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Latency Reduction in Ethernet Open - Audio Video Bridging Streams for Automotive Infotainment Network

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Abstract--- Ethernet is one of the most widely used high-speed interfaces at homes and offices, recently the trend is catching up towards its adoption to the automotive world where a high amount of data to be transported at very high speeds mostly in the infotainment domain. As with Controller Area Network (CAN) which is an automotive communication protocol, Ethernet is also packetized data communication system, where information is transferred in packets between nodes on various parts of the network. Ethernet would be the best candidate for replacing CAN in the future, but the high cost per node is a limiting factor for widespread use of it in an automotive environment. Due to this, it may probably not replace CAN networks in the near future but rather augment it. Reliability and fault-resilience being a characteristic for any automotive domain, the high data rate is an additional requirement for domains such as infotainment because the data that is transported is primarily multimedia. CAN network fail in this aspect, as the supported data rate is not sufficient for multimedia and high quantity sensor data. The alternative, OpenAVB is an open source Audio Video Bridging (AVB) system. In this paper, the customizing OpenAVB software for automotive use cases is discussed and analyzed. Also, it presents at enhancing the OpenAVB stack's stream reservation process to suit the automotive scenarios to reduce the streaming latency with stream reservation protocol at network startup by performing bandwidth reservation.

Keywords--- Ethernet, audio-video streams, infotainment, reservation, bandwidth

I. INTRODUCTION

In technical terms, Ethernet AVB is a collection of IEEE standards that have increased the capacity for data exchange, support and audio-video product realization over Ethernet. Commonly referred to as a switch, the purpose of an audio-video bridge is to realize time-synchronized, low latency streaming capabilities for audio and video data that guarantees bandwidth reservation [1]. The shift AVB brings in is the proposal and implementation of an in-vehicle network which is capable to transmit primarily audio-video data with deterministic presentation delays and high QoS.

The advantage of Ethernet lies in the speed that it can support which is about 100 times faster than that of a CAN bus. Ethernet is most suited for mid-bandwidth applications such as automotive Infotainment, navigation systems and control. It can be used almost the same way as a CAN bus while providing much more bandwidth and speed. The similarity between CAN and Ethernet is both are bidirectional, and the speed possible on any individual link decreases as the number of nodes on the system increases. Scalability is an inherent feature of Ethernet is an additional ingredient for future automotive use cases and an imperative reason for the adoption of this technology into the automotive world. The reduction of cabling weight is desirable in an automotive environment for fuel economy reasons due to this; twisted pair cabling is always preferred to regular LAN cables. This imposes a limit on speed to 100 Mbit/s for automotive Ethernet. Broadcom is a technology that uses twisted pair cable as a physical layer that adheres to stringent electromagnetic interference and compatibility constraints that are laid out for automotive uses [2]. With the adoption of Ethernet, auto world hopes that the maturity Ethernet has reached over past decades would help solve the ever-raising speed and reliability demands in-vehicle data communication [3]. The generalized precision time protocol (gPTP) is used for clock synchronization in the AVB network [4]. To accomplish this, the network clock in every AVB device on the network ensures that every other device in the network will have a close characterization of what the accurate time is at any point in time. There are algorithms devised as part of the AVB specification to select the best master clock among all the clocks of network nodes, based on which the rest of the nodes align its time offsets to have a common time reference throughout the network [5]. Each of the nodes in the network would use the time offset provided by the master clock as a means to calculate delays and to derive deterministic estimates for presentation.

Stream reservation protocol (SRP) is proposed to enforce the bandwidth guarantees by early bandwidth reservation reservations, also known as stream allocation/reservation [6]. The term "bandwidth reservation" and "stream reservation" convey the same meaning and they are used interchangeably. The bandwidth reservation process is characterized by a talker and one or more listener(s) declare their interest in a stream by sending SRP messages to the network. Each stream reservation process reserves bandwidth and other switch resources so that a talker can stream and one or more listeners can listen to it, as long as both the parties are interested in a stream. Withdrawing the interest in a stream by appropriate SRP messages by either of the parties invalidates the reservation and switch resources are freed.

The AVB specification also comprises other protocols such as MAC address acquisition protocol (MAAP) which is a mechanism to allocate talker addresses dynamically [7].

