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Network Fundamentals for Live Events

Carlos Portilla

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ABSTRACT

Tampereen ammattikorkeakoulu
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Networks used in live events have been undergoing a rapid change over the recent years. As a result, the number of networks that are being implemented in the live event industry has been increasing constantly. Almost every sound, video and lighting equipment used in the industry is network capable nowadays.

Different technologies have been created specifically for the live event industry, but many have been borrowed from other industries such as the networking protocols and standards. This thesis explores the network fundamental theory and revises four entertainment control systems that have been implemented in the live event field.

The purpose of this thesis is to present the protocols, standards and the technology that is used in networking to the technicians that are starting to work with networks in the live event industry. The control systems taken as practical cases for this thesis explain the needs, challenges and results of working with networks from the point of view of the professionals that designed, programmed and operated the networks. Their perspective and comments reassure that the live event industry will keep using networks. Networks make live event technology more versatile and reliable.

Key words: network, live event, technology.

CONTENTS

1 INTRODUCTION

Live events involve the gathering of people in a determined place and time that share a common interest. Throughout the year many events take place in different parts of the world. According to Roy, A. & Deshmukh, R. (2019) the most popular events include conference & exhibition, corporate events & seminars, promotion & fundraising, music & art performance, sports, festival, trade shows, and product launch.

The live event industry has experienced a growth in the use of technology. For the people working in the live event industry this thesis will introduce the networking fundamentals, which take part on the technical side of events (sound, video and lighting) where there is a good demand for skilled technicians and engineers.

With the increasing technology developments on taking audio, video and lighting signals to network standards, the knowledge of how networks are design will be crucial in the near future. The thesis will present entertainment control systems as practical cases where the design process, implementation and operation will be commented, as well as suggestions for improvements. The conclusion of the thesis highlights how networking has affected the live event technologies, what are the benefits on networked entertainment control systems as well as the key factor for successful implementations of networks in the event industry.

2 NETWORK FUNDAMENTALS

2.1 What is a Network?

Two computers are said to be interconnected if they are able to exchange information. The connection need not be via a copper wire; fiber optics, microwaves, infrared, and communication satellites can also be used. Networks come in many sizes, shapes and forms. They are usually connected together to make larger networks, with the Internet being the most well-known example of a network of networks. (Tanenbaum &. Wetherall 2010, Chapter 1.)

Computer networks are built primarily from general-purpose programmable hardware, and they are not optimized for a particular application. Instead, they are able to carry many different types of data, and they support a wide, and ever growing, range of applications. Today's computer networks are increasingly taking over the functions previously performed by single-use networks. (Peterson & Davie 2011, 2.)

A network is a set of two or more computers connected together to share information. It’s common to refer to each connected device as a node on the network to make the description applicable to a wider range of devices. Each node might have a different operating system or hardware. But as long as each node follows a set of rules, or network protocol, it can communicate with the other nodes on the network. To communicate correctly, all nodes on a network must understand the same network protocol. (Forshaw 2017, Chapter 1.)

Communication networks have become essential media for homes and businesses. The design of modern computer and communication networks must meet all the requirements for new communication applications. A ubiquitous broadband network is the goal of the networking industry. Communication services need to be available anywhere and anytime. The broadband network is required to support the exchange of multiple types of information, such as voice, video, and data, among multiple types of users, while satisfying the performance requirement of each individual application. Consequently, the expanding diversity of high-bandwidth communication applications calls for a unified, flexible, and efficient network. The design goal of modern communication networks is to meet all the networking demands and to integrate capabilities of networks in a broadband network. (Mir 2014, 4.)

A network is a group or system of things that are interconnected. In the AV and IT communications industries, a network is a group of devices connected in a manner that allows communication among them. Networks are categorized by the area they cover, or their scale. (AVIXA Inc. & Ciddor 2019, 119.)

The use of networks in entertainment applications has opened up the door to a range of new possibilities in terms of working with multiple computers at one time. This is especially true with regards to controlling media servers. Since all media servers are computer based applications, the server's built-in networking capabilities can be utilized, making setup and control a bit simpler. (Claiborne 2014, 91.)

A network consists of two or more nodes interconnected so that they can share meaningful data. All networks have two main parts: nodes and connections. Nodes are the devices that send and receive data. In the early days of networking, a node was basically a computer. Today a node can be a computer, a mobile device, a video server, a projector, a control panel, or some other electronic system capable of sharing data. Connections are the means by which data travels from one node to another. They can be any signal-transmission medium: radio frequency, copper cabling, light, and so on. (Grimes & InfoComm International 2014, 3.)

Networking allows the different computers and equipment to communicate with each other and to transfer and/or share video, audio, and other data. In order for the various gear to talk to each other, everything must be on the same local network. Different equipment can connect to networks wirelessly and/or via Cat 5/6 cables. (Oliszewski, Fine & Roth 2018, Chapter 5.)

2.2 Network Classifications or Network Types

There are different types of Networks. Networks can be categorized by their size. The size can be expressed by the geographic area they occupy and by the number of devices that are part of the network. For the purpose of this work, only LANs, WLANs and WAN’s will be mentioned.

