Annals of Emerging Technologies in Computing (AETiC)
Vol. 2, No. 1, 2018

Long Paper

Audio Networking in the Music Industry

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Received: 31st November, 2017; Accepted: 14th December 2017; Published: 1st January 2018

Abstract: This paper surveys the rôle of computer networking technologies in the music industry. A comparison of their relevant technologies, their defining advantages and disadvantages; analyses and discussion of the situation in the market of network enabled audio products followed by a discussion of different devices are presented. The idea of replacing a proprietary solution with open-source and freeware software programs has been chosen as the fundamental concept of this research. The technologies covered include: native IEEE AVnu Alliance Audio Video Bridging (AVB), CobraNet®, Audinate Dante™ and Harman BLU Link.

Keywords: Audio Video Bridging; AVB; CobraNet; Dante; BLU Link; Audio Networking

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1. Introduction

Computer networks not only form the backbone of the internet but also have been utilized for the purposes of the music industry for many years. Audio Networking has now become a specialism in its own right. The main protocols used and their properties are surveyed in this paper.

1.1 Organisation of the Paper

The first part surveys the main protocols used in audio networking covering: Audio Video Bridging (AVB), CobraNet, Dante and BLU Link. The second part covers a practical simulation of an audio network. The third section is an evaluation and discussion covering the audio channel capacity, latency and practical problems faced. The final section covers the conclusions.

2. Survey of Audio Networking Technologies and Protocols

2.1. Audio Video Bridging (AVB)

AVB (Audio Video Bridging) is a collection of IEEE open source standards that allows uncompressed audio and video data to be transmitted across networks (utilising network cables and specialised network switches) [BSS Audio, 2015]. As AVB is an open standard, no licence fees have to be paid and this significantly reduces the overall price of AVB equipment [BSS Audio, 2015]. AVB in most cases utilizes standard Ethernet network rules; standard CAT5e (or better) cables can be used with up to 100 m cable spans; fibre optic cables can also be used if a longer distance is required [BSS Audio, 2015].

Specialized network switches that maintain the QoS (Quality of Service) requirements automatically have to be utilized [BSS Audio, 2015]. According to the AVnu Alliance website only 52 switch models from one manufacturer are certified and outlined by the AVnu Certified Logo Program [Avnu Alliance, 2016], but the actual list of network switching devices contains seven manufacturers [Pavel Kudelin, 2015].

As AVB interacts with switches, part of the initial configuration process is not needed, for example, switches automatically perform routing of audio/video streams and setting the synchronization and also in the creation of the VLANs (Virtual Local Area Networks) for AVB to use. This thus makes these switches more cost effective and simpler to utilise, as less programming and administration is required [BSS Audio, 2015].

In comparison to those audio networks utilising the CobraNet networks, AVB time sensitive audio and/or video data cannot be corrupted by the stream of other data because the AVB network bandwidth is automatically reserved and network shaping is also performed by the AVB network switches [BSS Audio, 2015]. AVB preserves up to 75% of the available network bandwidth for its streams [Minich, L., 2013].

The maximum AVB input/output capacity varies depending on the device itself. As an example, the Soundweb London BLU-805 audio networked device has 64 by 64 input/output channels; these channels are subdivided into groups that are named "streams", each stream can contain from 1 to 32 channels each; up to 62 incoming and 64 outgoing streams can be in this specific device [BSS Audio, 2015]. Overall the AVB transmission capacity over the network is up to 420 digital inputs and 420 digital outputs; 840 channels in total [Biamp, 2012].

Unlike CobraNet, the multicasting is utilised in a much better way - any AVB stream can have one or more receiving devices; the AVB streaming device streams only to the designated stream receiver, the stream will not be spread across the whole network - this means that utilisation of a network is more optimised [BSS Audio, 2015].

AVB utilises 100 Mbps and 1000 Mbps (1 Gbps) Ethernet networks; increasing the bandwidth of a network significantly improves aspects of the audio/video networks; the latency gets reduced, increasing the quality or capacity of a channel and the synchronisation ability also is improved [Pavel Kudelin, 2015].

Low latency is guaranteed in working with AVB; latency directly depends on a number of hops (switches). The standard AVB has 2 ms latency [BSS Audio, 2015], but different switching devices from various manufacturers can reduce it further down to 0.25 ms per hop [Meyer Sound, 2015[]. Choosing a lower latency setting reduces the number of allowed switch hops. The maximum number of hops between the transmitting device and the receiving device in an AVB network is limited to ten; that means that placing more than nine switches between the transmitting device and the receiving device will cause errors in the transmitted bitstream [BSS Audio, 2015].

Each networked audio technology has its own specific terminology that describes the key elements, in AVB these being [Pavel Kudelin, 2015]:

- **Stream** – packetization of one or many audio/video channels over the network – this can be either unicast or multicast;
- **Talker** – the end device that can send a stream;
- **Listener** – the end device that can receive a stream;
- **Controller** – the controlling software that is used for the AVB streams routing, negotiating and allowing the connection between the devices.
- **Cloud** – the interconnected network nodes and the link between them that support the 802.1 AVB standards.
- **Bridge** – a network device that is utilised for AVB streams switching.

The setup of a connection is quite simple consisting of two stages: first, each participating device on the network advertises its AVB Talker streams that are available to be routed to other AVB listening devices; second, the user just needs to select the crosspoints of the talker and listener devices' streams using a controlling software, for exampe, Riedel AVB manager or AudioDesk from MOTU [Pavel Kudelin, 2015].

The use of AVB continues unabated, being used not only for professional audio and video but also for the market for amateur audio and video and in industrial control and the automotive industry [AVnu Alliance, 2015].

Many AVB devices have ports for redundancy option, but there are no official standards for AVB redundancy yet, so manufacturers implement failover behaviour using their own technologies [BSS Audio, 2015].

AVB is a sum of the following IEEE standards:

IEEE 802.1AS [Timing and Synchronization for Time-Sensitive Applications (gPTP)] – protocol that is used for maintaining precise timing synchronization. Network synchronization is formed if all devices follow the requirements of the 802.1AS and communicate with each other using this protocol. A single device (automatically or specifically assigned), that is named the grandmaster, provides the synchronization signal; other devices pick this signal and synchronize their clocks with reference to it [Garner, G., Ryu, H., 2011].

IEEE 802.1BA – a protocol that is used for identification of participating devices, specifying the default configuration for AVB devices. Any network devices (for example, an unmanaged bridge) that do not support AVB has to be identified and flagged, [IEEE 802, 2015].

IEEE 802.1Qat (Streaming Reservation Protocol (SRP)) – the reserved bandwidth path is created between a Talker and Listener (one or more); 802.1Qat makes certain that non-AVB devices are not allowed to corrupt the established stream [Pearson, L., 2011].

The creation of the path is done by SRP in three steps:

- Establishing of a protected cloud for AVB devices;
- Discovery of a path from Talker to Listener;
- Configuration of switches from Listener (one or more) back to Talker;

SRP is a combination of the following Multiple Reservation Protocols [Pearson, L., 2011]:

- Multiple Registration Procol (MRP)
- Multiple Stream Registration Protocol (MSTP)
- Multiple VLAN Registration Protocol (MVRP)
- Multiple MAC Registration Procol (MMRP)

IEEE 802.1Qav (Forwarding and Queuing for Time-Sensitive Streams (FQTSS) – protocol that is used for traffic shaping for A/V streams; using priority mechanisms it allows the separation of the traffic of a network into various traffic classes, mainly re-mapping of priority values and transmission selection algorithms; also it prevents the burst of other data [IEEE 802, 2015].

IEEE 1722 (Audio/Video Bridging Transport Protocol (AVBTP) – the purpose of AVBTP is to enable interoperable streaming by defining media and encapsulation, media synchronization mechanisms and multicast address assignment [Silfvast, R. 2013].

IEEE 1733 - the main purpose of this standard is to support interoperability between devices that stream time sensetive A/V data across the Local Area Networks with time synchronization and low-latency, bandwidth services. This is done by specifying various parameters: format of the packets, stream setup, control, synchronization and teardown protocols [IEEE, 2015].

The sample rate and bit depth of the audio data depend on the end device that starts a stream (talker) ADS's (analog-digital convertor) limits or settings that are used, the audio/video data does not get compressed during the stream; the data that is output from the talker gets transmitted over a stream [Pavel Kudelun, 2015].

2.2. CobraNet

CobraNet is a collection of technologies (hardware, software, network protocols) developed by Peak Audio in 1996. In 2001 the assets of Peak Audio were bought by the company Cirrus Logic and since that time the development of the CobraNet technology has stopped. This technology is used to allow uncompressed, low-latency and multi-channel audio data to move across standard Ethernet networks [Pavel Kudelin, 2015].

As CobraNet is a licenced technology, users must pay licence fees which significantly increases the overall prices of CobraNet devices.

CobraNet utilises standard 10 and 100 Mbps bandwidth Ethernet networks. CAT5 (or better) cables can be used with up to 100 m cable segment spans. Connections utilising fibre optic cables allows longer distance to be achieved (multi-fibre up to 2 km). CobraNet can utilize almost any network switch (100 Mbps or better), managed switches are advisable, but in spite of that, unmanaged switches can be used for small networks. Also manageable switches are recommended for monitoring the network activity that can help in the troubleshooting process. Specialized network interface controllers (NIC) are required to work with CobraNet [Cirrus Logic, 2011].

It is recommended to keep the CobraNet network isolated logically or physically (using VLANs or using separate switches, cables) to prevent dropouts in the audio caused by non-CobraNet traffic [Pavel Kudelin, 2015].

The maximum input/output capacity in CobraNet is 32 by 32 channels; that means that a CobraNet device can send 32 channels and receive 32 channels simultaneously. Channels are grouped into subdivisions named "bundles"; each bundle contains up to eight channels and hence there are four bundles that are incoming, as also four outgoing bundles in each CobraNet device. The number of channels that can be put into a bundle depends on the sample rate and bit depth of the audio data. Increasing one of these two parameters causes the consequent reduction of the number of channels in each bundle [BSS Audio, 2015]. Table 1 shows this with varying the parameters.

Table 1: Changes in the no. of channels depending on changes in the sample rate and bit depth [Cirrus Logic, 2006].

Sample rate (kHz)	**48**	**48**	**48**	**96**	**96**	**96**
Bit depth (bits)	16	20	24	16	20	24
No. of channels in each bundle	8	8	7	4	4	3

CobraNet network's size is not limited by the capacity of the input/output channels, rather its limitation is a size of the networks itself, for instance, a network can have 100 or even 1000 channels that are streamed across the entire network from one device to another, which has a limitation of 32 input channels that can be received simultaneously [BSS Audio, 2015]. The 1500-byte Ethernet MTU limits the number of channels per bundle [Cirrus Logic, 2006].