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Then, audio video transport protocol for time-sensitive streams (AVTP) for assembling and disassembling audio-video streams, audio/video device discovery, enumeration, connection management and control (AVDECC) which enables a command-based interface for device discovery, enumeration and control of endpoints and forwarding and queuing enhancements for time-sensitive streams (FQTSS) for traffic shaping and stream management functionalities. When an AVB node wishes to transmit data (known as a Talker), it transmits one or more media streams to the network if the stream is reserved already. When an AVB node choose to receive data (known as a Listener) it receives one or more streams from the network, provided a talker is existing and streams are reserved. The AVB bridge/switch acts as a mediator between these two endpoints, who guarantees bandwidth reservation. Both the talker and listener nodes request stream reservations and the bridge ensures the reservations, by regulating the streams between both endpoints and ensuring that they are subscribing to the proper streams. The AVB bridge/switch assures time-sensitive, loss-sensitive, real-time audio-video data transmission capabilities while allowing audio and video data to seamlessly share the same network [8]. The switches impose restrictions on the percentage of bandwidth that is usable by the AVB traffic so that traffic pertaining to other forms of LAN data transport is not delayed or lost as the rapid growth in the multimedia data such as video, images and audios [9].

Adopting AVB to the automotive arena brings unique possibilities for further enhancements to the technology, which is not inherent in the original AVB philosophy itself. One such potential enhancement is the static configuration of the AVB streams, which can also be termed as static stream/bandwidth pre-allocation. The management of the available network resources which includes the switch bandwidth, ports and physical layer capabilities are done by the SRP. An AVB stream is a channel characterized a by the producer (talker) of a media/control stream, one or more consumer(s) for the stream and the stream properties which are reserved in the AVB capable network switches in the reservation path [10]. This protocol is used to request the resources as and when they are needed and such requests propagate throughout the AVB domain. As the requests propagate through the network, the switches are configured, provided that there is at least one talker and listener for a stream and switches has enough bandwidth left. The reservation is withdrawn if the talker/listener is no longer interested in the stream.

The original AVB philosophy supports dynamic allocation and management of the AVB streams as and when they are needed by the nodes and this brings considerable advantages to a dynamic network where the communication patterns are diverse and complex. One such example is an AVB network which consists of a variable number of plug-and-play musical instrument nodes which may be connected or disconnected any point in time to the network. The flexibility and benefits of dynamic allocation of streams comes with the price of delayed network response while streaming due to the fact that the stream reservation process must happen in the network as a daisy-chained action through all the network switches and nodes, which is bound to consume considerable amount of time which adds up to the delay for actual streaming. This is termed as AVB streaming latency.

Whereas in the case of an AVB network that is custom tailored for an automotive use case, most of such scenarios do not apply. Invalidation of those scenarios also brings about new potential for improving the network from inherent limitations of AVB for using it in an automotive environment. Hence, this paper aims at optimizing the OpenAVB stack's stream reservation process to suit the automotive scenarios, which demands lower streaming latency for audio-video/control streams.

II. AN OVERVIEW: ETHERNET OPENAVB

Ethernet AVB (or AVB in short) standard is a collection of various IEEE 802 extensions such as such as IEEE Std. 802.1AS™-2011, IEEE Std. 802.1Q™-2011, IEEE Std. 802.11™-2012, IEEE Std. 802.1BA™-2011, and IEEE Std. 802.3™-2012 developed for transport of time-sensitive media streams over Ethernet network [11]. These standards aim at a proposal and implementation of an Ethernet-based network without any packet loss over transmission by providing bandwidth guarantee through prior bandwidth/stream reservation.

It also guarantees timely presentation of audio-video data on a network node in synchronization with the node which streams the data [12].

In addition, AVB provides priority-based time-sensitive networking by enforcing priority driven forwarding and queuing behaviour for streams. This guarantees delivery of time-sensitive data from a source to a listener with deterministic minimum latency. Finally, AVB specification provides a time synchronization protocol with high precision based on precision time protocol (PTP). It enables network nodes to synchronize their clocks with the precision of less than one microsecond. This synchronization is essential for time-sensitive streams to align their presentation delays on multiple network nodes [13].

Combination of these protocols enables an Ethernet network to be built which can stream and play media content with high fidelity in numerous application domains, including automotive infotainment. It also carries a potential non-media time-sensitive data streaming support, such as timing and latency sensitive automotive data bus such as a CAN.

OpenAVB is an open source AVB implementation originally stated at *Intel* by August 2012. It is later transferred to *AVnu Alliance* [14] which is a *"community for creating an interoperable ecosystem servicing the precise timing and low latency requirements of diverse applications using open standards through certification"* as *AVnu* describes itself in their web page.

The goal of OpenAVB under *AVnu* is to facilitate the development of AVB and time sensitive networking technologies in products that can be readily certified. The architecture of OpenAVB is shown in Figure.1.