2.2.1 Local Area Network (LAN)

A LAN is a privately owned network that operates within and nearby a single building like a home, office or factory. LANs are widely used to connect personal computers and consumer electronics to let them share resources (e.g., printers) and exchange information. (Tanenbaum & Wetherall 2010, Chapter 1.)

A LAN covers a “small area”, such as a single building or a small group of buildings, and it typically owned and maintained by one organization. Most shows networks are LANs based on Ethernet. (Huntington 2017, 153.)

A local area networking system allows for multiple devices, such as media servers, projectors, and light boards, to link locally to each other via different types of communication protocols and channels. Networking allows the different computers and equipment to communicate with each other and to transfer and/or share video, audio, and other data. In order for the various gear to talk to each other, everything must be on the same local network. (Oliszewski, Fine & Roth 2018, Chapter 5).

LANs use physical addresses to communicate. The physical address is the Media Access Control (MAC) address, which is hard-coded into each network in-

terface card (NIC). MAC addresses are unique—no other device on the planet should have the same MAC address as your video server or laptop.
Data sent across a LAN is addressed to the MAC address of a device on that LAN. A node sends the packet. A network switch receives the packet and examines the MAC address to which it's addressed. The switch then forwards the packet to the device that matches the MAC address. (Grimes & AVIXA Inc. 2014, 6).

2.2.2 Wide Area Network (WAN)

When traffic needs to be transported from one LAN to another, it travels over a wide area network (WAN), like the Internet. The true distinction between a LAN and WAN lies in how the data is addressed and transported: WAN data travels in Internet Protocol (IP) packets rather than Ethernet frames. A wide area network is a network that connects one or more LANs. WANs use logical addresses to communicate. The form a logical address takes depends on the type of WAN. However, for most modern WANs, the logical address is an Internet Protocol address. An IP address is assigned to a device, either manually or automatically. (AVIXA Inc. 2015, 344.)

The nodes on a WAN are routers. If a LAN is connected to other networks via a WAN, a router sits at the top of its network hierarchy. Any data that needs to travel to a device outside the LAN gets forwarded to the router. This protects the devices on the LAN. (Grimes & AVIXA Inc. 2014, 7.)

2.2.3 Wireless Local Area Networks (WLAN) or Radio Frequency Local Area Network (RF LAN)

In addition to transmitting signals over a cabled networked system, you can transmit signals wirelessly, with special devices on each end of the wireless signal to translate it back into wired Ethernet. The wireless connection is known as Wi-Fi. (AVIXA Inc. & Ciddor 2019, 128.)

A WLAN is where either an Access Point (AP) or a wireless router is implemented on a LAN to provide wireless access to the resources on the LAN. This provides freedom of mobility to the users on the wireless LAN. (Latchmepersad & Singh 2018, 52.)

There are other types of networks like Metropolitan Area Network (MAN), Storage Area Network (SAN), Personal Area Network (PAN). For the purpose of this work, LANs, WANs and WLANs are the ones subject for study.

2.2.4 Virtual Local Area (VLAN)

Virtual Local Area Network (VLAN) capability allows certain switch ports to be isolated from the other ports. This allows dividing up a larger switch into several virtual smaller switches. While this capability may not matter if all the data is unicast, if there is any multicast or broadcast traffic, there might be significant benefit to isolating that traffic to just certain ports. Some switches may allow data from several VLANs to share a common link to another switch without the data being mingled. Both switches must support the same method for doing this for it to work. Most today use a technique called tagging to allow isolated VLANs to share a common physical link between switches. (Ballou 2015, 1474)

2.3 Network Topologies

A network topology is simply the orientation or the layout of objects that are interconnected for the purpose of communication or sharing resources. To put it simply, it's the network diagram displaying where devices are located, the type of media used to physically connect the components, the interfaces or the physical ports used, and the IP addresses of each device. (Latchmepersad & Singh 2018, 47.)

2.3.1 Mesh Topology

In a mesh network, each node is connected via bridges, switches, or routers to at least one other node (Figure 1). This configuration allows the nodes to distribute data via many possible paths, providing high resilience to failure. Mesh topology is used for ad hoc wireless networks where wireless nodes may connect or disconnect at unpredictable intervals and where one node may act as a relay for other distant nodes. (AVIXA Inc. & Ciddor 2019, 125.)

