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An Integrated Monitoring Solution for Media Streams on IP Networks

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BRITISH BROADCASTING CORPORATION

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Abstract

The broadcast industry is increasingly using Internet Protocol (IP) networks for content delivery and distribution. The EBU IP Measurement (EBU ECN-IPM) group has investigated issues involved in monitoring the status of media streams, and identified the need for a standards-based approach of this on a multi-vendor network. The group has proposed a new standard for measuring a number of common media-specific network parameters. An open source software platform called EisStream was also developed, with capacity to benefit from this standard. The software functions include device and topology discovery and physical path tracing for both end-to-end communication and multicast streams. Once the new MIB standard becomes adopted by manufacturers, the EisStream platform will be able to achieve the ultimate goal of multilayer monitoring for streams on a multi-vendor network with fully media-specific parameters.

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An Integrated Monitoring Solution for Media Streams on IP Networks

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INTRODUCTION

With wider adoption of IP networks for broadcast media transmission, both for contribution and distribution, there is an increasing demand to monitor the network traffic with more media-focused specifications, especially for high data rate multicast streams. For example while common network phenomena such as jitter and delay can be tolerated to a certain extent in transaction based systems, they are critically damaging to real-time media flows and therefore have to be monitored more closely.

To achieve this, it is essential to maintain an end-to-end surveillance on the transmitting and receiving devices using a common set of media-specific monitoring parameters. However at the time of writing, such an industry standard is yet to be adopted by all the different manufacturers of network audiovisual equipment.

It is equally important to correctly identify and monitor the switches and routers that are involved in establishing the end-to-end connection. This will require accurate and precise information on the physical topology and IP layer routes. For monitoring multicast streams, complete information on the tree structure of multicast routers for each multicast group is needed. However unless being maintained manually, such information is not readily available for a typical multi-vendor network as used by many large organisations such as broadcasters.

To address the various issues in monitoring media streams on a multi-vendor IP network, an integrated solution is introduced, using only the Simple Network Management Protocol (SNMP), a widely-adopted standard method for accessing device information over network, and a minimum set of standard Management Information Bases (MIBs) (1). There are two parts to this solution: a new MIB standard comprising media-specific measurement parameters, and a software platform capable of calculating topology, routing and multicast information from existing standard MIBs.

This paper will first introduce the new MIB structure proposed by the EBU IP Measurement (EBU ECN-IPM) group (2). The structure comprises a set of parameters that are important for media over IP measurement. The parameters are organised under three categories: general unit parameters, network transport layer and application layer. Defining these measurement critical parameters in a common place lays the foundation to enable monitoring software to collect real time information from end devices and therefore build an end-to-end media flow map. The next section will give a detailed illustration of this new MIB structure.

The third section will introduce EisStream, an innovative software tool developed by BBC R&D. Released as an open source software, EisStream is able to discover all the devices on an unknown network, determine the physical topology and logical routes, and use this information to trace the exact physical path with respect to ports for any end-to-end connection. More importantly this software is capable of discovering all multicast groups with comprehensive information on the routing and forwarding structure of each group. The novel methods and algorithms developed with the software for advanced device and topology discovery, path-finding and multicast mapping will be elaborated in this section, followed by test results of the software on live transmission networks.

Conclusion and comments about the future development of the solution can be found in the final section.

THE NEW NETWORK MEDIA MEASUREMENT STANDARD

The EBU ECN-IPM group have specified a minimum set of parameters that are important for broadcasters when using IP networks for audio and video transmission. These parameters cover both the network layer and application layer (video and audio). Most, if not all, of these parameters already exist in some form within an end point device that has media flowing through it. However, different manufacturers store or have access to these parameters in different places within their equipment. This makes real-world access to these parameters difficult, unless a standard approach can be adopted where any particular named parameter, in the same format, is accessible from the same location, from any end point device, independent of manufacturer.

Many audio/video end point devices use SNMP already to gather and store these parameters, but usually in different places and/or formats within their MIBs. To address this issue and obtain information on these parameters, it is proposed that SNMP is used, along with the development of a new standard MIB.