In most cases CobraNet network's latency can be chosen from three settings: 5.333 ms, 2.666 ms or 1.333 ms [Cirrus Logic, 2006].

Table 2 shows the changes in the number of channels in each bundle; it can be seen that not only does the audio sample rate and bit depth settings affect the number of channels in each bundle, but also changes in latency as well.

Table 2: Changes in the number of channels depending on changes in latency, sample rate and bit depth [Cirrus Logic, 2006].

Latency (ms)	**Number of channel in each bundle**					
	48 kHz, 16 bit	48 kHz 20 bit	48 kHz 24 bit	96 kHz 16 bit	96 kHz 20 bit	96 kHz 24 bits
5.333	8	8	7	5	4	3
2.666	8	8	8	8	8	7
1.333	8	8	8	8	8	8

CobraNet has a very significant limitation, which appears in the dependence between the maximum number of switches between the transmitting and receiving devices and the latency. For example, when the latency is set to 5.333 ms, there should not be more then 7 switches in one chain between the transmitting and receiving devices; with 2.666 ms latency settings there should not be more then three switches, and for 1.333 ms only 1 switch is recommended. That means that by decreasing the number of the switches between transmitting and receiving devices the lower latency can be safely set [BSS Audio, 2015].

Almost all of the CobraNet devices have primary and secondary ports that can be used for redundancy option, which is based on a physical connection (port-link redundancy). Even though both primary and secondary ports are connected, only the primary port is active; the secondary port is inactive (it does not send nor receive) until there is a failure in a primary port or its cabling. Both ports can be connected to the same switch for tolerance against cable failure. The best option is to connect the ports to separate switches that can help to obtain tolerance against switch failure. If that option is chosen then both switches have to be connected together to avoid the situation when sending traffic to the secondary port on a receiving device, which is inactive due to the active connection on a primary port on the same device [BSS Audio, 2015].

The numbers from 1 to 255 that are reserved for multicasting create broadcast transmission on the CobraNet network (one—to-many); the numbers from 256 to 65279 are reserved for unicasting and transmit the data in one-to-one way; numbers from 65280 to 65535 are used as private bundles, these number are paired with MAC address of a transmitting device. For receiving a private bundle both the number of a bundle and the MAC address of a transmitting device must be specified. There are no limitations on the total number of private bundle within a CobraNet network, as 256 private bundles are obtainable for each transmitting device [Cirrus Logic, 2006].

One more type of bundle in CobraNet is multi-unicast; it uses the same range of numbers that unicast (256-65279) does, but the difference between multi-unicast, unicast and multicast is that unicast transmits data in one-to-one, multicast does it in one-to-many, but multi-cast uses one-to-four max method, so multi-unicast feature limits the number of receiving devices. It helps to prevent the spreading of the audio data not only between CobraNet devices, but also between non-CobraNet devices that can significantly decrease the utilization of a network [BSS Audio, 2015].

The configuration of audio routing is pretty simple; it can be done using graphical user interface software. To configure a CobraNet network, the following steps need to be taken: the inputs and outputs of logical blocks have to be connected; latency settings have to be selected; number and type of bundle (unicast, multicast, multi-unicast, private) have to be selected. The number of bundle depends on the type of bundle and must be matching on both the transmitting and receiving devices [Pavel Kudelin, 2015].

The CobraNet terminology consists of [Cirrus Logic, 2006]:

- **Conductor** – a CobraNet device that is automatically elected to act as a master clock and transmission arbiter in the network;
- **Bundle** – the element of audio routing in a CobraNet network;
- **Performer** – the CobraNet device that is used in case of the conductor's failure, which is automatically promoted to become the new conductor;
- **Transmitter** – the logical entity of the CobraNet interface that is able to transmit one Bundle.
- **Receiver** – the logical entity of the CobraNet interface that is able to receive one Bundle.

2.3. Dante

Dante (Digital Audio Network Through Ethernet) is a collection of hardware, software and network protocols that was developed in 2006 by Audinate. Dante allows delivery of uncompressed digital over multi-channels utilizing rules of the Ethernet network and Layer 3 IP packets. Just like CobraNet, Dante is licensed technology, so companies that manufacture Dante enabled products have to pay licensing fees and that is reflected on prices of these products [BSS Audio, 2015].

Dante utilizes standard Gigabit Ethernet rules; CAT 5e (or better) cables can be used if 100 m maximum length of cable segments is enough for requirements of a Dante network, if not, fibre optic cables can be used [BSS Audio, 2015].

Almost any switch (manageable or unmanageable) can be utilized for the purpose of Dante networks, but there is a recommendation for better utilization of a Dante network: manageable Gigabit switch with the support of DiffServ QoS, which has to be set to strict priority and four queues mode [BSS Audio, 2015]. DiffServ QoS is used to prioritize the Dante signals and clocking to avoid lowering of real-time performance on the network. All of Dante traffic is marked for QoS at the highest priority level [BSS Audio, 2015].

Another Dante recommended network switch feature, in case of using multicast flows, is IGMP Snooping; it is used to ensure that multicast flows are sent to chosen destination devices, not across the entire network causing decrease of network utilization [BSS Audio, 2015].

Unlike CobraNet, Dante can coexist in a mixed traffic network without any issues, so there is no need to keep Dante traffic in separate VLANs or physical network (if there is no special need for that) [BSS Audio, 2015].

The maximum capacity of the input/output per Dante device depends on the device itself. Technically 64 input channels are subdivided into groups named "flows" (up to eight channels in each), but actually all the process of creating these flows is done automatically, so there is no need to manage it [BSS Audio, 2015].

Like CobraNet, Dante is using two ways of sending the audio traffic to its destinations – unicast and multicast. Unicast flow usually assigns space for four channels, however, there is a limitation in the total number of unicast flows; sending of the same audio signal to many destinations simultaneously in Dante is named "fanout". Because of the utilizing of large fanouts, the supply of flows can be exhausted, this can happen as each identical audio signals consumes the bandwidth of a network. The use of multicast flow can help to avoid the fanouts and the data can still be broadcasted to multiple receivers using only one flow. In Dante networks, unicast is set by default, if there is a need it can be manually changed to multicast [Audinate, 2015].

Latency in a Dante network depends on the devices that are utilized. Latency can be set in the range between 0.083 ms to 10.000 ms. Like in AVB and CobraNet, the latency and switch hops are related; Dante utilizes the same rule - lowering the switch hops allows for a lower value of the latency to be safely chosen [BSS Audio, 2015].

Many Dante enabled products have a redundancy feature that can be used to run the same audio data on two networks simultaneously creating a failure-safe mechanism. The main idea of redundancy in Dante is to create completely separate networks (primary and secondary) using a set of switches and cables that are not connected to each other [Audinate, 2015].

Unlike CobraNet where redundancy is utilized using a link method (only one port is active at a time), in Dante two ports (primary and secondary) mirror each other; both ports have to be connected to two switches that are separated from one another that delivers the correct failover process [BSS Audio, 2015].

In case of the main switch (to which primary ports are connected to) failure, mirrored audio data will be transferred to its destination over the secondary ports and secondary switch. In case of failure of the cable that connects the primary port and primary switch, the same operation is performed. Whilst shared IT infrastructures can be utilised by the primary network, the secondary network is completely isolated; it does not carry or connect to mixed types of data. All the settings applied to the primary network are reflected on the secondary network; no additional configuration is required [BSS Audio, 2015]. Fig. 1, below, shows how the redundancy option is realized in Dante enabled devices. [Audinate, 2015].

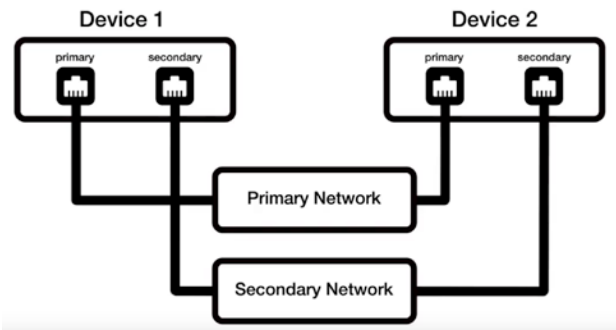

Figure 1. Redundancy set-up link in Dante enabled devices.

At the moment, Audinate offers three Dante related software applications – Dante Controller, Dante Virtual Soundcard and Dante Via. Many of the manufacturers that make Dante enabled products release their own software applications, whose purpose is to set up and manage Dante networks and devices [Audinate, 2015].

Dante Controller is a primary software application that allows setup and control of Dante networks; it allows discovering and configuring Dante devices, synchronization of clocks, assigning preferred Master Clock devices, routing the signals (managing subscriptions), changing latency settings, as well as also changing the type of communication between devices – unicast or multicast. Dante Controller is free, cross platform software that works with any Dante enabled device. It is very useful not only for configuring and managing, but also for monitoring network activity and troubleshooting [Audinate, 2015].

Subscriptions of Dante devices are made using names of the devices, not IP, MAC addresses or number of bundles, so routing of signals becomes pretty simple [Audinate, 2015].

Dante Virtual Soundcard is a software application, whose purpose is to turn a PC or Mac into a Dante enabled device; it allows transmitting and receiving audio data without additional devices, only standard Ethernet port is utilized [Audinate, 2015].

Dante Virtual Soundcard allows choosing different settings – the number of input/output channel (from 2 x 2 up to 64 x 64), latency (4, 6 or 10 ms), sample rate (44.1 kHz. 48 kHz, 88.2 kHz, 96 kHz, 176.4 kHz and 192 kHz) and network interface. Choosing the appropriate settings that are suitable for project needs allows saving of the computer's resources and makes the working process more efficient. This software can work with various Digital Audio Workstations (DAWs) (Logic, Pro Tools, Cubase, *et al.*), as well as also with consumer applications. As soon as a Dante Virtual Soundcard is installed, configured and enabled it can be chosen as an audio input/output device in applications. Currently Dante Virtual Soundcard does not support a redundancy option [Audinate, 2015].

Dante Via is a software application that allows computer based audio routing and a wide range of applications to be connected to a network and also be interconnected. It lets the user monitor Dante channels, isolate and route applications and create standalone audio networks in order to share different audio devices and applications in real-time. The same as the Dante Virtual Soundcard, Dante Via does not require additional devices [Audinate, 2015].

For configuring IP addresses, Dante has a built-in function that is using DHCP (Dynamic Host Configuration Protocol) servers (which are commonly built-in every modern router or even switch) on the network; standard DHCP protocol is used for the configuration. Having multiple DHCP servers on the same network or using IP addresses that are reserved for secondary link local devices for configuring a DHCP server on the primary network will cause an error. In cases when the network does not have a DHCP server, Automated Private Addressing (Link Local) is utilized. Automated Private Addressing is a usual case for simple, closed audio Dante networks that have no connection to the Internet. When a wait time is out and a Dante device does not get a response to a DHCP request, it automatically assigns itself an IP address using the special reserved set of values, after that the device performs a check and adjust its IP address if a conflict has occurred. The Link Local addresses in a Dante network are in the 169.254.X.Y range, where X and Y are values between 0 and 255 [Audinate, 2015].