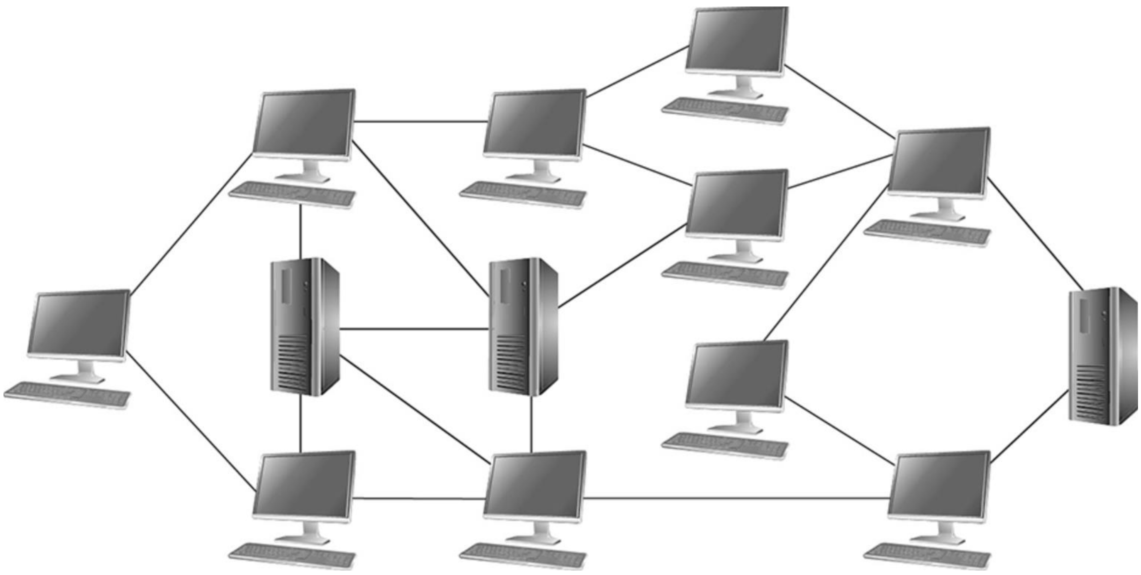


Figure 1. Mesh topology (AVIXA Inc. & Ciddor 2019, 125)

2.3.2 Star Topology

All nodes connect to a central point (Figure 2). This central point may be a router, switch, or hub. Star networks are hierarchical. Each node has access to the other nodes through the hub. If any node fails, information still flows. But the central device is a single point of failure; if it fails, communication stops. Star topologies are often extended to include more than one layer of hierarchy (often called an extended star topology). If any device fails, access to devices below it is cut off, but the rest of the network keeps operating. The central device, however, remains a single point of failure. (Grimes & AVIXA Inc. 2016, 417.)

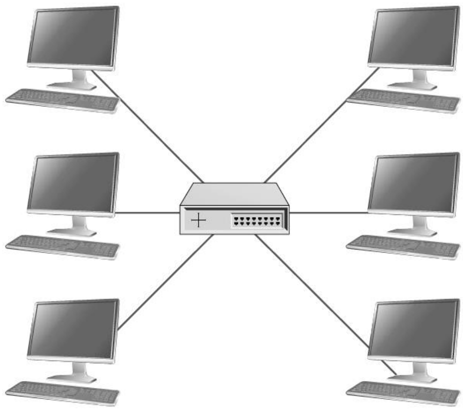


Figure 2. Star Topology (AVIXA Inc. & Ciddor 2019)

2.3.3 Wireless Topology (RF LAN or WLAN)

A wireless LAN (WLAN) topology is a type of physical topology. Because it uses radio frequency (RF) signals as a connection medium, a WLAN's size and shape aren't defined by cables. That said, a wireless topology's size is not unlimited. Nodes access a wireless topology through a wireless access point (WAP) instead of a physical cable. WAPs connect to each node via RF signals. The signals emitted by a wireless device—a node or an access point—form transmission lobes, which must overlap for communication to occur. With that in mind, the range and placement of devices in a wireless topology are constrained by several factors, including antenna type, signal strength, and physical obstructions to wave propagation (Figure 3). (Grimes & AVIXA Inc. 2014, 12.)

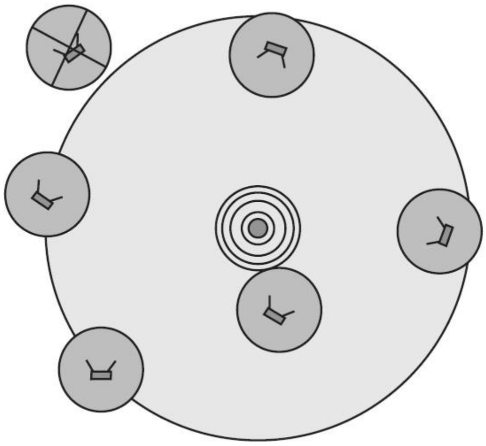


Figure 3. Wireless LAN; notice the device outside the transmission lobe (Grimes & AVIXA Inc. 2014, 13)

2.3.4 Hybrid Topology.

Most modern enterprise networks can't be described by one topology type. Instead, their designs incorporate several different topologies (Figure 4). This is known as a hybrid topology. (Grimes & AVIXA Inc. 2014, 14.)