General Unit Parameters	
Power Supplies	information about the power supplies for the unit.
Temperature	the temperature at one or more locations within the unit
Network/Transport Layers	
Internet Protocol (IP) version	
Port Number	
Real Time Transport Protocol (RTP)	
Session Initiation Protocol (SIP)	
Internet Group Management Protocol (IGMP) version	
Asynchronous Serial Interface (ASI)	
Application Layer	
Audio	
Audio Signal Format	defining the particular coding algorithm type used, or linear
Channel Arrangement	a description of the arrangement of individual channels of audio in an audio recording or audio stream, e.g. discrete mono, stereo and so on
Number of Channels	the number of individual channels of audio in an audio recording or audio stream, e.g. 1 (mono), 2 (stereo or 2x mono) and so on.
Audio Bit Depth	number of audio bits per sample in an encoded audio signal
Sampling Frequency	the sampling rate used to generate the digital audio signal
Audio Bit Rate	the amount of information stored per unit of time of an audio recording.
Audio PID	defining the data substream containing the Audio (either TV or Radio sound) information, e.g. 0256 or 0327 and so on
Audio Component Number	the identifier for each audio item, when there are one or more audio items associated with a single video stream/signal.
Audio Status	an indication of the presence of the audio signal of this audio component number.
Video	
Video Status	an indication of the presence, of a particular video stream/signal
Frame Rate	the Frame rate of the base video format in Hz
Source Type	an indication of the definition of the base video format, e.g. SD
Vertical Resolution	the number of lines of vertical resolution used in the base video format
Scan Type	the type of scanning used in the base video format, e.g. Progressive
Video Coding Format	the compression type or otherwise of the video signal, e.g. H264 or uncompressed
Video Bit Rate Type	the type of bit rate used in the base video format, e.g. variable bit rate (VBR)
Video Bit Rate	the current video bit rate of the encoded video signal or the maximum if VBR is being used
FEC (Forward Error Correction) Type	the type of FEC applied to the video, if present
FEC Length & Dimension	a description of the structure of FEC applied to the video stream
Receiver	
Buffer Status	the condition of the receive buffer of the decoding device, e.g. overflow.
Buffer Space	the amount of free buffer space in bytes in the receive buffer of the decoding device.
Media Delivery Index (MDI)	the Media Delivery Index (MDI) as in defined in RFC 4445
Time Stamped Delay Factor (TS-DF)	A Proposed Time-Stamped Delay Factor (TS-DF) for Measuring Network Jitter with RTP Streams (Draft RFC in progress).

Table 1: Parameters Specified in the New MIB Standard

The Parameters

The parameters defined in the new MIB standard are classified as Mandatory, Recommended or Optional. They will be available in an official EBU publication from the ECN-IPM Group.

Structure of the family of IEC 62379 standards

The new standard MIB for these parameters is based on the existing fundamental framework described in IEC 62379 (3) which specifies the Common Control Interface, a protocol for managing networked audiovisual equipment. It is intended to include the following Parts:

- Part 1 General - specifies aspects which are common to all equipment.
- Parts 2 Audio, Part 3 Video and Part 4 Data - specify control of internal functions specific to equipment carrying particular types of live media. Part 4 does not refer to packet data such as the control messages themselves.
- Part 5 Transmission over networks - specifies control of transmission of these media over each individual network technology. It includes network specific management interfaces along with network specific control elements that integrate into the control framework.
- Part 6 Transmission over networks - specifies carriage of control and status messages and non-audiovisual data over transports that do not support audio and video, such as RS232 serial links, with (as with Part 5) a separate subpart for each technology.
- A new Part 7 Measurement section specifying those aspects that are specific to the measurement requirements of EBU ECN-IPM group is proposed.
- An introduction to the Common Control Interface is given in IEC 62739-1 (3).

New MIB Structure

The overall structure of this new MIB follows that described in IEC 62379-1, where each type of functionality required is based upon a “block” describing that functionality.

An item of equipment (a "unit") is regarded as being composed of functional elements or "blocks" which may be linked to each other through internal routing. The block structure allows multiple instances of the same block type to be used within a unit, but each uniquely identifiable.

Blocks may have inputs, outputs and internal functionality. In general, the output of one block connects to the input of the next block in the processing chain. Blocks can have some associated control parameters and/or status monitoring accessible via the control framework management interface.

There is a special class of blocks called "ports"; ports provide an external connection to other equipment. An "input port" is one where audio, video, or other data enters the unit and an "output port" is one where it leaves the unit (3).

In Figure 1 there is a block which performs a mix between three inputs, two from the network and one from a physical audio port (or, looking at it another way, two from remote sources and one from a local source). The local source is connected via a pre-amplifier. The

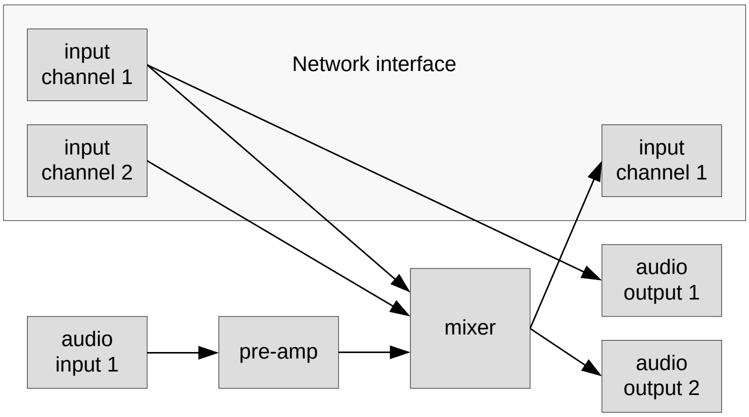

Figure 1: Example of a “unit”

resulting signal is output locally at output 2 and also transmitted on the network. There is another local output which carries a copy of one of the remote sources.