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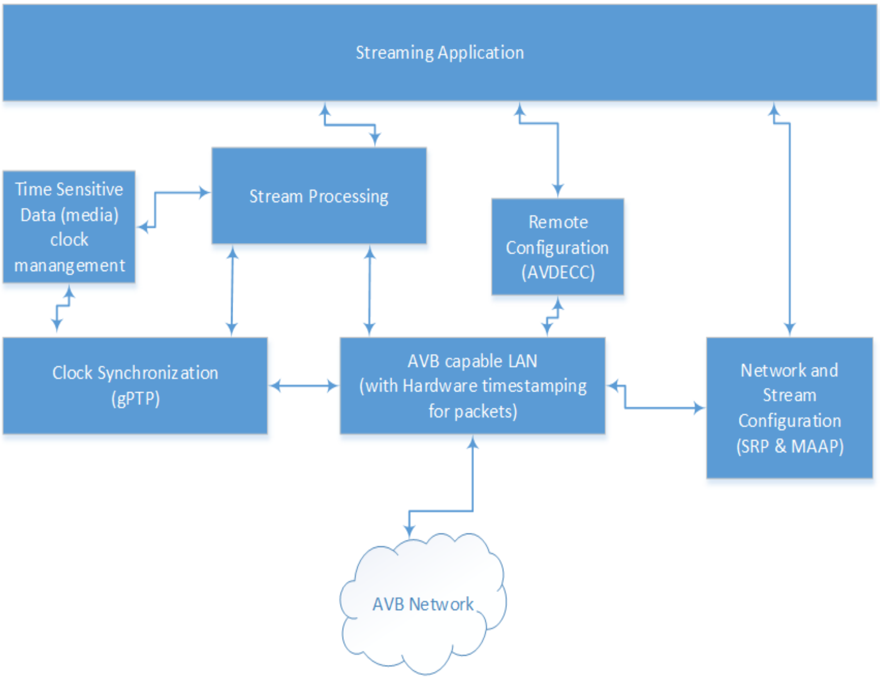

Figure 1: OpenAVB System architecture

Streaming application produces or consumes media streams and performs endpoint time synchronization across the network nodes for timely media data presentation. It also manages the bandwidth reservation that is required for the streams, which are either produced or consumed from the application perspective [15]. The streaming data need not necessarily be of media content rather it can replace any type of time-sensitive data that demands deterministic streaming latency guarantees. It may also use any higher layer protocol for data streaming and one of the commonly used protocol is AVTP for audio-video streaming.

Network and stream configuration entity performs the network and stream configuration of the AVB network. It detects and modifies AVB network parameters, join domains, register VLAN and advertise/revoke stream reservations. It also informs the streaming application about the key events in the network management process. The backbone of network and stream configuration is laid out on different variants of multiple reservation protocol (MRP) such as SRP, multiple VLAN registration protocol, and multiple MAC registration protocol. This entity also shall support the use of MAAP to be able to acquire the MAC address of endpoints during the network activity for multicast support.

Clock synchronization is used to establish a local clock reference for each network node which is synchronized to the time reference of a global clock which is termed as "*Grandmaster clock*". It enables all the nodes to have the same notion of elapsed time for accurate estimation of presentation delays for time-sensitive data [16]. It is specified with the gPTP protocol.

Media clock management uses synchronized gPTP clock reference to derive media clock for analog-to-digital and digital-to-analog converters of audio-video data [17]. It also manages a phase-locked loop based clock control for modifying frequencies on the fly for runtime rate conversion and offset corrections. AVB capable LAN interface refers to an Ethernet LAN interface which supports hardware timestamping of egress Ethernet frames. It connects an AVB capable SRP and gPTP enabled nodes to an AVB network. The AVB network can be visualized as a group of AVB capable nodes which belongs to an SRP domain and a gPTP domain.

The remote configuration allows detection of AVB capable node/device, configuration and stream connection management across an AVB domain. The protocol suite AVDECC is a collection of two protocols which facilitate connection management, enumeration and control [18]. Stream processing component handles encapsulation and decapsulation of media/control data while transmission or reception via AVB capable LAN. It also separates media data from other AVB related control data such as timestamps [19]. A simple AVB network can be visualized as a talker endpoint connected to a listener endpoint via an AVB capable LAN switch/router as shown in Figure.2.

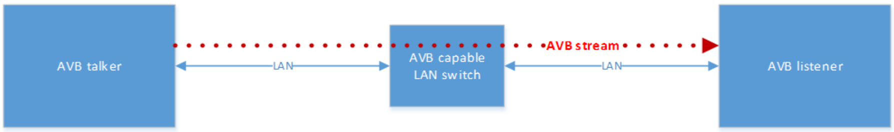

Figure 2: Simple AVB network

More detailed network configuration based on the above-mentioned network topology used for this work is depicted in Figure.3.