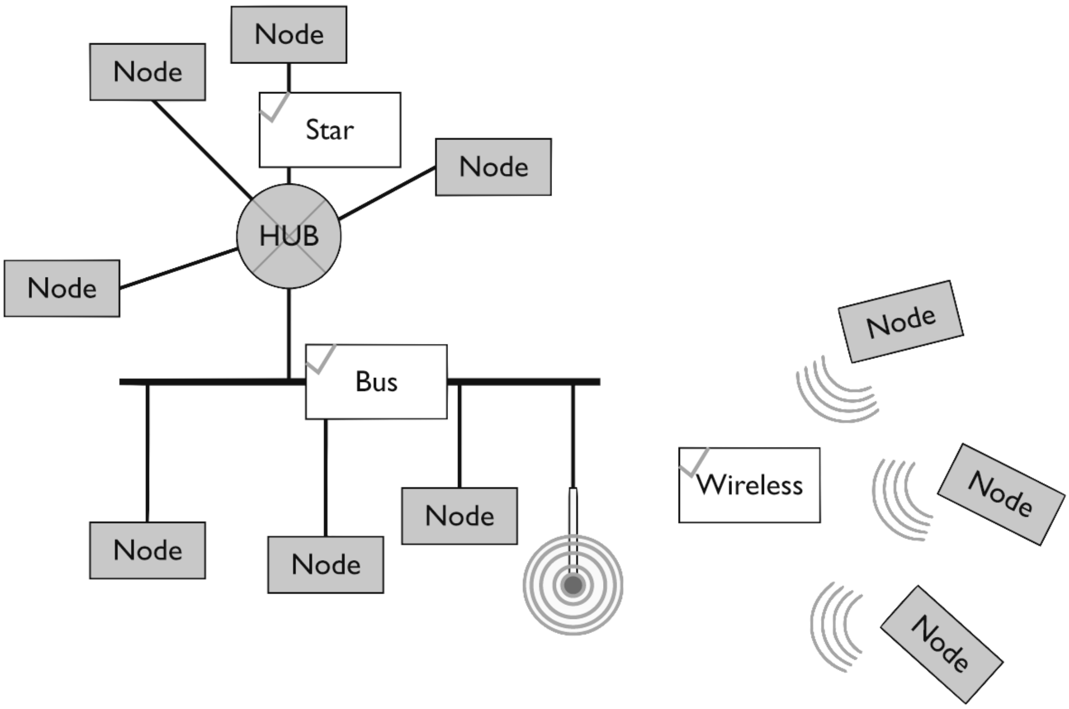


Figure 4. Hybrid Topology (Grimes & AVIXA Inc. 2014, 14)

3 THE OSI REFERENCE MODEL AND THE TCP/IP PROTOCOL SUITE

The Internet—the largest computer network in the world today, is constructed from several protocols and protocol suites that work together to allow users to communicate across the globe. A protocol is simply a rule, or a collection of rules and conventions, that a device follows in order to communicate with other devices around the world. A protocol suite is simply a collection of these rules, which work together to allow complex applications on networking devices to communicate with billions of other devices around the world, through an assortment of networking equipment and media.
Two protocol suites in particular have largely influenced the internet as we know it today:
The Open Systems Interconnection (OSI) reference model
The Transmission Control Protocol/Internet Protocol (TCP/IP) suite.
Although these two protocol suites possess significant differences between them, they both serve as important blocks in the foundation of the Internet. (Singh & Latchmepersad 2018, 6.)

3.1 The OSI Model

No matter what kind of connection you are using for your network, the framework that enables communication between devices must be standard, and you must have a common language to describe the process. The Open Systems Interconnection model was developed by the International Organization for Standardization (ISO) to standardize communication between devices all over the world, including those on the Internet. The OSI model separates communication connectivity into seven different layers, each with a specific duty. This allows for a variety of connection types, as well as the development of specific hardware and software to optimize the network. The layers are processed in a specific, sequential manner. (AVIXA Inc. & Ciddor 2019, 129.)

Data is sent across a network by applications. This means that when a computer sends a message, the message starts at Layer 7, the Application Layer, and moves down through the OSI model until it leaves the sending device on Layer 1, the Physical Layer. The data travels to the receiving device on Layer 1 and moves up through the OSI model until it can be interpreted by the receiving device at Layer 7 (Figure 5). (Grimes & AVIXA Inc. 2014, 22.)

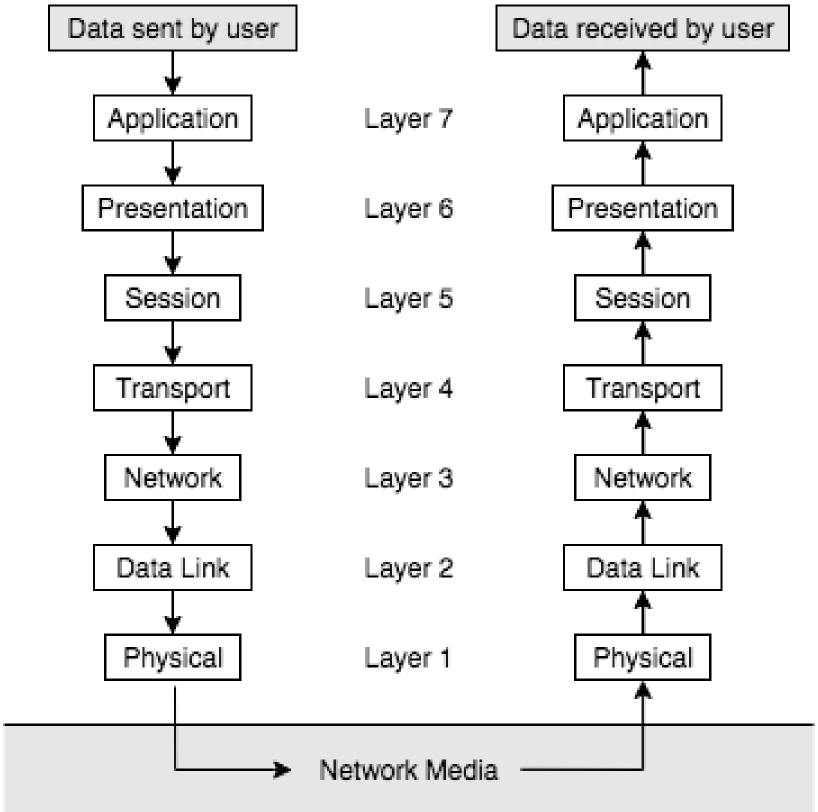


Figure 5. Data flow through the OSI Model (Portilla 2020)