Within this new MIB, another special class of block has been defined; a “measurement” or information block. This has no direct inputs or outputs, but does have internal functionality. This internal functionality offers only monitoring or measurement information collected from other MIB objects within an existing MIB in a unit. (Similar or identical parameters are highly likely to be located in different places within different units MIBs).This provides a means, therefore, to present similar, if not identical parameters, from different units, using a standardised method.

The new standard MIB is “imported” into the existing MIB within an end point device, allowing the defined parameters to be written into the various measurement information blocks in the format and locations defined within the MIB specification. A management station can then read the parameter values from any end point device incorporating this MIB, irrespective of manufacturer.

There are five “measurement” information block types defined in this MIB; each of these contains the parameters listed earlier.

- Audio
- Video
- Network
- Receiver
- Temperature

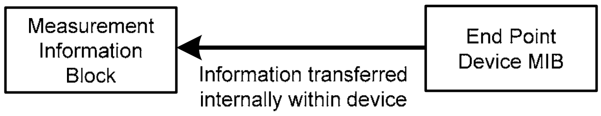

Figure 2: Internal Information Transfer

Although temperature measurement could be considered to be part of units general parameters, currently it is not defined as a general unit information block in IEC 62379-1 (3). Therefore it is defined in IEC 62379-7 as a separate measurement block.

In addition, the MIB also includes (imports) some objects associated with the overall block framework control and some standard objects associated with power supplies from the general unit parameters, both from IEC 62379-1 (3).

Figure 3 shows the relationship between the master block table from IEC 62379-1 (3) and the measurement information blocks, these containing the required parameters. The master block table identifies all block types, using a unique block identifier. This allows any number of the same types of blocks to exist within a unit. Although not shown (for clarity), some objects in some of the tables have a dependency upon objects either in their own or in other tables.