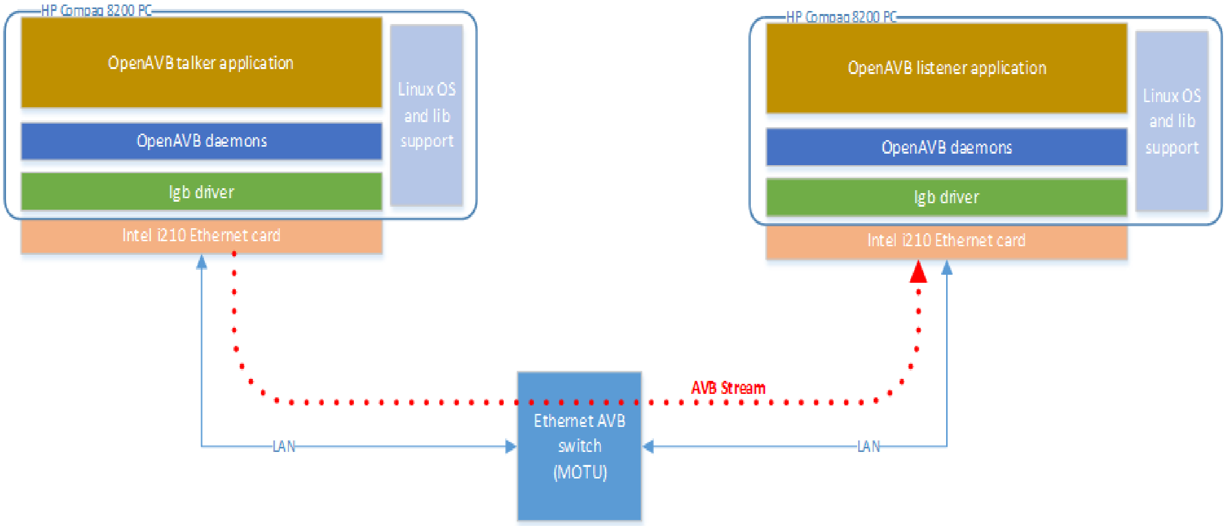

Figure 3: Experimental network setup

III. SRP BANDWIDTH RESERVATION

An AVB network mandates talkers to declare their bandwidth requirements prior to starting streaming on the network. Every node and network bridges in the network use SRP to propagate these requirements across the network [20]. Each bridge processes these attributes and entries are made in its network management tables to reserve bandwidth for catering to later transmission from the reserved talker endpoints. The bandwidth reservation for a stream from a talker is made only when one or more listeners are interested in such a stream. Such an acknowledgement propagates from a listener in a reverse fashion back to the talker. As this acknowledgement traverses back, all the switches in the path perform bandwidth reservation for the stream. In addition to this scenario, a listener can also declare its interest in a stream even before a declaration for that stream is made by a talker. Figure.4 shows the SRP stream reservation process.

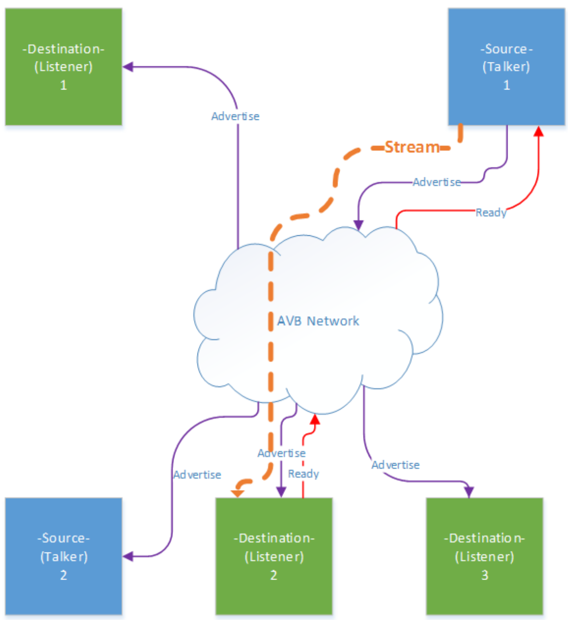

Figure 4: Bandwidth reservation process in AVB

The SRP specifies classes of SRP traffic based on the transmission speed requirements. Class A traffic declaration by a talker indicates that the application will produce at most one network frame in every 125 microseconds. Whereas, class B traffic declaration by a talker indicates that the application will produce at most one network frame in every 250 microseconds. Based on this declaration, each bridge in the path from talker to the listener tunes the traffic shaping algorithm to cater to such transmission speed demands. The SRP domain is characterized by user priority attribute of a stream and its traffic class, provided that the talker and the listener exist in the same VLAN [21]. This poses a mandate of the talker/listener joining the VLAN a priori, where other AVB endpoints are joined. A stream can stay active or stopped depending on whether it is in use or not. If no talker or a listener or both present for a stream which was active, the reservations are withdrawn from all the bridges in the path between the endpoints.

The streams are identified by attributes such as VLAN ID and priority, payload size, frame rate, stream rank, worst case latency, destination address and a stream ID. VLAN ID is a per-port parameter for stream related traffic, which is used as a parameter to announce a stream by a talker or a listener. Priority is used for stream tagging purposes with the help of a generated priority code point from priority input by the bridges. Payload size specifies the maximum frame size a talker would produce, to be able to calculate the bridges buffering requirements. The frame rate specifies the rate at which AVB packets will be sent to the network for bandwidth calculation purpose. Stream rank is an indicator of how important is one stream among other streams from a talker [22]. Latency specifies the worst-case latency of a media stream frame in the network between talker and a listener. The destination address specifies a multicast destination MAC address, and only one talker is allowed per destination address.