3.1.1 Layer 7. Application Layer.

The Application Layer defines how a user accesses and interacts with data on the network. Application Layer protocols present network data to user application software, such as a media player or a word processor, and vice versa. (Grimes & AVIXA Inc. 2014, 22.)

3.1.2 Layer 6. Presentation Layer. Format Data, Encryption.

The Presentation Layer is responsible for how information is represented while it's being transferred between Application Layer entities. This method of data representation is called the transfer syntax. This layer therefore provides services such as encryption (ensuring that data is not easily readable while being transferred), decryption (making the data readable again), and translation of data between different structures. (Latchmepersad & Singh 2018, 14.)

3.1.3 Layer 5. Session Layer. Start and stop sessions

The session layer establishes conversations — sessions — between networked devices. A session is an exchange of connection-oriented transmissions between two network devices. Each transmission is handled by the transport layer protocol. The session itself is managed by the session layer protocol.
A single session can include many exchanges of data between the two computers involved in the session. After a session between two computers has been established, it's maintained until the computers agree to terminate the session.
The session layer allows three types of transmission modes:
Simplex: Data flows in only one direction.
Half-duplex: Data flows in both directions, but only in one direction at a time.
Full-duplex: Data flows in both directions at the same time. (Lowe 2018, 88.)

3.1.4 Layer 4. Transport Layer. TCP, UDP, Port numbers

Transport Layer protocols manage end-to-end message delivery. When sending information, a Transport Layer protocol may divide long packets into smaller segments as necessary. At the receiving end, the Transport Layer builds segments back into the original message. The Transport Layer may also detect errors and send receipt acknowledgments. Ports are a Transport Layer technology.

For IP networks, the Transport Layer protocol will be either Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). The two methods differ in speed and reliability. You must be able to identify, and in many cases decide, what kind of transport protocol your AV devices will use to send information over the network. For example, during a web conference, audio and video are sent using the Transport Layer protocol User Datagram Protocol (UDP). UDP continuously sends the media packets to their destination without waiting for a receipt confirmation. (Grimes & AVIXA Inc. 2014, 24.)

3.1.5 Layer 3. Network Layer. IP Address, Routers

This layer addresses data packets and routes them to addresses on the network. Packets “ride” inside layer 2 frames. Layer 3 adds IP addressing. Routers can send, receive, and route IP addresses. Note that many routers include an integrated switch. (AVIXA Inc. 2015, 322.)

3.1.6 Layer 2. Data Link Layer. MAC Address, Switches.

This layer is the interface to the Physical layer; it uses frames of information to talk back and forth. The addressing scheme is MAC addresses. One MAC address talks to another MAC address. Switches use layer 2 to send and receive frames. (AVIXA Inc. 2015, 322.)

3.1.7 Layer 1. Physical Layer. The media and hardware.

It defines the electrical, timing and other interfaces by which bits are sent as signals over channels. The physical layer is the foundation on which the network is built. The properties of different kinds of physical channels determine the performance. (Tanenbaum & Wetherall 2010, Chapter 2.)

This layer provides the electrical, mechanical, and functional methods to move the actual bits of data (the 1s and 0s that encompass data in its raw forms) between networking and computing devices in order to facilitate the transparent transmission of bit streams between Data Link protocols. This movement of data is supported by various forms of media (both wired and wireless). (Latchmepersad & Singh 2018, 16.)

Layers 1–3, known as the media layers, define hardware-oriented functions such as routing, switching, and cable specifications. These are the areas that most concern AV professionals. Layer 4, the Transport layer, is also important to AV professionals because it is where the transition between gear and software occurs. (AVIXA Inc. 2015, 323.)

3.2 The TCP/IP protocol suite

The OSI model was created to describe any kind of network; its creators didn't have any specific protocols in mind. The TCP/IP stack is a specific set of protocols, developed by the Internet Engineering Task Force (IETF), divided into four categories (instead of the OSI's seven): Link, Internet, Transport, and Application (Figure 6) (Grimes & InfoComm International 2014, Chapter 7).