Clocking is really important in networked audio. Most of the clocking process in Dante networks is performed automatically, but understanding of its functioning is very helpful during installation and troubleshooting of Dante networks [Audinate, 2015].

One of the main clocking objectives is to prevent time delay, phase shifting and especially jitter. Jitter is unacceptable in real-time audio networks, as it generates harmonic distortion in the original audio signal. In Dante networks, audio clocking is recreated in each endpoint and synchronized over the network. One device is assigned as the Master Clock which is responsible for synchronization with all devices on the network; generally it is not important which Dante device has this rôle and by default, Dante sets the Master Clock device automatically. A Dante system does not allow setting more than one master clock device simultaneously. Many devices in a Dante network can be assigned as the Master Clock automatically, but the following criteria will prioritize the device in Master Clock election – device has clock inputs (Word Clock or AES3), device has better connection (1 Gbps over 100 Mbps), device has lowest MAC address. If there is a need to assign the particular device as Master Clock, it can be done using the Dante Controller software, just setting the device as Preferred Master, thus the device will then have a priority in the Master Clock election. If two or more devices are assigned as the Preferred Master, the device with the lowest MAC address will be chosen [Audinate, 2015].

All other Dante devices act like Slaves Clocks; each of them have their own internal clock and makes small adjustments to the Master Clock. The time synchronization data is transferred over the Dante network using the IEEE 1588 Precision Time Protocol (PTP). If the Dante Master device's clock synchronization fails, it is instantly muted and another device is assigned as the Master Clock. As soon as clock synchronization is restored, the device comes back online. This mechanism prevents the asynchronous audio from reaching the audience. In case of using the Dante Virtual Soundcard, the computer's clock is used as the Master Clock [Audinate, 2015].

2.4. BLU Link

BLU Link is a digital bus technology that is designed to allow digital audio to be transferred between the Harman manufacturer devices, utilizing standard network cables. Despite BLU Link being licensed by Harman, fees are not charged, thus lowering the prices of their products. Initially BLU Link was developed by BSS audio, but it started to be utilized in various Harman products, for example, amplifiers, input/output expanders, personal monitor controllers, speaker processor and mixing consoles [BSS Audio, 2015].

Unlike AVB, CobraNet and Dante, BLU Link is not Ethernet based technology, but in spite of that, similarities exist. For instance, BLU Link utilizes standard network cables – CAT 5e (or better) or if coverage of longer distance is required fibre optic cables can be used. BLU-MC1 Gigabit media converter is recommended for use with BLU Link devices, it allows for the transfer the data at a distance up to 10 km [BSS Audio, 2015].

Any network hub, switch or router can be used with BLU Link. BLU Link will not function if it is connected to any network device. Instead of using network devices, direct connections between BLU Link devices are used; two types of topologies are utilized – Daisy Chain and Ring. All BLU Link ports are bidirectional, but it is important not to make input-to-input or output-to-output connection between BLU Link devices [BSS Audio, 2015].

The physical setting-up of a BLU Link network is straightforward; to do that, network cables need to be connected from the output to the input ports on all of the devices of the BLU Link network. Each BLU Link enabled device has input and output ports. If the first and the last devices of the network are not connected together then the network is connected using Daisy Chain topology. If the first and the last device are connected and a loop is complete then the network is connected with Ring topology. Daisy Chain topology allows audio data to be transmitted from any source to any destination on the BLU Link network without issues, but Ring topology can be considered as better practice, because it allows BLU Link networks to be fault tolerant. If any cable or device has a failure, devices that have no connection between them will detect the failure and the audio data will be automatically redirected and transmitted using the reverse direction - literally speaking, the Ring topology will become Daisy Chain. These two topologies allow up to 60 devices per BLU Link network [BSS Audio, 2015].

The BLU link ports pass audio data only, for control data, separate ports (labeled Ethernet) are used. The key difference between BLU Link and other network enabled audio technologies is that the audio data in BLU Link networks is completely separated from the Ethernet network. The benefits of this solution are that corruption of audio data is prevented by separating it from other network traffic using dedicated cables, also it helps to avoid the process of the configuration of the network switches [BSS Audio, 2015].

The maximum number of channels in a BLU Link network is 256 with a sample rate of 48 kHz, doubling up the sample rate to 96 kHz decreases the number of channels in half, to 128 channels accordingly. Unlike in CobraNet networks, the bitrate is not variable, it is always 24 bits [BSS Audio, 2015].

Unlike other audio networking technologies that utilize various ways of sending audio traffic to its destination (unicast, multicast and variations of these methods), broadcasting is used in BLU Link; that means that for sending audio data to a number of destinations from one source, only one from 256 (or 128) channels needs to be consumed. For example, if a home is connected to ten BLU-160 BLU Link enabled sound processors from Soundweb London to which ten powered speakers are connected using analogs outputs. If a microphone is assigned to a BLU Link channel, the audio data will reach its destination (ten powered speakers) simultaneously. Practically it is irrelevant to which of the amplifiers the microphone is connected to, as the assigned audio data will still eventually reach all the destination devices [BSS Audio, 2015].

The latency in BLU Link networks depends on the physical path between the source and destination devices. The latency between the first (source) and the second devices is 11 samples, the latency for each next hop is four samples [BSS Audio, 2015].

For instance the latency of the system that was mentioned above can be calculated as follows:

T_1 = 0 samples

T_2 = 0 + 11 = 11 samples

T_3 = 11 + 4 = 15 samples

T_4 = 15 + 4 = 19 samples

T_5 = 19 + 4 = 23 samples

T_6 = 23+ 4 = 27 samples

T_7 = 27+ 4 = 31 samples

T_8 = 31 + 4 = 35 samples

T_9 = 35 + 4 = 39 samples

T_{10} = 39 + 4 = 43 samples

Fig. 2, shows the changes in latency from speaker to speaker that are connected to the BLU Link device; in this case 48 kHz sample rate setting is shown.

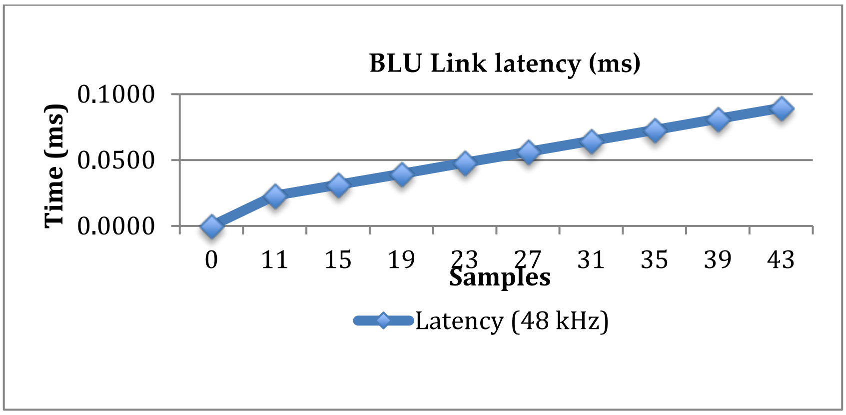

Figure 2. The Changes in Latency from Speaker to Speaker connected to BLU Link device.

That means that sound exits the second speaker 11 samples later than from the first speaker, the third speaker 15 samples later and so on. Now when latency is known in samples, these values can be converted to time units. This can be done by dividing the number of samples by the sample rate, i.e. ***samples/kHz*** [BSS Audio, 2015]. As a result, the sound exits the last speaker 0.895 ms (43 samples/48000 Hz) later than the first speaker, or 0.447 ms (43 samples/96000 Hz) later if 96 kHz sample rate is set.

Fig. 3, shows the changes in the latency from speaker to speaker that are connected to the BLU Link device; in this case 48 and 96 kHz sample rate settings are shown to see the difference.

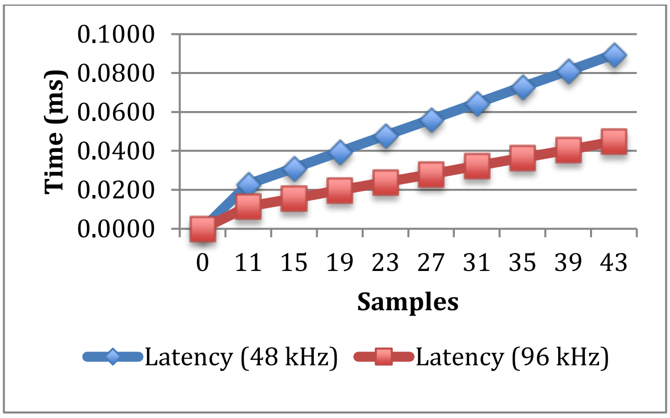

Figure 3. The Changes in Latency from Speaker to Speaker connected to BLU Link device for two different sampling rates.

That means that sound that is exiting the speakers is not completely time aligned, it can be manually done using a delay and simple calculations [BSS Audio, 2015].

One of the key benefits of BLU Link technology is its ability to create a hybrid between Ethernet based audio networks and BLU Link networks. Use of BLU Link minimizes the load on the network and the switch ports, as audio data is separated to dedicated cables, while AVB, CobraNet and Dante use standard network infrastructure which allows to minimize the extra cable-pulling [BSS Audio, 2015].

Combining CobraNet and BLU Link allows solving the limitation of the CobraNet channel count (32 inputs, 32 outputs). It can be done by directly by connecting CobraNet and BLU Link devices together in a ring [Harman Pro, 2014].

Combining BLU Link with AVB allows creating a diversified network with increased channel count, optimized bandwidth and reduced complexity of the configuration. The physical connection of AVB and BLU Link hybrid looks similar to CobraNet, but switches that support AVB have to be utilized [BSS Audio, 2015].

Utilizing a combination of Dante and BLU Link provides solution for a high channel count, as well as support of Layer 3 technology. As many manufactures in the professional audio industry are releasing Dante enabled products, the choice of Dante allows interoperability with lots of devices [BSS Audio, 2015].

As it is not possible to combine more than one Ethernet transport type (AVB, CobraNet, Dante) in the same BLU Link ring, the two Ethernet transport network have to be connected together to share the same clock even if there may be no audio data transmitted between them. However, one of the most utilized combination methods is connecting Blue Link rings with a centralized Ethernet network cloud [BSS Audio, 2015]. The different types of combinations that are possible consist of [BSS Audio, 2015]:

- BLU Link and one Ethernet transport (AVB, CobraNet, Dante);
- BLU Link and multiple Ethernet transports;
  - BLU Link, AVB and Dante;
  - BLU Link, CobraNet and Dante;
  - BLU Link, AVB and CobraNet combination is not possible because of the conflict in synchronization (described below).