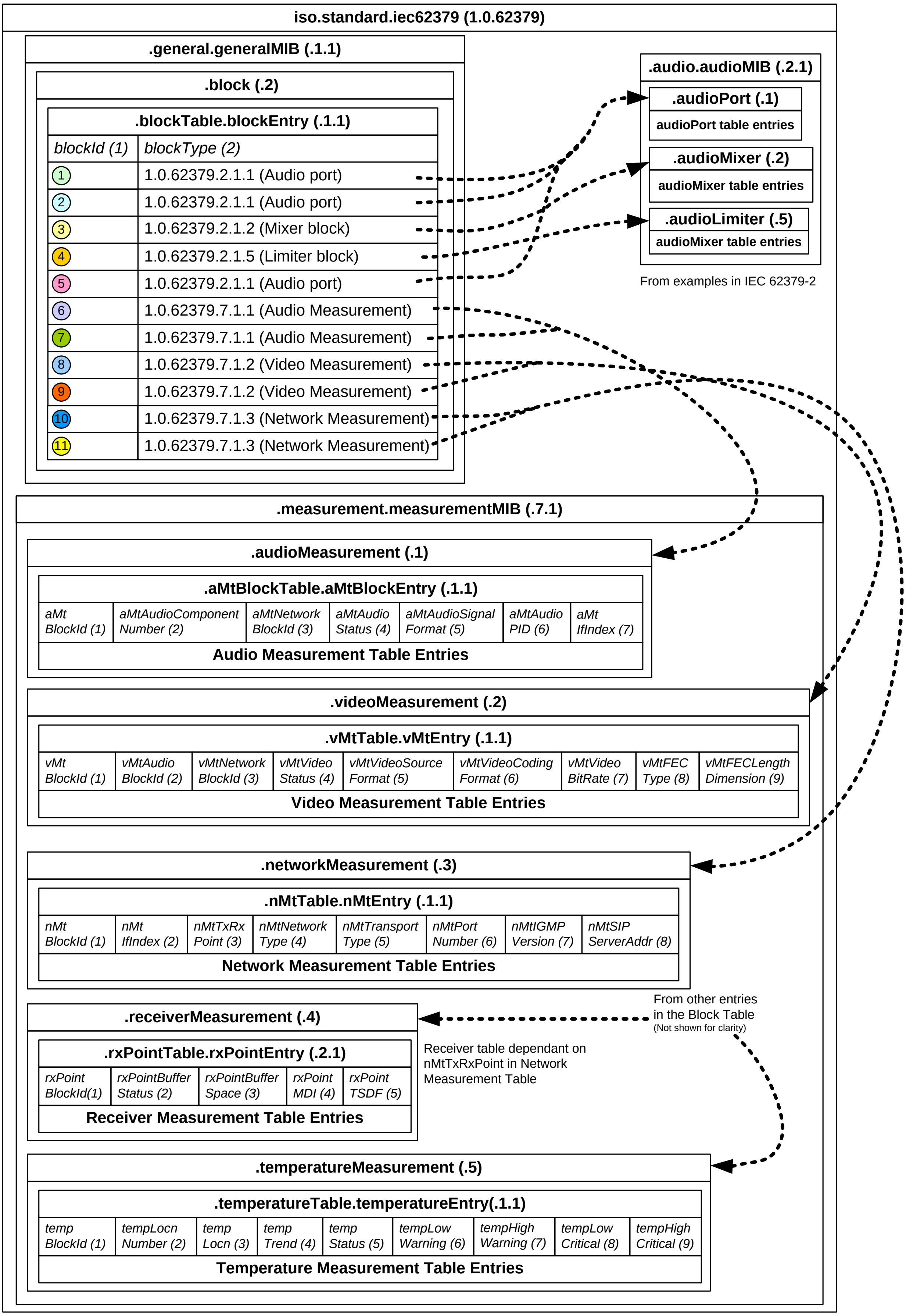

Figure 3: Measurement MIB Tables and Parameters

EISSTREAM – THE SOFTWARE PLATFORM FOR THE SOLUTION

The EBU IPM SNMP Stream Monitor (EisStream) software is a powerful network discovery and analysis tool that is capable of providing a range of useful information needed for monitoring media streams, calculated from a small set of common MIB data extracted from different network devices via SNMP. It will be able to monitor media streams using the new parameters once the proposed MIB standard is adopted by manufacturers. The source codes of this software have been released on SourceForge.

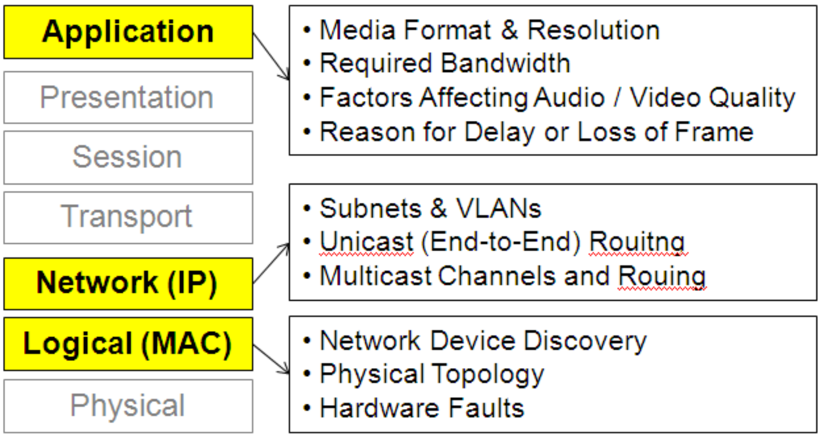

Figure 4: Planned Monitoring Level of EisStream using the new MIB

At present EisStream provides the following features:

- Device Inventory – automatically drawing a list of network devices
- Physical Topology – port-level connection information between all devices
- End-to-End Physical Path – all the nodes involved in transmitting a media stream
- Multicast – list of all channels and for each channel the entire routing structure

All devices on the network are categorised into three main groups: Routers (including multilayer switches), Bridges (Layer2-only switches) and Hosts (audiovisual equipments). As pre-requisites, a list of SNMP read-only community strings of all the devices on the network is needed, and the routers and bridges must support the SNMP data objects in Table 2. This software is capable of deducing the existence of some bridges or hubs that does not support SNMP, which will be explained later. This software does not require any host except the starting device to support SNMP, since all the topology, routing and multicast information are obtained solely from the routers and bridges. However it will be impossible to monitor those hosts which do not support SNMP.

MIB	Table	Object	Required Support
MIB-II	(Leaf Objects)	sysDescr	All devices
		sysServices	
		ipForwarding	
	ifTable	ifIndex	
		ifDescr	
		ifPhysAddress	
	ipAddrTable	ipAdEntAddr	
		ipAdEntIfIndex	
		ipAdEntNetMask	
	ipRouteTable	ipRouteDest	
		ipRouteIfIndex	
		ipRouteNextHop	
		ipRouteType	
	ipNetToMediaTable	ipNetToMediaIfIndex	
		ipNetToMediaPhysAddress	
		ipNetToMediaNetAddress	
IP-FORWARD-MIB	ipCidrRouteTable	ipCidrRouteDest	Routers Only
		ipCidrRouteMask	
		ipCidrRouteNextHop	
		ipCidrRouteIfIndex	
		ipCidrRouteType	
BRIDGE-MIB	dot1dTpFdbTable	dot1dTpFdbAddress	Multilayer Switches & Bridges
		dot1dTpFdbPort	
		dot1dTpFdbStatus	
IPMROUTE-STD-MIB	ipMRouteTable	ipMRouteSource	Multicast Routers
		ipMRouteSourceMask	
		ipMRouteUpstreamNeighbor	
		ipMRouteInIfIndex	
		ipMRouteRtAddress	
		ipMRouteRtMask	
	ipMRouteNextHopTable	ipMRouteNextHopIfIndex	
		ipMRouteNextHopState	
	ipMRouteScopeNameTable	ipMRouteScopeNameString	