OSI Model		TCP/IP Model
7	Application layer	Application layer
6	Presentation layer	
5	Session layer	
4	Transport layer	Transport layer
3	Network layer	Internet layer
2	Data Link layer	Network Access layer
1	Physical layer	

Figure 6. The seven layers of the OSI Model compared to the TCP/IP model (AVIXA Inc. & Ciddor 2019)

We can immediately notice some key differences between both models. The OSI model we discussed previously consisted of seven layers, while this TCP/IP model consists of only four. The Presentation and Session Layers of the OSI model have been absorbed into the Application Layer, while the Physical and Data Link Layers of the OSI model have been combined to form the Link Layer here. The Internet Layer corresponds to the Network Layer of the OSI model, while the Transport Layer remains unchanged. This simplified structure of TCP/IP was actually a key factor in its dominance over the OSI model.
However, in spite of these differences, many of the concepts we discussed in the OSI reference model are also applicable to the TCP/IP suite. Applications still utilize the concepts of encapsulation and decapsulation that we discussed previously, and protocols at a particular layer still communicate with protocols at that same layer in end hosts. (Latchmepersad & Singh 2018, 19.)

3.2.1 Layer 4. Application Layer

At the very top of the protocol stack exists the Application Layer. The programs that we use every day on our desktop computers and mobile devices exist at this layer. Protocols at this layer create data that needs to be transmitted to or received from other internet hosts. (Latchmepersad & Singh 2018, 20.)

3.2.2 Layer 3. Transportation Layer

The transport layer, as the layer 4 protocol in the TCP/IP protocol stack model, handles the details of data transmission. Transport-layer protocols are implemented in the end points but not in network routers. The transport layer ensures a complete data transfer for an application process, free from any networking issue or detail of physical infrastructure. This layer clearly acts as an interface protocol between an “application” of a communicating host and a network as seen in Figure 7.

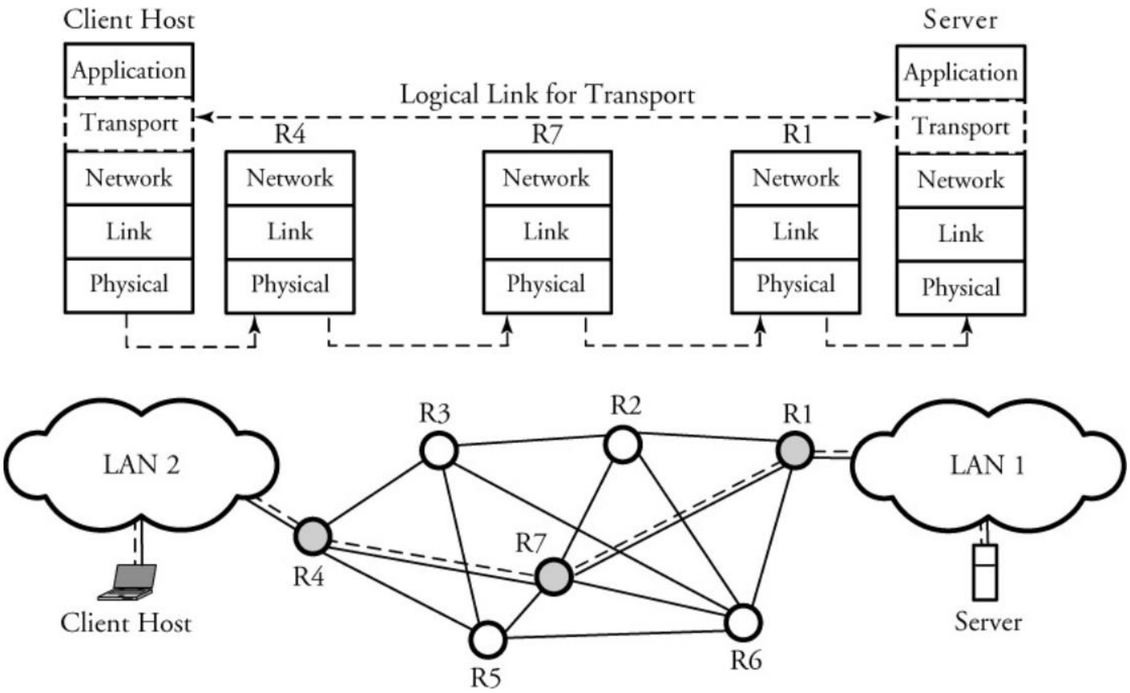


Figure 7. Demonstrating a “logical” end-to-end communication link at the transport layer between a client host and a server (Mir 2014, 290)

The transport layer provides a “logical” communication between application processes. As seen inFigure 7, a client host in LAN 2 is running an application in connection with an application on a server in LAN 1 through a logical, but not physical, link between the two end points. By logical link, we mean that it is as if two end points, such as a client and a server, running their application processes were directly connected, while end points may be distant from each other and connected via physical links, switches, and routers. For example, the client host and the server shown in the figure are located on opposite sides of the network and connected via routers R4, R7, and R1. This way, an application process sends messages to another application process using a logical link provided by the transport layer while disregarding the details of how handling these messages is carried out. (Mir 2014, 290.)

There are two well-known protocols at this layer—TCP and the User Datagram Protocol (UDP). TCP provides connection-oriented transmission of data, requiring a connection to be set up between internet hosts before data can be transmitted, but also providing features such as reliable, in-sequence delivery of data. UDP, on the other hand, is a connectionless protocol that does not require any setup before data can be transmitted, but also does not offer features such as guaranteed delivery of data. (Latchmepersad & Singh 2018, 20.)

Live video and multimedia applications are best suited for UDP. They can tolerate some data loss, but require little or no delay. Examples include VoIP and live streaming video. (Cisco Networking Academy 2016, Chapter 9.)