In the BLU Link network, one device is used as the Master Clock to synchronize the whole network. The rules of synchronization in the BLU Link network are:

If only one device is synchronized to the word clock (BNC), then this device is the Master Clock [Soundcraft Electronics Ltd, 2015];

If multiple devices are synchronized to the BNC then the comparison of the mastership is done; if the priority of devices is the same then MAC address comparison is done to choose the Master Clock [Soundcraft Electronics Ltd, 2015];

If CobraNet and BLU Link are combined as one system, then one of the devices from the CobraNet network acts as the Master Clock; all BLU Link network devices act as Slaves to the Master Clock [Soundcraft Electronics Ltd, 2015];

If AVB and BLU Link are combined – one of the AVB devices acts like the Master Clock, BLU Link devices act as Slaves [Soundcraft Electronics Ltd, 2015];

If Dante and BLU Link are connected together as one system, then the Master Clock can be chosen from either network. But usually by default the Master Clock is provided by the Dante network [Soundcraft Electronics Ltd, 2015];

If combinations of the CobraNet, Dante and BLU Link are used together, the Master Clock is then provided by the CobraNet network. This means that the BLU Link and Dante networks act like Slaves to the Master Clock [Soundcraft Electronics Ltd, 2015];

Another supported combination is when the AVB, Dante and BLU Link networks are connected; AVB provides the Master Clock to other networks [Soundcraft Electronics Ltd, 2015];

The only combination that is not supported is a connection of AVB, CobraNet and BLU Link networks; as AVB and CobraNet send conflicting Master Clock signal to the BLU Link network and that compromises the BLU Link audio [Soundcraft Electronics Ltd, 2015].

2.5. Comparison of Technologies

2.5.1 Technical Comparison

Table 3 is a comparison summary of the information about the four network enabled audio technologies. Some of the parameters depend on specific devices that are chosen; for this case devices from BSS Audio by Harman was selected as only these devices support all four technologies and also their combinations thereof. This also makes the comparison of these technologies fair.

Table 3: Comparison of Technologies

	AVB	**BLU Link**	**CobraNet**	**Dante**
Max Supported Bitrate	1 Gbps	1 Gbps	100 Mbps	Gigabit Ethernet
Transport Type	Switched Network	Proprietary Ring	Switched Network	Switched Network
Network Layer	Layer 2	-	Layer 2	Layer 3 (IP routable)
Licensed by	open standard	Harman	Cirrus Logic	Audinate
Channel capacity per device (device dependant)	64 × 64 (BSS Audio)	128 × 128 (BSS Audio)	32 × 32 (BSS Audio)	64 × 64 (BSS Audio)
Network Channel Capacity	Virtually unlimited	256 × 256	Virtually unlimited	Virtually unlimited
Latency (ms) (min – max)	0.25 – 2 (by default)	11 samples - 1st hop 4 samples – each next hop	1.333 – 5.333	0.083 -10.000
Maximum bit depth	No restriction	24 bits	24 bits	24 bits
Max sample rate	No restriction	96 kHz	96 kHz	192 kHz
Ethernet based	Yes	No	Yes	Yes
Passing through network switches	Yes (AVB specialized switches required)	No	Yes	Yes

Level of risk of non-A/V traffic causing failure in network	Low	None	High	Medium
Coexistence with non-A/V traffic on a single cable	Yes	N/A due to use of dedicated cables	Yes	Yes
Required switch management	No	N/A due to use of dedicated cables	No	Yes (large systems)
VLANs required	No	No	Yes	Yes (large systems)
Redundancy	Implemented by specific manufacturers	Yes	Yes (port-link)	Yes
Video data support	Yes	No	No	No

The naming of one of these technologies as "the best" is totally incorrect, because besides the advantages, each of them also have their own disadvantages. The fairest criteria for choosing the specific technology are the needs and budget of a project, where one or more technology (or even combinations of them) will be utilized. The following section contains further information about AVB, BLU Link, CobraNet and Dante and their applications.

2.5.2 Use of Technologies

In most cases, AVB should be used for new installations, as specialized AVB switches have to be utilized and not every existing IT infrastructure allows for the replacement of switches. However, the use of AVB switches is quite rational, as "smart" switches can reduce the setting up and management costs; also the level of risk that non-A/V traffic will cause failure in the audio network or vice versa is low, as all of the audio data is separated from non-A/V traffic in automatically created VLANs [BSS Audio, 2015].

AVB is open standard; this fact has both advantages and disadvantages. In contrast to Dante, which was developed "behind the closed doors" by Audinate and released in 2006, the idea of AVB was first announced to the public and only after that development started; the final release of the technology was in 2013. That means that Dante has an advantage in time aspect. The fact that AVB is an open standard gives companies and manufacturers advantages not only in avoiding licenses fees, but also that this technology provides flexibility and interoperability. The vendors are thus more neutral (monopoly is not so strong); not only big companies can participate in its development process, small vendors or even amateurs can take a part in developing of solutions for the technology [Pavel Kudelin, 2015].

One of the largest projects where AVB technology is involved is for the new ESPN's digital centre [DC 2]; replacing previous ESPN's all-MADI audio transport system AVB fully meets the requirement of such a large project. It is planned to utilize one of the key functions of AVB – video data streaming in this project as well that it makes a choice of AVB significant, as AVB is the only technology that supports this option. Scale, importance and requirement of this project helped in development of AVB, as many manufactures that have been involved into the working process agreed to make support of AVB in their devices [Sport Video Group, 2014].

BLU Link should be used instead of other technologies if the project has constraints in budget and the size of the network can be limited to 256 sources; also BLU Link can be used to interconnect other technologies for creating a large network, adding a large amount of channels, sources and reducing the costs. If existing IT infrastructure does not allow coexistence of some other types of data (audio) with current traffic, then use of BLU Link is necessary, as dedicated cables are utilized for it [BSS Audio, 2015].

CobraNet can be called a legacy system, as it is not in development anymore and it is used “as it is”, so generally it should be used for enlargement of existing CobraNet networks and equipment, not for new projects. This technology has too many limitations and new installations based on CobraNet nowadays are not rational due to its inherent: small capacity of input/output channels, relatively high latency and complexities in network setting up. Thus the management makes this technology not the best choice for projects that require network enabled audio technologies [BSS Audio, 2015].

The next project example is not much related to the music industry, but it perfectly reflects the contrast between older and newer network enabled audio technologies and how the legacy technology is replaced by a more modern one.

In 1999 it was decided to update the sound system of the world famous Wembley Stadium in London, England. At that moment the existing audio system was used for ten years and consisted of a single fibre optical cable. The main requirements of the project were building a network with dual redundancy and fault detection system in each of the stadium’s zone, as well as replacing the various hardware system with digital domain processors. CobraNet technology was utilized for this project; 14 MediaMatrix units (two main, 12 subs) were installed around the stadium, these units were connected together via Ethernet for controlling; each unit was equipped with CobraNet interface DSP cards. Use of 14 fully decentralized processors allowed high redundancy in the whole system; the system was able to function in normal mode even in case of half of the equipment failing. The single fibre optical cabling was replaced by a dual ring, which was laid around the stadium; to increase the level of redundancy the sub unit racks connection to the fibre optic rings were alternated – Ring Pair A was connected to odd-numbered units, Ring Pair B – the even. In the case of primary ring failure changeover was automatically made to the secondary ring using two-channel fibre hubs that were installed in each unit rack [Cirrus Logic, 2005].

CobraNet technology was utilized in Wembley Stadium for 12 years; in 2011 before the 5th regular NFL game, Dante technology has been chosen and deployed to enlarge the existing A/V stadium’s system. To achieve this 14 Dante enabled processors from Lab Gruppen were used; nearly two kilometers of analogue cabling were replaced with fibre optic cabling to transfer audio and control data; that allowed getting noiseless digital signal flow, as well as reducing to zero the degradation of the signal because of the distance. The use of Dante technology allowed for having easily manageable, lower installation cost, zero noise, reliable, low latency system with faster control and tolerance to degradation of the signal due to the long distances of the cable run [Audinate, 2015].

Dante technology has been chosen instead of the system that existed (including CobraNet) for this specific event because of its reliability, popularity and wide range of Dante enabled products that are provided on the market. Also Dante technology allows faster setup and teardown time that is an important aspect during live events, which require large A/V systems or augmentation of existing systems that have some limitations and do not meet the requirement of the event, for instance, larger audience, larger amount of artists and musicians, scale of the event itself.

Currently Dante is the most popular and developed network enabled audio technology, a current list of 127 Dante licensed manufactures (at the time of writing this paper) easily proves it. That means that the use of Dante should be considered if the installation requires various devices from different manufacturers. Also a wide range of Dante enabled products is provided on the market, so devices that meet the requirement and budget of a specific project can be easily selected. One more reason for using Dante is the requirements of existing IT infrastructure, where Layer 3 management and standard, non-specialized switches have to be used [Audinate, 2015].

Utilization of Dante technology has also spread to various areas, which require extremely low-latency, synchronized transmission of digital media over standard networks. Currently Dante covers such areas as live sound, professional recording, broadcasting, public address (airports, stadiums, stations), places of worship and commercial sector (bars, restaurants, casinos, hotels).

Currently one of the largest projects for professional studio recording utilizing Dante was completed in The College of Music at University of North Texas in August 2015. The main requirement of the project was to have a solution for good connectivity of two main performance halls that are located in separate buildings; each of the halls has its own recording control room, as well as a portable jazz workshop. Networks in two buildings are connected together with RedNet D64R units, which act like the MADI (Multichannel Audio Digital Interface); that allows combining two networks in one or working separately. 44 Dante enabled RedNet units from Focusrite in total are used for this project. The existing network (fibre optic cabling) and sound recording (ProTools | HD system and a lot of various hardware) infrastructures were one of the reasons for choosing Dante [Audinate, 2015].

2.5.3 Analysis of the Market of Network Enabled Audio Devices

Also the statement that Dante technology is the most popular on the professional A/V market can be qualified using the analysis of the trends and dynamics of the audio networking market from RH Consulting, that is a company that deals with consultancy in audio and A/V scope. The company claims that the analysis is independent and none of the competitive companies had some influence on their analysis of the results or opinion.

A lot of questions have been raised during the analysis, for instance, was the project successful; was the product utilized as a networking application; was another technology more successful. Unfortunately many of these questions can not be answered, as even the analysis's authors say that it is nearly impossible to get reliable and exact data of the network enabled audio interface sales, as manufacturers do not release this kind of information, as also it is impossible to find out how much profit does the manufacturer get from one or another product. One more issue for collecting data for the analysis is that the existence of a network port in the device does not mean that it is utilized in a networked application [RH Consulting, 2015]. Furthermore, this analysis cannot be used as the only source of opinion, but it can help to understand what is the situation on the network enabled audio technology market and what are the key moments that affect and change the situation. Further insight can be gleaned by analyzing the trends in the progression of network enabled audio technologies. Fig. 4, shows the number of licenses for AVB, CobraNet and Dante) during the six years period (July 2009 – January 2015) [RH Consulting, 2015].