Table 2: MIB Support required by EisStream

Device Inventory

All monitoring software relies on accurate device and topology information. Therefore it is necessary to gather up-to-date data regularly from the network devices and discover unknown devices as much as possible. For distribution networks which are geographically distributed, an automated network inventory tool is significantly useful.

EisStream is capable of discovering an entirely unknown network from any given IP address on the network, provided the device at that IP address supports SNMP. If this address is not specified, the software can also start with a loopback address. All necessary MIB data of the devices for calculating topology, routing and multicast information, as listed in Table 2, are extracted and stored on a database during this stage.

Two types of data are used for discovering new devices: the Next Hop address and ARP address. The Next Hop address is used for discovering the router that connects the current device to other networks. Once a new router is found, the Next Hop of this router leads to the discovery of another router. On the other hand the ARP address is used for discovering logical neighbours of a current device within the same network. Using a recursive algorithm to find new Next Hop and ARP addresses, the software is able to discover the entire network. EisStream uses no other information for device discovery.

Discovery through Next Hop is preferred over ARP by this software, as it leads to the discovery of new routers and therefore has higher chance of discovering more devices. Whenever a new device is found, either through Next Hop or ARP from the previous device, the first data to look at is always the Next Hop of the current device. The discovery through ARP only starts when no new router has been found through Next Hop.

When the discovered IP address does not respond to SNMP, it is possible that either the device does not support SNMP, or it has been disconnected. If this IP address is a Next Hop, indicating the device is a router, it is more likely that the router is disconnected because it is highly uncommon for a router not to support SNMP. If the device is discovered through ARP, it is more likely to be a connected device without SNMP support.

While the layer3 routing information remains constant on a device, the ARP data only resides on the memory for a limited period of time. This causes a problem for device discovery as non-communicating neighbours within the same subnet will disappear from each other's ARP records.

This problem has a direct impact on discoverability of the bridges, which under normal operations are transparent to the IP layer. The only way SNMP can

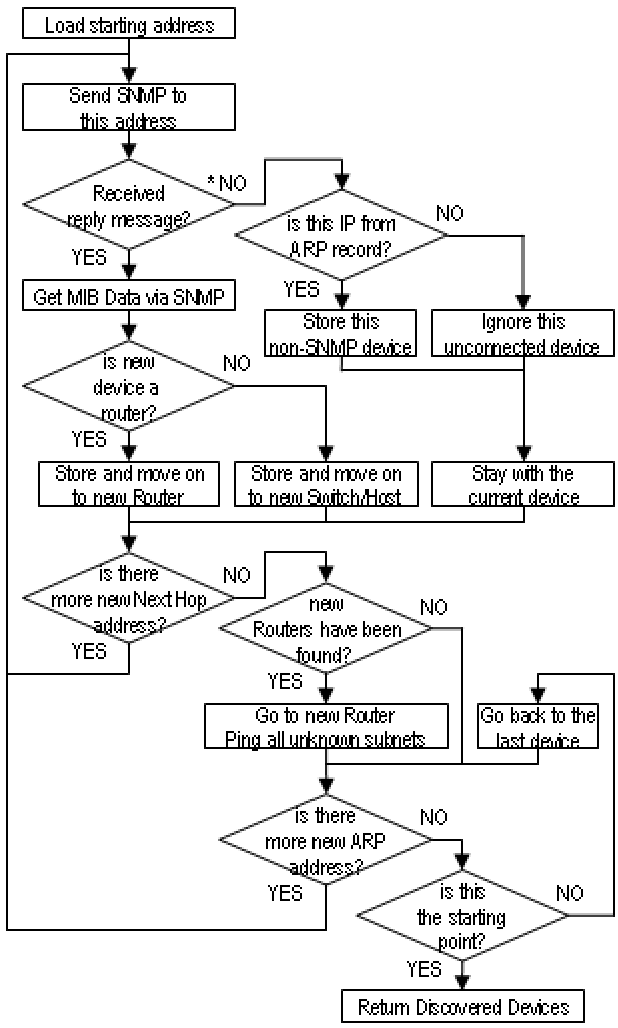

Figure 5: Device Discovery Algorithm

(*: Never happens at the start)

communicate with a bridge is via its management port, which has a valid IP address. But unless the bridge is constantly being monitored, the management port usually remains idle.