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The stream ID is a unique identifier used to match a talker with one or more listeners and it is primarily derived out of talker's MAC address [23].

IV. DESIGN AND IMPLEMENTATION

Some of the scenarios where an automotive AVB network fundamentally differs from the original AVB philosophy are described below, with an emphasis on the potential for further improvement to the technology for automotive use cases due to these differences. The various use cases are as follows,

1. *"Limited number of known" nodes (no stranger nodes)*

In contrast with original AVB philosophy where the count and *types* of network nodes may vary to a great extent as a function of time, automotive scenario offers a much simpler network topology in terms of both the number and the types of network nodes. In practice, an automotive AVB network consists of only a fixed number of nodes whose types are known from the initialization of the network (*no "stranger" node ever being plugged into the network in the runtime*). This brings about the benefit of AVB network switches having the prior knowledge about the count and types of network nodes in the start-up itself, which eliminates the need for having a dynamic acquisition of streams by each node at a later point in time. The advantage is that it offers a lesser streaming latency for media/control streams, which is a desirable characteristic for an automotive AVB network which is explained later in this section.

2. *Prior knowledge about the type and properties of streams needed by each node*

Unlike in the original AVB concept, an automotive AVB scenario is simplified enough to an extent that it needs only a few constant numbers of active AVB streams any point in time during the network is functional for each of the nodes. Most likely, the *roles* and *properties* of each stream for any node in the network remain unchanged throughout. This is regardless of the fact whether the streams are active or not at a point in time. In case of a stream which is inactive for a period of time, the state of being "*reserved*" has no effect on the network other than the AVB switch keeps the reservation entries intact– provided the switch and network have enough resources to cater to the bandwidth requirement of then-active streams.

The major positive implication of having this prior knowledge is that it helps in reserving streams much earlier to the point in time where the stream is needed by the node, which reduces streaming latency. This reservation can be registered to the network switch, preferably in the network start-up itself either by any of the two methods to do so, which are explained later in this section.

3. *Most likely – "a single AVB domain per network"*

As per *IEEE Std. 802.1BA-2011*, an AVB domain refers to the intersection of an SRP domain (*specified in 35.1.4 of IEEE Std. 802.1Q-2014*) and a gPTP domain (*specified in 8.1 of IEEE 802.1AS-2011*). In other words, an AVB domain simply refers to a group of network nodes/ports networked by means of AVB capable network switches where all the nodes are timed by the same grandmaster node and are adhering to the same SRP constraints like stream reservation class and priority. Most of the automotive AVB scenarios are characterized by a less complex network with a single predefined grandmaster and a single SRP domain which leads to having a fairly simple AVB network. This simplicity helps in configuring the network statically at the time of start-up also by considering other characteristics specified in [i] and [ii].

4. *Predictability of other network traffic by TCP/IP or UDP packets*

AVB network also supports the transport of non-AVB data but it is confined to a quarter of the total available bandwidth. In a non-automotive AVB scenario, the non-AVB traffic can vary anywhere between 0-25%. Whereas in an automotive scenario, exact estimation is possible for non-AVB traffic at any point in time due to the prior knowledge of the network and its simplicity. This helps in safeguarding the network from plunging to a bandwidth crunch when it comes to non-AVB traffic.

5. *Need for "early" availability of the network*

The discussions so far were centred at the fundamental differences of automotive AVB scenario from the original AVB philosophy, and how these differences could bring about new improvements which are pivotal for adopting this technology to automotive arena. The need for having the stream available very early in the system start-up is imposed by the legislation constraints for rear view camera (RVC) for an automotive if it is connected to the AVB network as a video talker. Such use cases resort to one of the two static stream reservation options described later in this section.

The primary motivation for proposing early static bandwidth allocation for the automotive scenario is how to reduce the streaming latency parameter as it brings faster network response for establishing streams between nodes. This is an imperative quality an automotive infotainment network must possess due to several reasons such as the need for instantaneous streaming of media/control between the nodes (*RVC, HUD, Cluster etc…*) and availability of early RVC support mandated by legislation. There are two ways in which static stream reservation can be done for AVB network tailored for automotive use as discussed follows,

6. *Pre-allocate streams using SRP at the network start-up*

With this approach, SRP is used to configure the switch early in the startup and refrain from doing the allocation of streams anytime later during the operation of the network. Since all the nodes know about the stream requirements in the network start-up itself, need for stream reservation at any late point in time becomes unnecessary. All the nodes that need to communicate media/control data either as a talker or listener must try to register the intention with the switch(s) during the network initialization.