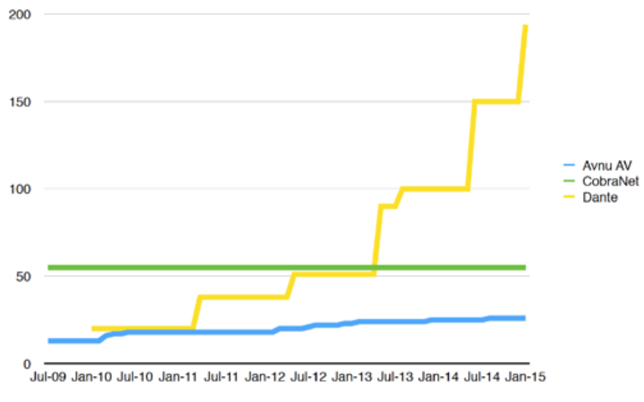

Figure 4. The Issuance of Licences from July 2009 – Jan. 2015 for AVB, CobraNet and Dante.

Fig. 4, shows that Dante technology has seen an increase in licenses (new adopters or products) by 400% in the two years period (2013 – 2015) and in Jan. 2015, Dante had almost four times more licences than CobraNet and eight times than AVB. Also that no new licenses for CobraNet were issued, so there has not been any further progress at all with CobraNet [RH Consulting, 2015].

To get more reliable results only the manufactures that work in the professional A/V sector were chosen for this study; products for automotive, industrial, consumer, switch production were not included [RH Consulting, 2015].

- The next analysis was conducted based on these assumptions [RH Consulting, 2015]:
- Only products that are available for shipping were used;
- Every SKU (Stock Keeping Unit) of a product was included;
- If the product is offered in various card configurations then this product is counted as one product, for instance, sound processors with 16 inputs/outputs, 24 inputs/8 outputs, 8 inputs/24 outputs etc. are considered as one product, as the total number of the channels is the same;
- If a product is available in various models with different input/output number of channels, then it is considered as separate products;
- Products from manufacturers that are not members of the AVnu Alliance were not included;
- Products (hacks, circuit boards) that do not allow a product to become networked were not included;
- Software solutions that allow supporting of network enabled audio technology for PC or Mac were included.

Fig. 5 shows the audio related product availability by category [RH Consulting, 2015].

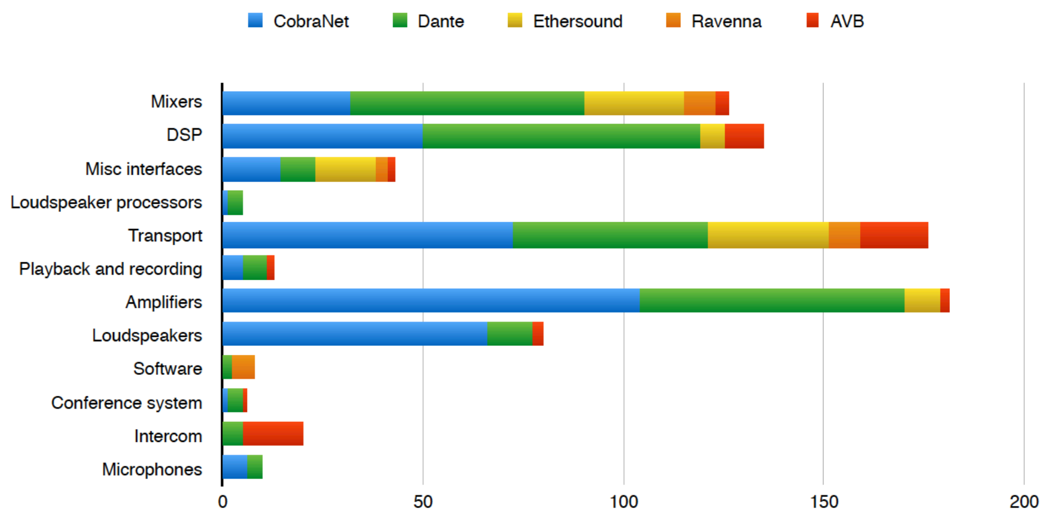

Figure 5. The audio related product availability by category [RH Consulting, 2015].

According to the results of the analysis, 53 of the 66 CobraNet enabled loudspeakers are released by one manufacturer, also 25 of the 104 CobraNet enabled amplifiers are products of one manufacturer; this distorts the result and makes the success of CobraNet deceptive [RH Consulting, 2015].

Dante is the only technology, which offers products in each category [RH Consulting, 2015].

The categories on which the analysis was focused on are – the interfaces, audio transports and software solutions. That was done for the following reasons:

The manufacturers have no interest in exactly networking, they want their audio products to be sold.

The use of the audio transport devices is rational only if not all the devices on the network are network enabled, without it use of audio transport devices is irrelevant.

Software solutions that enable PC or Mac to be the part of the audio network were one of the points of the analysis. Also it is worth noting that more software solutions have been developed and have now appeared on the market [RH Consulting, 2015]. If technical limitations (latency, number of input/output channels) can be left out then software solutions offer a great opportunity to expand the possibilities of computers being used to connect to the audio network. It can help in many work processes, for example, monitoring, recording, editing. It can save the budget, as software solutions that enable audio network functions straight from a workstation are more affordable than investing in the purchase of additional hardware network enabled audio interface solutions. One of the main questions is will network audio networking completely replace older analogue technology, or will it just find its niche application in the business?

According to the analysis from RH Consulting, innovation in a technology in most cases begins a new business, which in its turn makes a loss in the existing business model. Talking about network enabled audio technology, when the technology has started to become popular it made a loss in the field of existing technology, in this case – analogue audio. The simplest example is cabling and the connector; it is an additional way to earn extra profit, as all the devices need to be interconnected. Analogue cabling has plenty of disadvantages, not only the technical one, but also in terms of price. The form factor for devices usually is set by the size of the connectors, as they have to be fitted onto the device and if the number of inputs/outputs is large, therefore the number of connectors will be also large [RH Consulting, 2015].

The form factor of network enabled audio device usually is more flexible and standard, as standard Ethernet cables (Cat 5 or better) and connectors (RJ-45) are utilized [RH Consulting, 2015]. Also the use of standard cabling can reduce or eliminate the cost of installation labour, as the existing network infrastructure can be utilized for the purpose of audio networking and it can be done by any IT cabling company. Whereas the service for running the temporary analogue cabling, terminating it or permanently installing it will cost much more [RH Consulting, 2015].

The business model for audio networking is still not mature. AVB is an open standard, but to become more popular it needs more investments for its promotion, testing and development. Also at the moment the number of companies that are utilizing AVB for the purpose of professional A/V is small. BLU Link is licensed technology with avoided licensing fees, but that still has not help to spread its technology widely as it is mostly used by Harman itself. CobraNet and Dante are licensed technologies which helps to raise their profit; Dante also charges for software solutions.

The success of CobraNet and Dante is possibly connected with licensing politics, as, firstly, it gives more profit to companies, secondly, open standards usually are seen by manufacturers (adopters) and users as something more unreliable and they do not want to take the risk because of various factors; one of them being that open standards usually do not get appropriate support from the manufacturers. Also the success of Dante can be determined by the level of product support and development. Table 4, shows the introduction of Dante products. Such a number of products in only nine years shows that Audinate is committed to manufacture product solutions to be adopted regularly and that new products are released to meet developing market requirements. Also the number of manufacturers continues to grow as Audinate actively participates in adoption of new products and projects [RH Consulting, 2015].

Table 4: Dante Product Release Dates [RH Consulting, 2015].

Product	Year
Dante Legacy Module	2006
Dante Virtual Soundcard	2009
Dante Brooklyn	2010
Dante Brooklyn II	2011
Dante PCI-e card	2011
Dante HC	2014
Dante Ultimo 2x2	2014
Dante Ultimo 4x4	2014
Dante Via	2015

CobraNet is still considered as a successful protocol, as it was one of the first technologies that was invented and became popular; currently it is still utilized in a large number of equipment [RH Consulting, 2015]. However, CobraNet will, however, be discarded by manufacturers in favour of more efficient network enabled audio technologies, as CobraNet has a large amount of limitations and disadvantages being a legacy system.

3 Experimental Setup

Fig. 6, below illustrates the experimental setup using two digital audio workstations (DAWs).

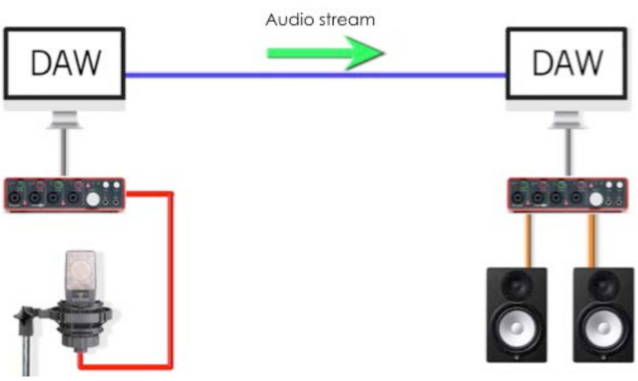

Figure 6. The experimental setup between two DAWs.

This basic setup allows to record voice o, instrument at the sender side, convert the analogue signal to digital using ADC (Analogue Digital Converter) in USB audio interface, transfer the digitalized audio data across the LAN (Local Area Network) to the receiver side and after the digital to analogue conversion monitor the recorded audio signal.

Figure 7, illustrates the workflow of the above setup. It was decided to use Audacity as the DAW for this experiment. There are number of reasons for that, specifically, small system requirements, ease-of-use, functionality, efficiency and that fact that it is distributed under GPL (GNU General Public License), which means that Audacity is open-source software program [Audacityteam, 2015].

VB-Audio Virtual Cable will be used as it is a donationware software program that allows the interconnection between various audio applications. The basic version of this software program can be used completely for free; the main differences between VB-Audio Virtual Cable and VB-Audio Hi-Fi Cable are the number of inputs and output; Hi-Fi version has two more virtual audio devices, for both playback and recording audio devices; also it differs with quality settings (supports 24 bits 384 kHz audio streaming [André Michel, 2016]. The basic version of a virtual audio cable, which will be used for the purpose of the experiment, allows setting of the sample rate between 8 and 192 kHz (on input and output) and supports all Windows Audio Interfaces – MME, Direct Sound, WDM, WASAPI, ASIO [Burel, V., 2016].

