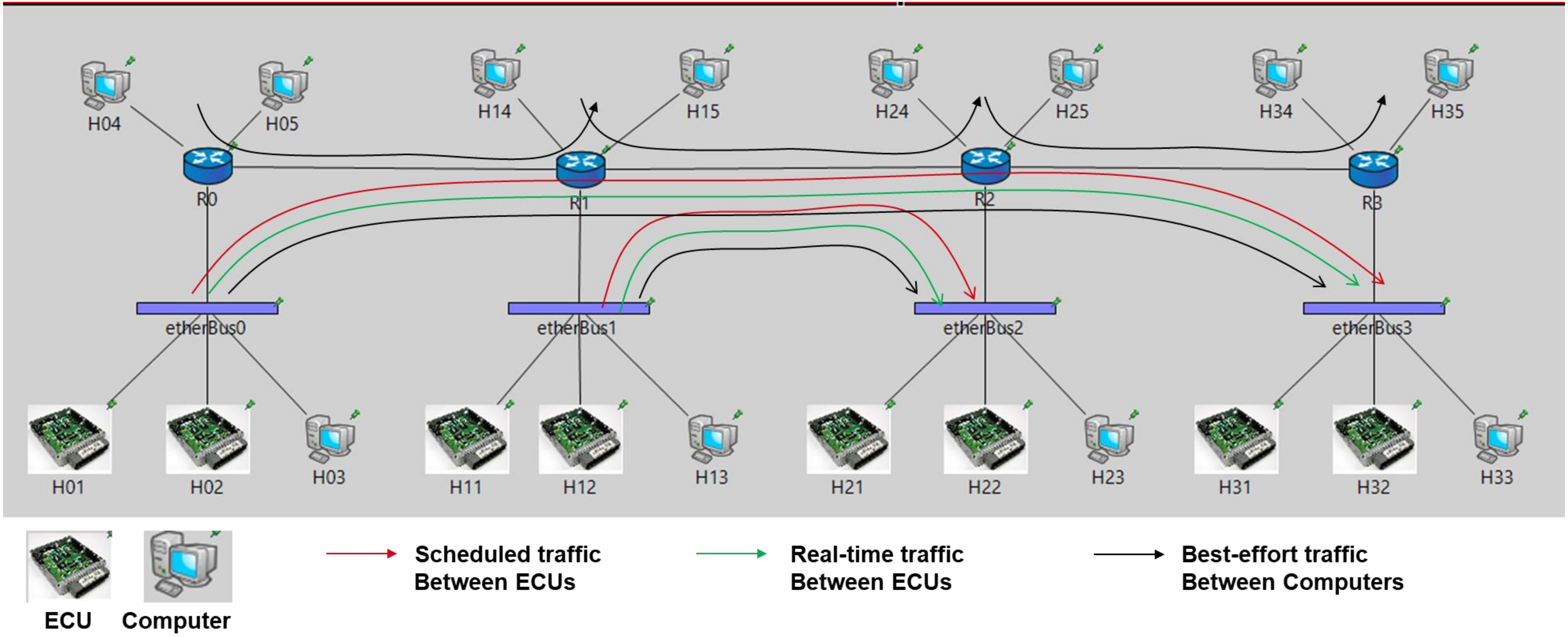
Simulation Setup (by omnetpp)