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Once the registration is complete, the SRP component of each node can choose to remain alive or terminate. It would be worth terminating the SRP process of all the nodes once the reservation is complete because the SRP component will no longer be used for registration any further. The drawback of this approach is its inability to cater to the stringent timing requirement for early RVC due to the time-consuming SRP handshakes. Also, these SRP messages constitute the increased network load while starting up.

a. Configure streams in the switch by programming means

Some AVB capable switches offer a programming interface, through which its network management tables can directly be programmed, mostly in a non-volatile way. This approach eliminates the need for having an SRP based stream reservation mechanism, even during the network start-up. This also helps to eliminate the integration of SRP component to the software stack for every network nodes. The advantage of this approach is the availability of reserved streams very early in the network start-up as it doesn't rely upon the SRP handshakes. This helps in achieving early RVC support which needs to meet stringent power-up timing. An additional advantage of this approach is that it reduces the network message exchanges during the start-up, which improves the system stability. The downside of this approach is that the switch must provide a programming interface to able to modify its stream management tables.

The bandwidth/stream reservation for original OpenAVB implementation is done on a need basis. This method is best suited for non-automotive use cases where streaming latency is not a critical operational parameter. Another aspect to consider is, the stream reservation is tightly coupled with the talker/listener process and they come alive together once the talker/listener functionality is needed by an endpoint. This imposes high latency for data presentation at the listener end due to the bandwidth allocation process that must happen beforehand the streaming. The solution devised to address this drawback is to pre-allocate and reserve bandwidth by every node in the automotive AVB network to be able to stream the data as and when needed. This approach proves to be successful due to the prior knowledge on the type of each stream needed by every node and its static nature of configuration on the network. The work emphasis only on the approach *(a)* specified above.

The steps to be followed for performing stream reservation by a network node are listed below. The steps performed for stream configuration differs between talker and listener nodes, the difference in request pattern is also specified within the bracket,

- Send VLAN to join (*Talker/Listener*)
- Send domain registration (*Talker/Listener*)
- Send talker to advertise (*Talker*)
- Send listener ready (*Listener*)

4.1. Stream Bandwidth pre-allocation using SRP at the network start-up

Figure.5 shows the process of OpenAVB original stack start-up and operation with emphasis on the stream allocation process.