To solve this issue, the software is enabled with an optional mechanism for re-establishing the ARP neighbourhood record by sending a single ICMP (ping) packet sequentially to all possible management IP addresses. This will refresh the ARP record for a brief period of time without straining the network.

Physical Topology

EisStream is capable of automatically generating the physical network topology, which can be extremely useful for network administrators as it is increasingly difficult to keep this information manually over time for a large-scale distribution network.

Every host on the network is connected to a router or a bridge, which is further connected by other routers or bridges. Therefore to establish the full topology of a network, the physical connections between all routers and bridges must be determined first. Three different types of physical connections can possibly exist between the ports on any routers or bridges, which can be identified by examine the number of APR record on the ports and their associated entries on the Forwarding Information Base (FIB) of the device.

The ARP record shows the number of logical neighbours that a port is currently having. As along as a port contains more than one ARP record, it is connected to a layer2 (L2) port. The FIB is only stored in the BRIDGE-MIB of a bridge or multilayer switch and indicates the port to which L2 packets with a particular external destination MAC address should be forwarded onto. As long as a port appears in the FIB, it is a L2 port.

Using the logic shown in Table 3, the connection type of a port on a router or a bridge can be accurately decided.

Connection Type		No. of Entries in FIB		
		0	*1*	*n*
No. of ARP Entries	*0*	n/a	L2-L2	L2-L2
	1	L3-L3	L2-L3	L2-L2
	n	L3-L2	L2-L2	L2-L2

Table 3: Connection Type Decision Table

For example if a port does not appear FIB, it is then a layer3 (L3) port. Then looking at the ARP record of the port, if it has multiple data entries, the port must have a L3-L2 connection. If a port appears more than once in the FIB, which means it is forwarding L2 packets to more than one MAC address, the port connected to it therefore must be a switch port too. Hence the connection is definitely a L2-L2.

L3-L3 connections are the most straightforward to identify, which only exist between routed ports, with the IP address of the only ARP entry of on port match the IP address of the other port, L2-L3 and L3-L2 are also relatively easy to determine with the MAC address of the L3 port being the only destination of the L2 packets forward by the connected L2 port.

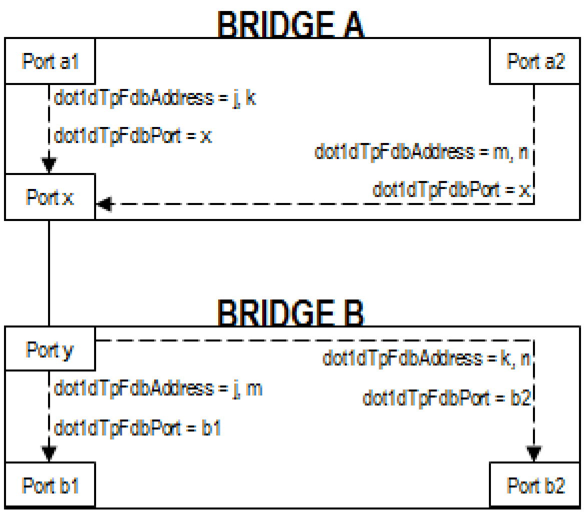

Figure 6: Determining an L2-L2 Connection

The most challenging task is to find the L2-L2 connection, especially between 2 bridges that contain no L3 information at all. For determining this type of connection, only the FIB data can be used. A set of novel algorithms were developed for the EisStream software to process the FIB data and correctly identify the L2-L2 connections under different situations, such as bridges joined in daisy chain or ring arrangements (4). As shown in Figure 6. Port X on Bridge A is connected to Port Y on Bridge B. The L2 packets forwarded by Port X are exactly the same as those received at Prot Y. Hence the following condition must be fulfilled for a L2-L2 connection:

1. The two sets of destination MAC addresses of the L2 Packets forwarded by Port X and Port Y must be mutually exclusive to one another;

2. All MAC address forwarded by Port X except the MAC addresses of Bridge B must also be forwarded by other ports on Bridge B and vice versa for Port Y and other ports on Bridge A.

In this case Port X is forwarding L2 packets to MAC address j, k, m and n, which are not at all forwarded by Port Y but other ports on Bridge B.

End-to-End Physical Path

Tracing the end-to-end physical path between any two hosts on the network and identifying every individual port on the various devices involved in the connection is the ultimate purpose for building a complete network diagram. Using the layer3 routing information on all the routers, EisStream is able to trace the full physical path for any media stream.

Figure 7 is an example of a typical modern network of 3 VLANs. VLAN 1 and 2 are routed via Router A and VLAN 2 and 3 via Router B. Bridge 2 is a backbone switch with ports configured for all VLANs, where port 2-3 is connected to port 1-3 on Bridge 1 in VLAN 1 and port 2-4 to port 3-3 on Bridge 3 on VLAN 3.