VLC an open-source with GNU Lesser General Public License v2.1+ was used, as it supports the following input and output stream formats: HTTP, UDP/RTP (unicast and multicast), RTSP and MMSH. These stream formats can be combined during one stream; for example, one stream can be transferred over a network using HTTP, RTP and UDP at the same time, which is useful if various streaming methods are required. Also, if the use of transcoding is considered, a user needs to make sure that the streaming format is compatible with the chosen transcoding method [VideoLAN, 2016].

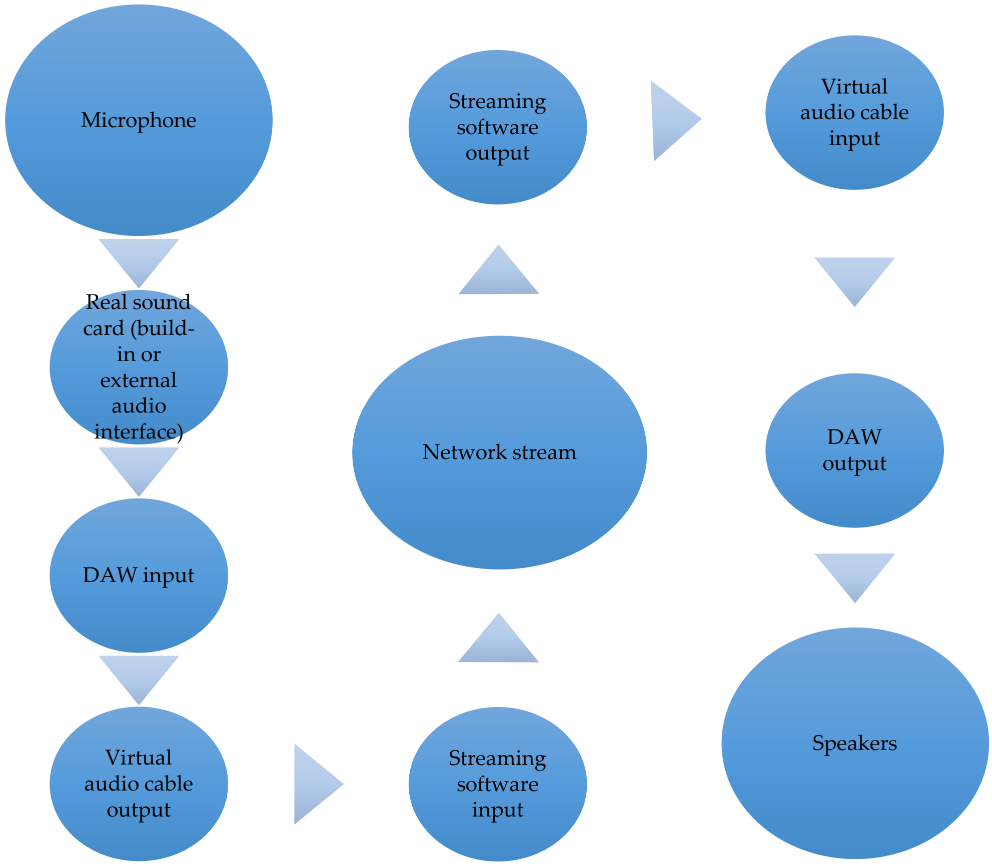

Figure 7. The Experimental Workflow of the DAWs.

For the purpose of the experiment the author has chosen Oracle VM VirtualBox, because of its obvious advantages (open-sourceness, ease-of-use, efficiency) VirtualBox showed itself as the most stable and reliable virtual environment in the past and looking ahead it was efficient within the framework of the experiment and completely was able to replace real receiver's machine and network components [Oracle, 2016]. Using a laptop with Windows 8 operating systems and Oracle VM VirtualBox, the author installed Windows 10 virtual machine.

For the purpose of the experiment the author has chosen the HTTP protocol as the module for outputting the stream. HTTP is a basic protocol that is used for exchanging or transferring hypertext, but nowadays it is used for many kinds of media and multimedia streaming is not an exception. TCP (Transmission Control Protocol) is also utilized because even though when TCP is used more bandwidth is needed due to a bigger header size (20 bytes compared to 8 bytes when using UDP), its utilization is more rational because of its higher reliability [PieterExplainsTech, 2014].

The outcome of the experiment was dismal in terms of latency and showed the need to use coordinated and integrated hardware and software. The latency experienced was rather high and this set-up was for only sending voice data. The results and comparison with the established protocols are summarized in Table 5, below. At the current stage the author was not enable to find the reason of such a high latency of 2 s, which can lie in the wrong configuration, the lack of appropriate settings, limitation in used software programs, or even the limitation of basic hardware or virtual environment that were used for the purpose of experiment. One suggestion is to use automated batch files that would effectively and configure all the settings for the various pieces of software to work efficiently and thus lower the unexpected latency of the basic experimental setup.

Table 5. Comparison of the Experimental Set-up against the Established Protocols.

	AVB	BLU Link	CobraNet	Dante	Author's method
Max Supported Bitrate	1 Gbps	1 Gbps	100 Mbps	10 Gbps	1 Gbps
Channel capacity per dependant device	64 × 64 (BSS Audio)	128 × 128 (BSS Audio)	32 × 32 (BSS Audio)	64 × 64 (BSS Audio)	1
Channel capacity per network	Virtually unlimited	256 × 256	Virtually unlimited	Virtually unlimited	1
Latency (ms) (min – max)	0.25 – 2 (by default)	11 samples -1st hop 4 samples – each next hop	1.333 – 5.333	0.083 -10.000	2 seconds
Maximum bit depth	No restriction	24 bits	24 bits	24 bits	32 bit (depends on hardware)
Maximum sample rate (kHz)	No restriction	96	96	192	192 (depends on hardware)

5. Conclusions

The principles of open-source software programs and finding ways of replacing proprietary solutions, with the combination of free software solutions, is the first challenging point that was discovered. Proprietary hardware and software network enabled audio solution are demandable and beneficial, but usually they do not meet amateur users requirement in terms of price and they can be replaced by open-source solutions or its combination, which can be configured and become relevant with the needs of users.

The advantages of network technologies, which are used for the purpose of the music industry, in comparison to analogue technologies are the probability that the audio technologies that operate over the IT infrastructure, will replace the standard audio technologies in the future, due to obvious advantages, for instance, the possibility of utilization of existing network infrastructure, instead of analogue cable runs, having easier manageability, lower installation costs, lower latency and tolerance to degradation of a signal due to the long distances; the probability is indicated by the increasing demand for network enabled audio technologies not only among users and institutions, but also vendors and development companies, which participate in improvements of the technology by bringing new ideas and adopting the existing solutions.

In spite of that the proposed method has a lot of limitations, for example, high latency and limited number of audio channels that can be transferred over the network simultaneously; it is not so beneficial in comparison to existing proprietary solutions, but it fulfilled its main task – replication of network enabled audio interface functions and gave a variety of ideas for the future development and improvement.

The research also outlined and presented the current audio networking protocols that are currently being used: AVB, BLU Link, Dante and CobraLink.

Acknowledgments: Many thanks to Arish Siddiqui (lecturer, second marker), Michael Bunce (ADI modules' leader), Jonathan Bell (Technical Demonstrator-Music of UEL) and Gabriel Tukaj (coursemate).

References

[1] Audacityteam (2015) About | Audacity. Available at: http://www.audacityteam.org/about/ (Accessed: 14.04.2016)

[2] Audinate (2008) Recommended Network Topologies for Dante Networks, Whitepapers. Available at: http://support.labgruppen.com/attachments/token/1hrgpplobxwyoxj/?name=AUDt-ANO-QoS+Switch+Configuration-Lab.gruppen.pdf (Accessed: 20/10/2015).

[3] Audinate (2011) Dante Just Got Easy (Designing Dante Networks). Available: https://www.youtube.com/watch?v=p1TKxj9AIhY (Accessed: 17/10/2015).

[4] Audinate (2015) 'Three Pillars of Audio Networks' Whitepapers, Available: http://go.audinate.com/hubfs/campaign/3pillars/three-pillars-audio-networking-whitepaper-audinate.pdf?t=1449278400272 (Accessed: 07/11/2015).

[5] Audinate (2015) Dante Licensed Manufacturers | Audinate. https://www.audinate.com/products/dante-enabled/partners?option=com_content&view=article&id=343 (Accessed: 25/11/2015).

[6] Audinate (2015) Dante Via - Getting Started. Available at https://www.youtube.com/watch?v=qEIwBbS4aR0 (Accessed 18/11/2015)

[7] Audinate (2015) Getting Started with Dante: 1. Dante Overview. Available: https://www.youtube.com/watch?v=XNpncQzqLDE (Accessed: 15/10/2015)

[8] Audinate (2015) Getting Started with Dante: 2. A Simple Dante Network. Available: https://www.youtube.com/watch?v=ZrWU41Q2F7I (Accessed: 15/10/2015)

[9] Audinate (2015) Getting Started with Dante: 3. Dante Conroller. Available: https://www.youtube.com/watch?v=xr1dJSwNZ9g (Accessed: 15/10/2015)

[10] Audinate (2015) Getting Started with Dante: 4. Dante Virtual Soundcard. Available: https://www.youtube.com/watch?v=K36uBZXnWhk (Accessed: 15/10/2015)

[11] Audinate (2015) Getting Started with Dante: 5. Networking Basics for Audio. Available: https://www.youtube.com/watch?v=j_ih6YCbws0 (Accessed: 15/10/2015)

[12] Audinate (2015) Getting Started with Dante: 6. Dante Clocking Basics. Available: https://www.youtube.com/watch?v=UuxV7ApkLJ4 (Accessed: 15/10/2015)

[13] Audinate (2015) Getting Started with Dante: 7. Unicast and Multicast Transport. Available: https://www.youtube.com/watch?v=clY65dm9YPY (Accessed: 15/10/2015)

[14] Audinate (2015) Getting Started with Dante: 8. Dante Redundancy. Available: https://www.youtube.com/watch?v=7Rgei0UQm88 (Accessed: 15/10/2015)

[15] Audinate (2015) Networking 101 Basics for Audio - Chris Ware at AV Networking World 2015. Available: https://www.youtube.com/watch?v=r---OMjVCps (Accessed: 09/11/2015)

[16] Audinate (2015) The College of Music at University of North Texas, Large Installation | Audinate. Available: https://www.audinate.com/solutions/projects/college-music-university-north-texas-large-installation.

[17] Audinate (2015) The NFL at Wembley Stadium, AV Systems Augmentation | Audinate. Available: https://www.audinate.com/content/nfl-wembley-stadium-uk-2011#media (Accessed: 20/11/2015).