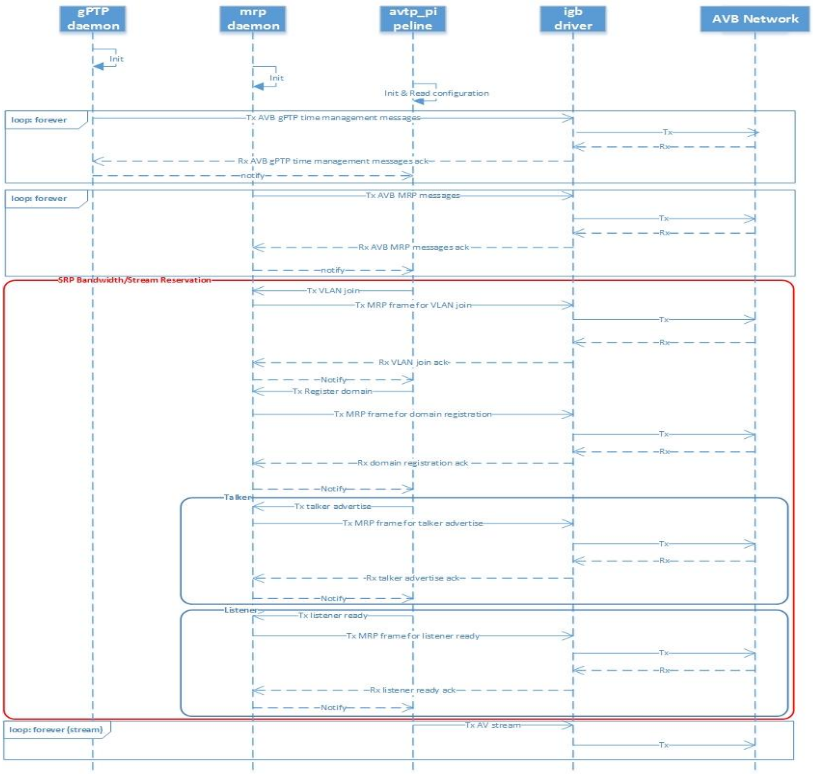

Figure 5: OpenAVB startup sequence without bandwidth pre-allocation

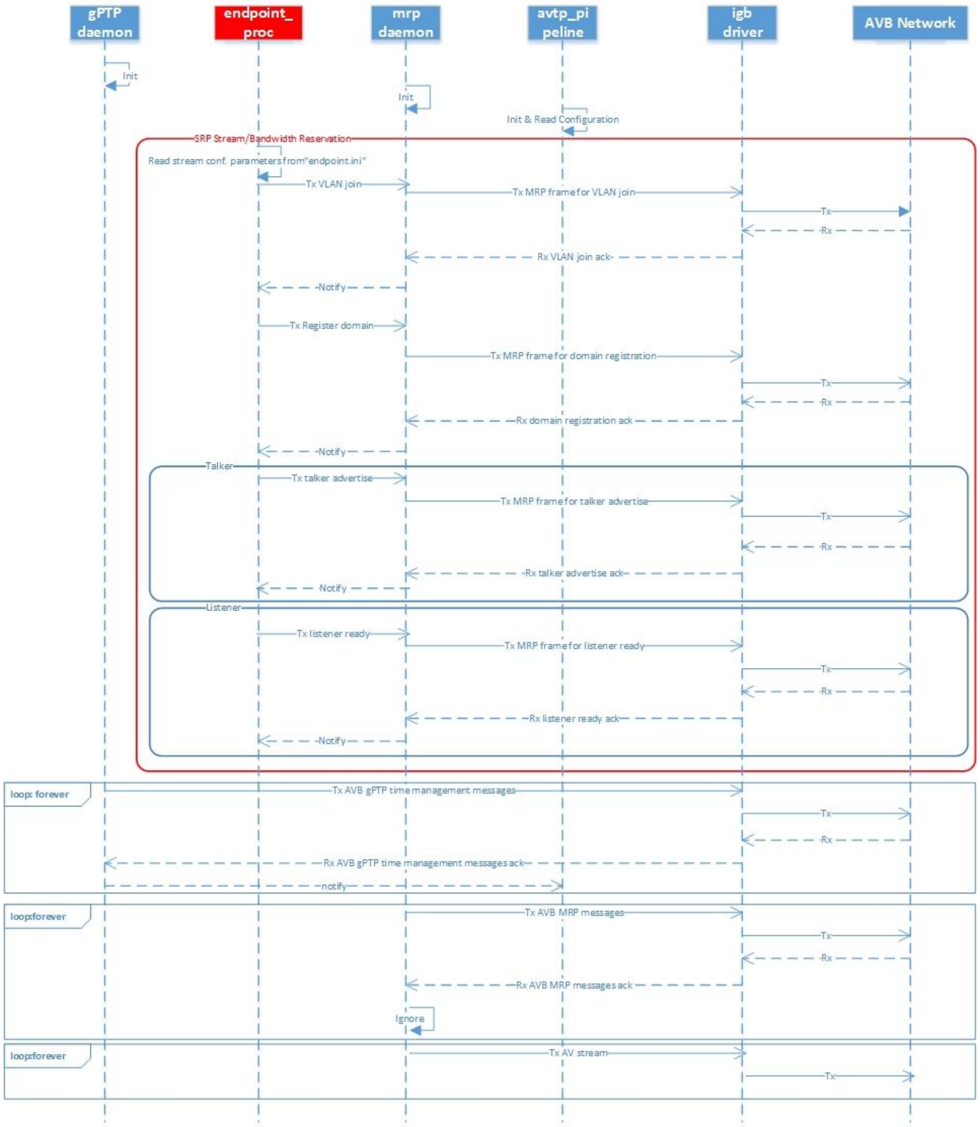

Figure 6: OpenAVB startup sequence with bandwidth pre-allocation

The stream reservation activity is done from the avtp_pipeline process when a talker/listener stream required by the endpoint for the original OpenAVB stack. In contrast to this, the change in software design is presented in Figure.6 and bandwidth pre-allocation implementation is listed in Table.1.

4.2 Software design and implementation

Table 1: Bandwidth pre-allocation implementation

S.No	Implementation strategies of bandwidth pre-allocation
1.	Removal of the stream reservation mechanism from the *avtp_endpoint talker/listener* endpoint implementation.
2.	Implementation of an additional Linux process "*endpoint_proc.out*" with stream reservation mechanisms to make stream reservation independently accessible.
3.	Stream parameters for all the streams for an endpoint are read from the newly introduced configuration file "*endpoint.ini*". These parameters are used for stream reservation mechanisms.
4.	An open source configuration parsing library "*inih*" is used for reading the configuration file.
5.	MRP messages delivered to *mrp daemon* are not dispatched to avtp_pipeline process anymore.
6.	After completing the stream reservation process, *mrp daemon* and *endpoint_proc* can choose to terminate as these processes are not needed to keep the reservation entries in the network switch.
7.	Removing stream reservation mechanism from avtp_pipeline reduces its memory footprint.