3.2.3 Layer 2. Internet Layer

Provides the service of moving data from the Transport Layer across networks, using forms of Internet addressing. IP has become the most utilized protocol at this layer, and you are certain to deal with IP addresses from both version 4 of the protocol, IPv4, as well as version 6, IPv6. Devices that operate at this layer include routers and layer 3 switches. (Latchmepersad & Singh 2018, 21.)

3.2.4 Layer 1. Network/Link Layer

At the bottom of the TCP/IP protocol suite, we will find the Link Layer. This layer operates only on the local segment that a host is physically connected to, and is responsible for delivering data between devices that are connected in the same local segment/network. (Latchmepersad & Singh 2018, 21.)

4 ETHERNET

In the previous chapter, we spoke about the OSI reference model and the TCP/IP stack. We've observed that layer 2 (Data Link Layer) is where the Protocol Data Units (PDUs) are either entering or exiting a system and layer 1 (Physical Layer) is the actual media used for transporting the bits. At these two layers, both the Physical and the Data Layers, we can find Ethernet (Figure 8). (Latchmepersad & Singh 2018, 52.)

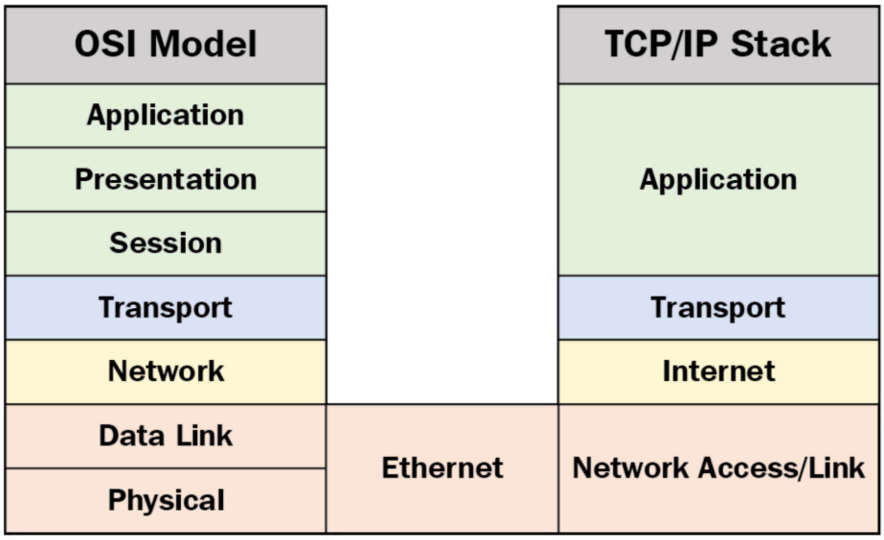


Figure 8. OSI Model and TCP/IP stack (Latchmepersad & Singh 2018, 52)

4.1 What is Ethernet?

Ethernet is the main Data Link Layer technology used to transport data on LANs. Ethernet relies on MAC addresses to identify the source and destination of data on a network. Devices on the same LAN can use Ethernet switches to communicate directly, without having to send their traffic through a router. The switches know the MAC addresses of all connected nodes, so if the destination node is on the same LAN as the sender, the switch can pass the Ethernet frame directly to it. (InfoComm International & Grimes 2014, 45.)

Ethernet is now the predominant LAN technology in the world. Ethernet operates in the data link layer and the physical layer. The Ethernet protocol standards define many aspects of network communication including frame format, frame size, timing, and encoding. When messages are sent between hosts on an Ethernet network, the hosts format the messages into the frame layout that is specified by the standards. (Cisco Networking Academy 2016, 233.)

Ethernet is the de facto networking standard for entertainment control. While other networking standards are used in larger IT world (especially in WAN applications), you are not likely to see them on a show. You will find Ethernet even on small productions, carrying lighting control data, connecting video control equipment, linking show control computers to sensing systems, transporting multichannel digital audio and control data throughout entertainment facilities of all sizes, and connecting components in scenic motion-control systems.
Ethernet is responsible only for transporting bits from place or another, while higher-level protocols (such as TCP, IP, ARP, etc) are responsible for packing the data and making sure that the message is delivered reliably and appropriately. (Huntington 2017, 154.)

Ethernet is an excellent control communications solution for shows. It offers the following:

- Open standard
- Very high bandwidth
- Low cost
- Near “real-time” delivery using (high-quality) full duplex switches
- Electrical isolation due to Ethernet’s use of transformers for twisted pair connections (or fiber)
- High-quality CRC error check of every single frame transmitted across the network
- “Guaranteed” delivery through the use of TCP or other protocols (Huntington 2017, 167.)