[18] Audinate (2015) What Can I Do with Dante Via?. Available at https://www.youtube.com/watch?v=mb12tWpe--8 (Accessed 20/11/2015)

[19] AVB Networking Conference (2012) Part 1a - AVB overview (first half). Available: https://www.youtube.com/watch?v=fy3_URsaR2w (Accessed 04/10/2015)

[20] AVB Networking Conference (2012) Part 1a - AVB overview (second half). Available: https://www.youtube.com/watch?v=C1LtFsroHjc (Accessed 04/10/2015)

[21] AVB Networking Conference (2012) Part 1b - AVB overview: AVB switches. Available: https://www.youtube.com/watch?v=aaEt139XmI8 (Accessed 04/10/2015)

[22] AVB Networking Conference (2012) Part 2 - AVB in the field. Available: https://www.youtube.com/watch?v=35R-k7z40FQ (Accessed 04/10/2015)

[23] AVB Networking Conference (2012) Part 3 - AVB in large venue design. Available: hhttps://www.youtube.com/watch?v=_csP98NWWlo (Accessed 04/10/2015)

[24] AVB Networking Conference (2012) Part 4 - AVB in large performance venues. Available: https://www.youtube.com/watch?v=-_OmbMRcYXE (Accessed 04/10/2015)

[25] AVB Networking Conference (2012) Part 5 - AVB in broadcast design. Available: https://www.youtube.com/watch?v=kQ7FBbH-krM (Accessed 04/10/2015)

[26] AVB Networking Conference (2012) Part 6 - AVB in hospitality systems. Available: https://www.youtube.com/watch?v=XIEyjD077nY (Accessed 04/10/2015)

[27] AVB Networking Conference (2012) Part 7 - AVB in house of worship design. Available: https://www.youtube.com/watch?v=dJL4XoFbqMc (Accessed 04/10/2015)

[28] AVB Networking Conference (2012) Part 8 - The Avnu Alliance (first half). Available: https://www.youtube.com/watch?v=qxd5HBqGMo8 (Accessed 04/10/2015)

[29] AVB Networking Conference (2012) Part 8 - The Avnu Alliance second half). Available: https://www.youtube.com/watch?v=waOou3c83lY (Accessed 04/10/2015)

[30] Avnu Alliance (2015) Certified Products | AVnu Alliance. Available: http://avnu.org/certified-products/ (Accessed: 25/01/2016)

[31] Biamp (2012) Biamp Digital AV Transport. Available at https://www.youtube.com/watch?v=w8Z4yoWIvk0 (Accessed 10/10/2015)

[32] BSS Audio (2015) Chapter 5 - Networked Audio - CobraNet. Available: https://www.youtube.com/watch?v=Qmr7QKvdK70 (Accessed: 17/10/2015)

[33] BSS Audio (2015) Chapter 6 - Networked Audio - BLU Link. Available: https://www.youtube.com/watch?v=LdTvzsYdpPw (Accessed: 19/10/2015)

[34] BSS Audio (2015) Chapter 7 - Networked Audio - AVB. Available: https://www.youtube.com/watch?v=hHMQGsklr5E (Accessed: 10/10/2015)

[35] BSS Audio (2015) Chapter 8 - Networked Audio - Dante. Available: https://www.youtube.com/watch?v=5V_26emxD8U (Accessed: 20/10/2015)

[36] BSS Audio (2015) Chapter 9 - Networked Audio - Choosing the Right Networked Audio. Available: https://www.youtube.com/watch?v=77eo-ibefjw (Accessed: 20/10/2015)

[37] Burel, V. (2013) 'Configuring VB-CABLE System Setting', Docimentation. Available: http://vb-audio.pagesperso-orange.fr/Cable/VBCABLE_SystemSettings.pdf (Accessed: 20.04.2016)

[38] Burel, V. (2016) VB-Audio Virtual Apps. Available at: http://vb-audio.pagesperso-orange.fr/Cable/ (Accessed: 29.04.2016)

[39] Choi, Y., Lee, J., Ryu, S., Kim, S. (2008) 'A Forwarding Method on the IEEE 802.1 AVB' Advanced Language Processing and Web Information Technology, 2008. ALPIT '08. International Conference, 978-0-7695-3273-8/08 $25.00, pp. 497-502.

[40] Cirrus Logic (2005) Wembley Statium London | CobraNet HOME. Available: http://cobranet.info/community/installations/wembley (Accessed: 20/11/2015).

[41] Cirrus Logic (2006) 'Programmers Reference' http://www.cobranet.info/support/developer/manual (Accessed: 20/11/2015).

[42] Cirrus Logic (2011) CobraNet Networked Digital Audio - CobraNet Silicon Series, CobraNet System Modules, CobraNet Software Tools. Available: http://www.cirrus.com/en/products/pro/techs/T9.html (Accessed: 20/11/2015).

[43] Cirrus Logic (2015) Bundle Assignments in CobraNet Systems | CobraNet HOME. Available: http://www.cobranet.info/support/design/bundle_assignments (Accessed: 15/10/2015).

[44] Diarra, A. (2013) 'Ethernet Layer 2 End-to-End Data Safety', AVnu Automotive Advisory Council (AAA2C) Materials. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AAA2C_Ethernet-Layer-2-End-to-End-Data-Safety_Aboubacar-Diarra.pdf

[45] FFmpeg (2015) About FFmpeg. Available at: https://www.ffmpeg.org/about.html (Accessed: 29:04.2016)

[46] FFmpeg (2016) Documentation. Available at https://ffmpeg.org/documentation.html (Accessed: 29:04.2016)

[47] Focusrite (2015) ' RedNet Brochure', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-pcie-card/downloads (Accessed: 22/01/2016)

[48] Focusrite (2015) 'RedNet 1 User Guide 1.0', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-1/downloads (Accessed: 22/01/2016)

[49] Focusrite (2015) 'RedNet 2 User Guide 1.0', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-2/downloads (Accessed: 22/01/2016)

[50] Focusrite (2015) 'RedNet 3 User Guide 1.0', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-3/downloads (Accessed: 22/01/2016)

[51] Focusrite (2015) 'RedNet 4 User Guide 1.0', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-4/downloads (Accessed: 22/01/2016)

[52] Focusrite (2015) 'RedNet 5 and HD32R User Manual', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-hd32r/downloads (Accessed: 22/01/2016)

[53] Focusrite (2015) 'RedNet 6 and D64R User Manual', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d64r/downloads (Accessed: 22/01/2016)

[54] Focusrite (2015) 'RedNet A16R Data Sheet', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-a16r/downloads (Accessed: 22/01/2016)

[55] Focusrite (2015) 'RedNet AM2 Data Sheet', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-am2/downloads (Accessed: 22/01/2016)

[56] Focusrite (2015) 'RedNet D16 and D16R User Manual', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d16r/downloads (Accessed: 22/01/2016)

[57] Focusrite (2015) 'RedNet MP8R User Manual English', Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-mp8r/downloads (Accessed: 22/01/2016)

[58] Focusrite (2015) RedNet 1 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-1 (Accessed: 22/01/2016)

[59] Focusrite (2015) RedNet 2 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-2 (Accessed: 22/01/2016)

[60] Focusrite (2015) RedNet 3 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-3 (Accessed: 22/01/2016)

[61] Focusrite (2015) RedNet 4 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-4 (Accessed: 22/01/2016)

[62] Focusrite (2015) RedNet 5 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-5 (Accessed: 22/01/2016)

[63] Focusrite (2015) RedNet 6 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-6

(Accessed: 22/01/2016)

[64] Focusrite (2015) RedNet A16R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-a16r (Accessed: 22/01/2016)

[65] Focusrite (2015) RedNet A16R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-a16r (Accessed: 22/01/2016)

[66] Focusrite (2015) RedNet AM2 | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-am2 (Accessed: 22/01/2016)

[67] Focusrite (2015) RedNet D16 AES | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d16-aes (Accessed: 22/01/2016)

[68] Focusrite (2015) RedNet D16R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d16r (Accessed: 22/01/2016)

[69] Focusrite (2015) RedNet D64R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d64r (Accessed: 22/01/2016)

[70] Focusrite (2015) RedNet HD32R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-hd32r (Accessed: 22/01/2016)

[71] Focusrite (2015) RedNet MP8R | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-mp8r (Accessed: 22/01/2016)

[72] Focusrite (2015) RedNet PCIe Card | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-pcie-card (Accessed: 22/01/2016)

[73] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-1/specifications (Accessed: 22/01/2016)

[74] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-2/specifications (Accessed: 22/01/2016)

[75] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-3/specifications (Accessed: 22/01/2016)

[76] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-4/specifications (Accessed: 22/01/2016)

[77] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-6/specifications (Accessed: 22/01/2016)

[78] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d16-aes/specifications (Accessed: 22/01/2016)

[79] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d16r/specifications (Accessed: 22/01/2016)

[80] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-d64r/specifications (Accessed: 22/01/2016)

[81] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-hd32r/specifications (Accessed: 22/01/2016)

[82] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-mp8r/specifications (Accessed: 22/01/2016)

[83] Focusrite (2015) Specifications | Focusrite. Available: http://uk.focusrite.com/ethernet-audio-interfaces/rednet-pcie-card/specifications (Accessed: 22/01/2016)

[84] Fradette, A. (2013) 'How Big do my pipes need to be?" – Traffic Shaping & Infrastructure planning' AVnu Alliance Broadcast Advisory Material. Available:

http://avnu.org/wp-content/uploads/2014/05/AVnu-AABAC_Traffic-Shaping-Infrastructure-Planning_Andre-Fredette.pdf (Accessed 07/10/2015)

[85] Garner, G., Ryu, H. (2011) 'Synchronization of Audio/Video Bridging Networks Using IEEE 802.1AS' Communications Magazine, IEEE, 49(2), pp. 140-147.

[86] Gunther, C. (2009) 'AVB VLAN Tagging', IEEE802 plenary, Vancouver BC 10/03/2009. IEEE. Available: http://www.ieee802.org/1/files/public/docs2009/ba-cgunther-vlan-tagging-0309.pdf (Accessed 19/10/2015)

[87] Gunther, C. (2013) 'SRP in Automotive', AVnu Automotive Advisory Council (AAA2C) Materials. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AAA2C_SRP-in-Automotive_Craig-Gunther.pdf (Accessed: 19/10/2015)

[88] Harman Pro (2014) 'Guide to audio networking' Audio Architect Networking, Available: http://adn.harmanpro.com/site_elements/resources/697_1417040794/Audio_Architect_Guide_to_Audio_Networking___November2014_original.pdf (Accessed: 29/10/2015).

[89] Hellerud, E., Svensson, U.P. (2007) 'Robust Transmission of Lossless Audio with Low Delay over IP Networks' Signal Processing and Information Technology, 2007 IEEE International Symposium, 978-1 -4244-1 835-0/07/$25.00, pp. 590-594.

[90] Hellerud, E., Svensson, U.P. (2007) 'Robust Transmission of Lossless Audio with Low Delay over IP Networks' Signal Processing and Information Technology, 2007 IEEE International Symposium, 978-1 -4244-1 835-0/07/$25.00,pp. 590-594.