In terms of physical ports, any IP packet from the source in VLAN 1 to the destination in VLAN 3 would follow this path:

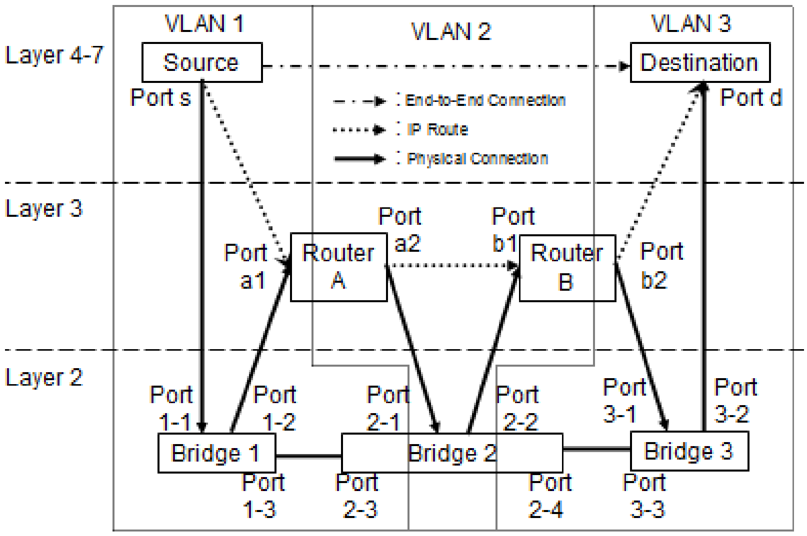

Figure 7: Cross-VLAN Path Tracing

s >> 1-1>1-2 >> a1>a2 >> 2-1>2-2 >> b1>b2 >> 3-1>3-2 >> d

where ">>" indicates a physical cable and ">" indicates the internal switching or routing on a device from one port to another.

However on a simple physical topology diagram without layer3 information the path could easily be misinterpreted as:

s >> 1-1>1-3 >> 2-3>2-4 >> 3-3>3-2 >> d

To correctly identify the physical path for any end-to-end connection, it is important to identify the layer3 routes between the source and destination. By investigating the source's Default Gateway setting in the Next Hop information, the first router on the layer 3 route can be identified easily. For hosts without this setting, their network numbers can be deduced from their IP addresses and the subnet mask. The gateway router can be found by comparing the host's IP address and mask with every router's locally routed subnets.

Once the router on the host network is found, the routing table of this router is studied to find the Next Hop address for the destination network, or the default route if the destination network is not in the routing table. The router found with the Next Hop address is the next layer 3 node the route. This process is repeated until the router in the destination network is found.

It is important to always record the downstream interface for every router. For multilayer switches the downstream interface could refer to a VLAN with multiple switch ports. In this case, information about every individual switch port is to be collected and kept with the router.

L2 paths are determined individually between every two adjacent routers, as well as between routers and hosts at each end of the route. It is relatively easy to spot the path on a diagram between two points. Nevertheless an algorithm similar to Spanning Tree (5) is required to find the path programmatically.

Within the same VLAN, using the physical topology information, the L2 connection from the all the downstream ports of the first router is traced to the immediate neighbours, then to the neighbours' neighbours, and so on until the next router on the path is reached.

The same algorithm applies for finding the physical path between a router and a host, except that the starting device is always the router. This is to accommodate the fact that a host can be connected to a router via a hub and some of the hosts may not support SNMP.

Multicast

One unique feature of EisStream is that it has been developed from the outset with the consideration of how to extract media multicast channel information. The data gathering process for multicast functions forms an integral part of the discovery process. Every time a new router is discovered, it is tested with the multicast routing MIB (IPMROUTE-STD-MIB) to check if it is a multicast router, and if so then all the multicast data on this router is extracted and stored. The software keeps a list of the multicast routers, which contains all the multicast information of the network.

Another new feature of EisStream is its independence from manual configuration settings of the multicast routers, such as PIM mode, IGMP version, bootstrap router priority and Rendezvous-Point settings. The software is only interested in learning the final routing decision made by the individual multicast routers; this is stored in the MIB.

Every multicast group is uniquely identified by the multicast address. There can be more than one source for a multicast group. On a multicast router, the interface on which the multicast transmission is received is called the upstream interface and those on which this transmission is forwarded to are called the forwarding interfaces of this multicast group. The IP address of the device where the multicast traffic is received from is treated as the upstream neighbour. EisStream collects the above information for every multicast group from all routers to establish the complete forwarding tree structure, consisting of all multicast routers involved in forwarding the traffic of this group.