V. TESTING AND ANALYSIS OF BENCHMARKING RESULTS

The configuration file "endpoint.ini" can be modified with proper role assignments and stream parameters. Figure.7 shows the configurations to be followed on both talker and listener nodes at the system startup.

```
sudo rmmod igb
sudo insmod /kmod/igb/igb_avb.ko
sudo daemon_cl $eth_if
sudo mrpd -mvs -i $eth_if &
sudo endpoint_proc –I lib/avtp_pipeline/endpoint/endpoint.ini
sudo lib/avtp_pipeline/build/bin/openavb_harness -I $eth_if -s 1 -d 0 -a $stream_id,
role.ini, sr_class=A,
                                                    map_nv_tx_rate=8000,
max_transit_usec=2000,
                                                    map_nv_sparse_mode=0,
intf_nv_device_name=default,
                                                    report_seconds=0
```

Figure 7: Configurations of system startup required at talker and listener nodes

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The setup consists of two *HP Compaq 8200* PC installed with Intel *i210* Ethernet card. The Ethernet AVB switch used is MOTU AVB switch. The talker-listener pair used is *AAF file talker* which is available in the original OpenAVB software package.

Table 2: Benchmarking results

Streaming latency without a stream pre-allocation mechanism	Streaming latency with a stream pre-allocation mechanism
5.7 seconds	0.8 seconds

In comparison with original AVB solution, the streaming latency is reduced roughly by about 85% with the bandwidth pre-allocation mechanism implementation as listed in Table.2. Since this implementation and testing is done on a non-embedded environment, it is expected that the streaming latency is much lesser if it is ported to a real automotive embedded hardware platform. This improvement makes AVB technology favourable to be used in an automotive environment, especially in infotainment domain. For testing and benchmarking, same multimedia file with the.avi extension is used.

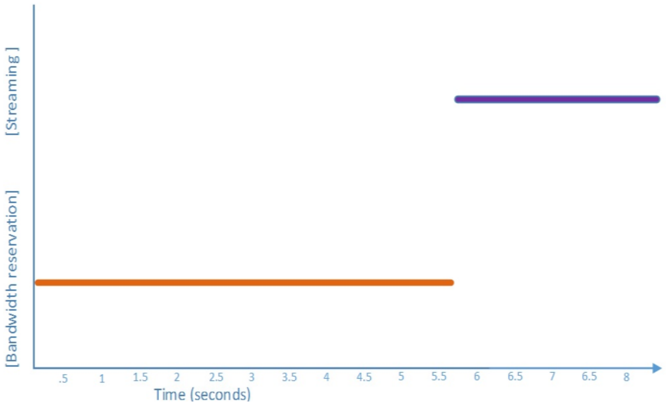

Figure 8: Streaming latency without bandwidth pre-allocation

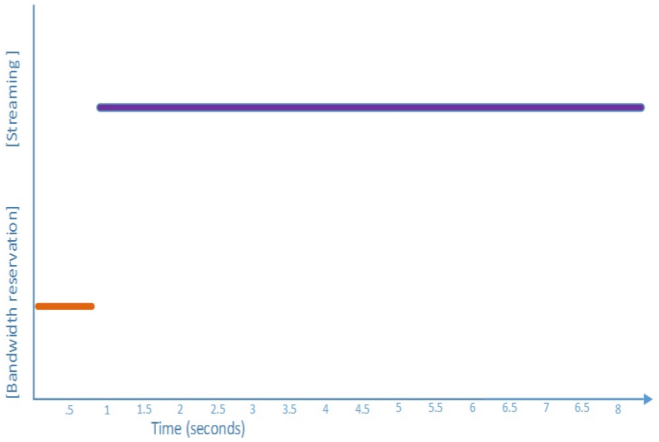

Figure 9: Streaming latency with bandwidth pre-allocation

Figure.8 depicts the scenario where no bandwidth pre-allocation is made thus resulting in a high streaming latency of 5.8 seconds. Whereas Figure.9 depicts the scenario with bandwidth pre-allocation, this yields a reduced streaming latency of merely 0.8 seconds. With this, it becomes apparent that the latency for streaming multimedia data from one network node to the other has improved by 80% with the bandwidth pre-allocation implementation. It reduces the time-to-stream parameter in an automotive environment, which enables features like early rear view camera to be available while starting the automobile.

VI. CONCLUSION

Ethernet technology and AVB provides opportunity and mechanisms for high-speed data transport within automotive environments with the quality of service guarantee and reliability. While these being highly sought-after requirements especially in infotainment domain, other protocols such as CAN was only able to address the reliability part of the equation. However, ring-topology protocol was able to cater to the demand for medium data-rate infotainment applications, but it failed in the aspect of providing a simple network topology. Ethernet & AVB can deem as a hybrid of all sought-after requirements that an ideal communication protocol must possess, which includes high data rate, simple bus network topology, quality of service guarantee and reliability. The present paper is addressed the issue of a missing element and reduced multimedia streaming latency to be able to use in automotive infotainment environment.

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