[91] IEEE (2015) AVB L3 Transport WG. Available at: http://grouper.ieee.org/groups/1733/ (Accessed: 20/11/2015)

[92] IEEE 802 (2015) IEEE 802.1: 802.1BA - Audio Video Bridging (AVB) Systems. Available: http://www.ieee802.org/1/pages/802.1ba.html (Accessed: 17/10/2015).

[93] IEEE 802 (2015) IEEE 802.1: 802.1Qav - Forwarding and Queuing Enhancements for Time-Sensitive Streams. Available at: http://www.ieee802.org/1/pages/802.1av.html (Accessed: 17/10/2015).

[94] Imtiaz, J., Jasperneite, J., Weber, K., (2012) 'Approaches to reduce the Latency for High Priority Traffic in IEEE 802.1 AVB Networks', Factory Communication Systems (WFCS), 2012 9th IEEE International Workshop, 978-1-4673-0692-8/12/$31.00, pp. 161-164.

[95] Johas Teener, M.D., Fredette, A.N. ; Boiger, C. ; Klein, P. ; Gunther, C. ; Olsen, D. ; Stanton, K. (2013) 'Heterogeneous Networks for Audio and Video: Using IEEE 802.1 Audio Video Bridging' Proceedings of the IEEE, Vol. 101, No. 11, November 2013, pp. 2339-2354

[96] Johas Teener, M.D., Garner, G. (2008) 'Overview and Timing Performance of IEEE 802.1AS' Precision Clock Synchronization for Measurement, Control and Communication, 2008. ISPCS 2008. IEEE International Symposium, 978-1-4244-2275-3/08/$25.00, pp. 49-53.

[97] Kehrer, S., Kleineberg, O., Heffernan, D. (2014) 'A comparison of Fault-Tolerance Concepts for IEEE 802.1 Time Sensitive Networks (TSN)' IEEE Emerging Technology and Factory Automation (ETFA), 2014 IEEE, pp. 1-8. doi: 10.1109/ETFA.2014.7005200 .

[98] Kleineberg, O., Fröhlich, P., Heffernan, D. (2012) 'Fault-tolerant Audio and Video Bridging (AVB) Ethernet: A novel method for redundant stream registration configuration' Emerging Technologies & Factory Automation (ETFA), 2012 IEEE, 978-1-4673-4737-2/12/$31.00, pp. 1-8.

[99] Kreifeldt, R. (2009) 'AVB for Professional A/V Use', Technical Whitepapers. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-Pro__White-Paper.pdf (Accessed: 07/10/2015)

[100] Live Design (2015) Focusrite’s RedNet Systems Give The University Of North Texas Ultimate Connectivity | Briefina Room content from Live Design. Available:

http://livedesignonline.com/briefing-room/focusrite-s-rednet-systems-give-university-north-texas-ultimate-connectivity (Accessed 20/11/2015).

[101] Mann, E., Pearson, L., Elder, A., Hall, C., Gunther, C., Koftinoff, J., Butterworth, A., and Underwood, D. (2013) 'AVB Software Interfaces and Endpoint Architecture Guidelines', Architecture Guidelines. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu_SWAPIs_v1.0.pdf (Accessed: 09/10/2015)

[102] Meyer Sound (2015) D-Mitri : Digital Audio Platform. Available: http://www.meyersound.com/product/d-mitri/avb.htm (15/10.2015)

[103] Meyer, P., Steinbach, T., Korf, F., Schmidt, T. (2013) 'Extending IEEE 802.1 AVB with Time-triggered Scheduling: A Simulation Study of the Coexistence of Synchronous and Asynchronous Traffic' 2013 IEEE Vehicular Networking Conference, 978-1-4799-2687-9/13/$31.00, pp. 47-54.

[104] Minich, L. (2013) 'AVB Bandwidth Reservation', AVnu Alliance Broadcast Advisory Material. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AABAC_AVB-Bandwidth-Reservation_Lee-Minich.pdf (Accessed: 08/10/2015)

[105] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/112d (Accessed: 19/01/2015)

[106] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/1248/body.html (Accessed: 19/01/2015)

[107] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/16a (Accessed: 19/01/2015)

[108] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/24ai-24ao/body.html (Accessed: 19/01/2016)

[109] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/8m (Accessed: 19/01/2015)

[110] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/avb-switch (Accessed: 19/01/2015)

[111] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/monitor8 (Accessed: 19/01/2015)

[112] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/stage-b16 (Accessed: 19/01/2015)

[113] MOTU (2015) Overview. Available: http://www.motu.com/products/avb/ultralite-avb (Accessed: 19/01/2015)

[114] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/112d/specs.html (Accessed: 19/01/2016)

[115] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/1248/specs.html (Accessed: 19/01/2016)

[116] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/16a/specs.html (Accessed: 19/01/2016)

[117] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/24ai-24ao/specs.html (Accessed: 19/01/2016)

[118] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/8m/specs.html (Accessed: 19/01/2016)

[119] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/avb-switch (Accessed: 19/01/2016)

[120] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/monitor8/specs.html (Accessed: 19/01/2016)

[121] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/stage-b16/specs.html (Accessed: 19/01/2016)

[122] MOTU (2015) Tech Specs. Available: http://www.motu.com/products/avb/ultralite-avbl (Accessed: 19/01/2016)

[123] motuTV (2015) MOTU at NAMM 2015: seven exciting new AVB audio interfaces. Available: https://www.youtube.com/watch?v=i_oQw4D6d04 (Accessed: 20/01/2016

[124] Olsen, D. (2012) 'Audio Video Transport Protocol (AVTP)', AVnu Automotive Advisory Council (AAA2C) Materials. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AAA2C_Audio-Video-Transport-Protocol-AVTP_Dave-Olsen.pdf (Accessed: 09/10/2015)

[125] Oracle (2016) Chapter 1: First Steps. Available: https://www.virtualbox.org/manual/ch01.html (Accessed: 13.04.2016)

[126] Pavel Kudelin (2015) Network protocols COBRANET, DANTE, AVB. Available: https://www.youtube.com/watch?v=Cf6XrGkkDjk (Accessed: 16/10/2015)

[127] Pearson, L. (2014) 'Stream Reservation Protocol', Architecture Guidelines. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu_Stream-Reservation-Protocol-v1.pdf (Accessed: 09/10/2015)

[128] PieterExplainsTech (2014) UDP and TCP: Comparison of Transport Protocols. Available: https://www.youtube.com/watch?v=Vdc8TCESIg8 (Accessed: 10.04.2016)

[129] RH Consulting (2015) 'The Death of Analogue and the Rise of Audio Networking' Whitepapers, Available: http://go.audinate.com/hs-fs/hub/457797/file-2507344704-pdf/assets/rise-of-audio-networking-audinate-wp.pdf?t=1449278400272 (Accessed: 07/11/2015).

[130] Roychoudhuri, L., Al-Shaer, E., Hamed, H., Brewster, G.B. (2002) 'On Studying the Impact of the Internet Delays on Audio Transmission' IP Operations and Management, 2002 IEEE Workshop, 0-7803-7658-7/02/$17.00, pp. 208-213.

[131] Silfvast, R. (2013) 'IEEE 1722 Media on AVB Networks', AVnu Alliance Broadcast Advisory Material'. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AABAC_IEEE-1722-Media-on-AVB-Networks_Rob-Silfvast.pdf (Accessed: 08/10/2015)

[132] Soundcraft Electronics Ltd (2015) BLU Link Overview. Available: http://audioarchitect.harmanpro.com/aa_help/BSS_BLU_Devices/BLU_Link.htm (Accessed 19/10/2015).

[133] Sport Video Group (2014) ESPN's DC2 Scales AVB Large. Available: http://www.sportsvideo.org/2014/06/10/espns-dc2-scales-avb-large/ (Accessed: 20/10/2015)

[134] Stanton, K. (2009) 'Real Time Protocol (RTP) over LANs supporting 802.1 AVB, an overview (A.K.A. IEEE P1733)', IEEE802 plenary, Vancouver BC 11/03/2009. IEEE. Available: http://www.ieee802.org/1/files/public/docs2009/avb-stanton-rtp-over-avb-aka-ieee1733-0309.pdf (Accessed: 09/10/2015)

[135] Stanton, K. (2012) 'Tutorial on Time-Synchronization for AAA2C based on IEEE Std 802.1AS™-2011', AVnu Automotive Advisory Council (AAA2C) Materials. Available: http://avnu.org/wp-content/uploads/2014/05/AVnu-AAA2C_Tutorial-on-time-synchronization-for-AAA2C-based-on-IEEE-Std-802.1AS%E2%84%A2-2011_Kevin-Stanton.pdf (Accessed: 08/10/2015)

[136] Tasaka, S., Misaki, N., (2009) 'Maximizing QoE of Interactive Services with Audio–Video Transmission over Bandwidth Guaranteed IP Networks' Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE, 978-1-4244-4148-8/09/$25.00, pp. 1-7.

[137] VideoLAN (2016) VideoLAN – Legal. Available at: http://www.videolan.org/legal.html (Accessed: 15.04.2016)

[138] VideoLAN (2016) VideoLAN – Streaming Features list. Available: https://www.videolan.org/streaming-features.html (Accessed: 15.04.2016)

[139] VideoLAN (2016) VideoLAN – VLC – Features. Available at: https://www.videolan.org/vlc/features.html (Accessed: 15.04.2016)

[140] Yamaha System Solutions (2006) 'Networked audio system design with CobraNet' Training for System Designers / Integrators, Available: http://download.yamaha.com/api/asset/file/?language=en&site=countrysite-master.prod.wsys.yamaha.com&asset_id=47405 (Accessed: 20/10/2015).

[141] Yamaha System Solutions (2014) 'An introduction to networked audio' Training for System Designers / Integrators, Available: http://download.yamaha.com/api/asset/file/?language=en&site=countrysite-master.prod.wsys.yamaha.com&asset_id=47399 (Accessed: 20/10/2015).

[142] Yamaha System Solutions (2014) 'Networked audio system design with ES100™' Training for System Designers / Integrators, Available: http://download.yamaha.com/api/asset/file/?language=en&site=countrysite-master.prod.wsys.yamaha.com&asset_id=47411 (Accessed: 20/10/2015).

[143] Yucel, S., Saydam, T., (2001) 'An Architecture for Realizing CORBA Audio/Video Stream Specification over IP Technologies' Global Telecommunications Conference, 2001. GLOBECOM '01. IEEE, 4, pp. 2479-2483.

[144] Zagursky, V., Riekstinch, A., Zarumba, I. (2003) 'Testing the methods of sound signal compression' Video/Image Processing and Multimedia Communications, 2003. 4th EURASIP Conference, 2, pp. 595-600.