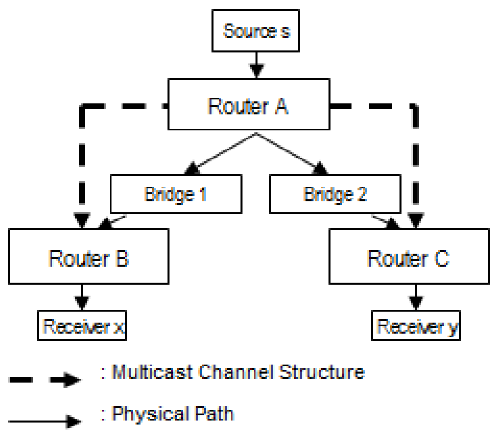

Figure 8: Physical Path for Multicast Traffics

When a multicast group has no receiver on a multicast router there will not be any traffic forwarded by this receiver, the entry for the forwarded interface of this multicast group on this router will be null.

Apart from indicating a multicast router has no receiver, EisStream is also able to report the number of receivers existing on a multicast router, using the L2-L3 multicast MIB (IGMP-STD-MIB). However receivers are not included in the multicast tree structure as they are subject to much more frequent changes.

Using the mechanism for end-to-end physical path discovery and the information on the channel structure of all multicast groups, every node involved in the delivery of a particular multicast stream can be identified.

The physical path for connections between routers, connections between the source and the RP, and connections between receivers and multicast routers can be determined in exactly the same manner as for an end-to-end connection.

Test Results

The software was developed using the Agile Software Development method and rigorously tested on the BBC R&D network on every iteration cycle.

As shown in Figure 9, the network consists of a single router and many bridges and hosts, over 250 in total. Every transparent box indicates a device that does not support SNMP (EisStream times out when attempting to contact such devices).

The software was also tested on a media distribution network consisting of 37 routers and over 300 hosts.

As shown in Figure 10, the software is able to discover all the routers and bridges on the network. There is also a large number of hosts that do not support SNMP, which resulted the software running time to exceed 20 minutes.

Throughout discovery, the overall network traffic did not exceed 500kbps. However the local CPU of the host running the software saturated at 50%.

Figure 9: Topology of BBC R&D Network

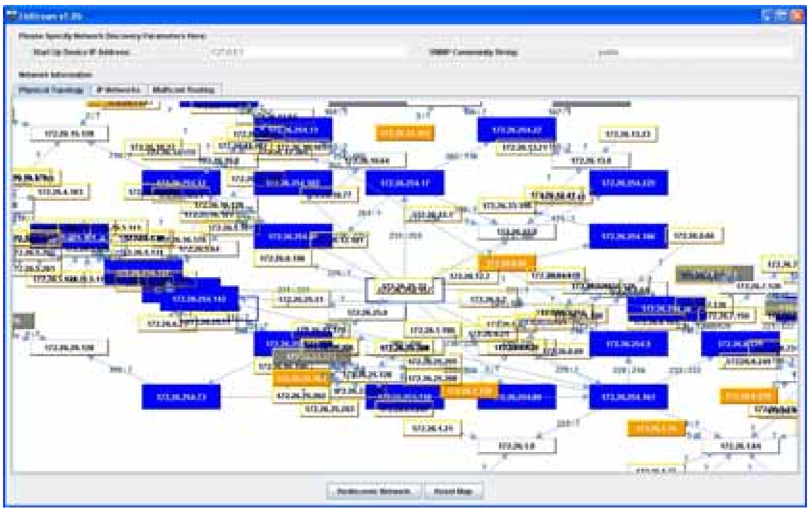

Figure 10: Topology of a Live Transmission Network

CONCLUSION

With the proposal of a new network measurement standard tailored for media requirement and the development of a universal software platform capable of monitoring any device port for a media stream, an integrated solution for fully audiovisual-oriented network monitoring is now ready.

The next step is to publish and promote the new standard into an industry-wide adoption by major media network manufacturers.

The functions of the EisStream platform can potentially be developed as web services as shown in Figure 13 and APIs for distributed or embedded deployment.

Once the new MIB standard becomes adopted by manufacturers, the EisStream platform will be able to achieve the ultimate goal of multilayer monitoring for streams on a multi-vendor network with fully media-specific parameters.

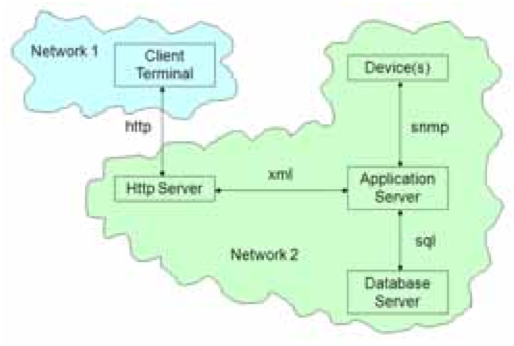

Figure 13: EisStream as a Web Service

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