Simulation Results

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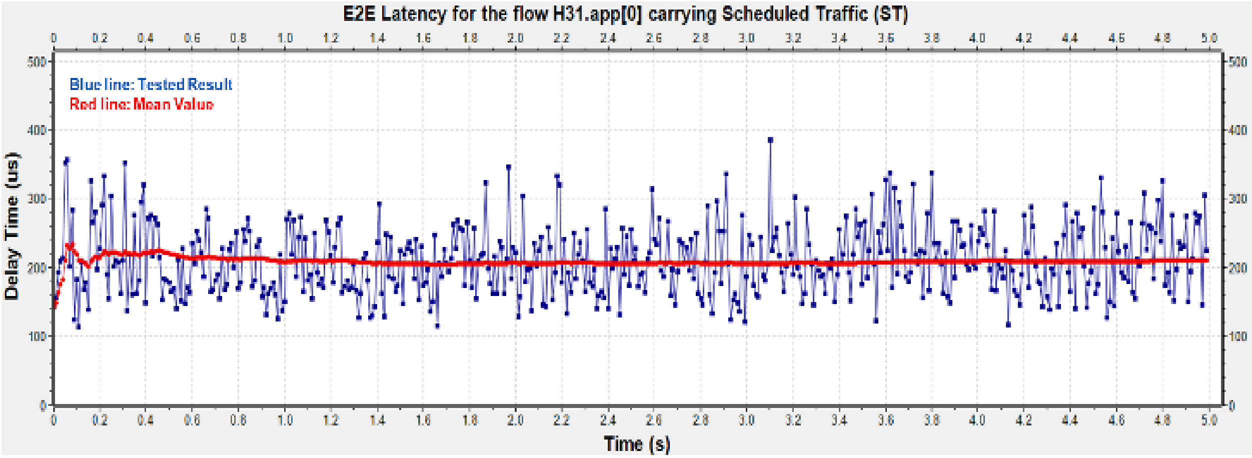
Algorithm	Class and traffic	Estimated max number of packet in Egress Q					Estimated Total Queuing Latency (us)	Calculated Total Serialization Delay (each hop has 20 us)	Estimated Total E2E Delay (us)
		Host	R0	R1	R2	R3			
PQ+DWRR	EF for ST	0	3 (r_{EF}=2)	6 (r_{EF}=4)	3 (r_{EF}=1)	3 (r_{EF}=1)	305	100	405
	AF4x for RT	0	4 (r_{AF4x}=2)	6 (r_{AF4x}=4)	4 (r_{AF4x}=1)	4 (r_{AF4x}=1)	365	100	465
PQ+DWRR +CQ	EF for ST	0	2 (r_{EF}=1)	2 (r_{EF}=1)	2 (r_{EF}=1)	2 (r_{EF}=1)	162	100	262
	AF4x for RT	0	2 (r_{AF4x}=1)	2 (r_{AF4x}=1)	2 (r_{AF4x}=1)	2 (r_{AF4x}=1)	162	100	262

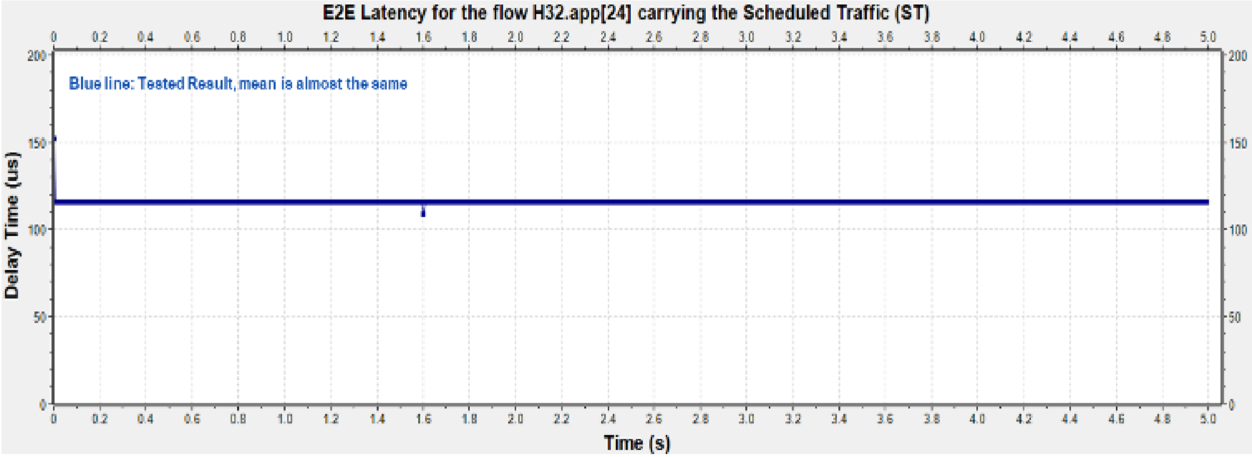
TABLE 1. The E2E Delay Estimation of ST and RT



1. 1st Algo: The E2E Latency (min=108us, max=391us) for the worst performed ST flow

Algorithm	Min/Max E2E Delay (us) for the worst performed flow carrying ST between H01/H02 to H31/H32		Min/Max E2E Delay (us) for the worst performed flow carrying RT between H01/H02 to H31/H32	
	Experiment	Estimation	Experiment	Estimation
PQ+DWRR	108/391	100/405	278/542	100/465
PQ+DWRR+CQ	109/152	100/262	169/169	100/262

TABLE 2. The comparison of experiment result and estimation



1. 2nd Algo: The E2E Latency (min=109us, max=152us) for the worst performed ST flow

Conclusion

- New IP based IVN can achieve the targets of latency, jitter and packet loss.
- It can be alternative solution for legacy IVN protocols and TSN.
- It has obvious advantages over other solutions.
  - L2 independent, higher link utilization, more flexible topo, simpler and lower cost
  - Easier for APP development
  - Easier for V2X integration
- New IVN is key part of V2X and will be integrated with future Internet.