Ethernet is the most commonly used method of transferring data on a LAN. It is an Institute of Electrical and Electronics Engineers (IEEE) standard that governs how computers exchange information over the network medium.
The Ethernet standard specifies the physical transmission media (cable, fiber, wireless) and how signal information is handled (frames or packets) on a network. The standard is called IEEE 802, and it is revised periodically to include improved technology and applications. Such revisions are indicated as 802.x.x, where the xs represent the revision numbers.
Variations of Ethernet operate in all LAN topologies and use a variety of network media (cable, fiber, and wireless). The topology and the connecting medium determine the speed and distance of data transfer.
Ethernet is a packet-based system. Large files or streams of data are broken into smaller chunks called packets. These packets are 1,500 bits or smaller. Because of the nature of Ethernet, it is possible for packets to take different paths and arrive at the destination at different times or out of order. The receiving device must keep track of missing packets and either request the missing information again or have the ability to ignore missing packets. Ethernet is designed as a “best-effort” delivery system. (AVIXA Inc. & Ciddor 2019, 126.)

To make sure that each transmission is heard clearly by all devices and that collisions can always be detected, the Ethernet specification includes restrictions on the physical length of cabling as well as the minimum size of an Ethernet frame. The restrictions on cable length vary with the type of physical cable used and are related to the signal strength in the cable medium. A minimum transmission size is required to ensure that devices can detect any collision with its own transmission before it stops transmitting. When sending a small amount of data, padding is required to bring the frame above the minimum size. (Matthews 2005, Chapter 5.2.)

5 PHYSICAL LAYER MEDIA TYPES

Media Type is the physical entity that is used to make the network connection. This can be different types of cable, fiber optic, radio or even microwave. A specific Media Type can be used for a number of Physical Layers. (Howell 2013, 45.)

5.1 Bandwidth/Frequency and Data Rate/Throughput

One initially confusing aspect about cabling is that cables are rated in hertz rather than bits per second. Network engineers are more concerned with how much data can be pushed through the cable than with the frequency at which that data is traveling.
Frequency is the number of cycles completed per unit of time and is generally expressed in hertz (cycles per second). Data cabling is typically rated in kilohertz (kHz) or megahertz (MHz). The more cycles per second, the more noise the cable generates and the more susceptible the cable is to signal level loss.
Data communication over cabling networks occurs by transmitting bits of digital data in a serial fashion. The speed at which these bits are transmitted and received is known as the bit rate and is expressed in bits per second (bps).
The bandwidth of a cable is the maximum frequency at which data can be effectively transmitted and received. The bit rate is dependent on the network electronics, not the cable, provided the operating frequency of the network is within the cable's usable bandwidth. (Oliviero & Woodward 2014, 35.)

The data rate (throughput or information capacity) is defined as the number of bits per second that move through a transmission medium. It's tough to keep pushing the bandwidth of copper cables higher and higher. There are the laws of physics to consider, after all. So techniques have been developed to allow more than 1 bit per hertz to move through the cable. (Oliviero & Woodward 2014, 36.)

The physical layer produces the representation and groupings of bits for each type of media as:
Copper cable – The signals are patterns of electrical pulses.
Fiber-optic cable – The signals are patterns of light.
Wireless – The signals are patterns of radio or microwaves. (Cisco Networking Academy 2016, 167.)

Physical cables form the backbone of virtually every network in existence. While wireless links may be more appropriate for certain situations, wired media typically constitutes the vast majority of links in a network. (Latchmepersad & Singh 2018, 168.)

5.2 Twisted pair copper cables

A twisted-pair link is the simplest form of guided medium used for data transmission. A twisted pair is normally manufactured using copper and consists of two insulated wires. (Mir 2014, 73.)

The insulation on the cables is color coded to help distinguish them and arrange them according to wiring standards. The spline separating the cables helps to reduce cross-talk between the pairs. (Latchmepersad & Singh 2018, 169.)

A twisted pair consists of two insulated copper wires, typically about 1 mm thick. The wires are twisted together in a helical form, just like a DNA molecule (Figure 9). Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, the waves from different twists cancel out, so the wire radiates less effectively. A signal is usually carried as the difference in voltage between the two wires in the pair. This provides better immunity to external noise because the noise tends to affect both wires the same, leaving the differential unchanged.

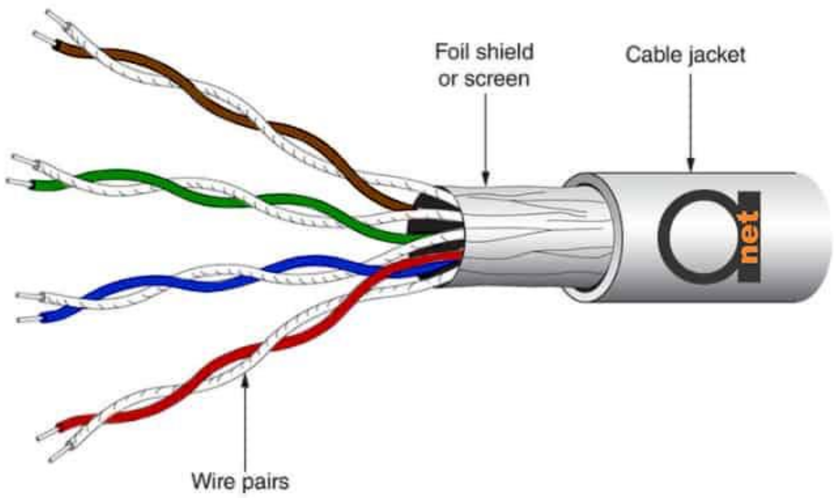
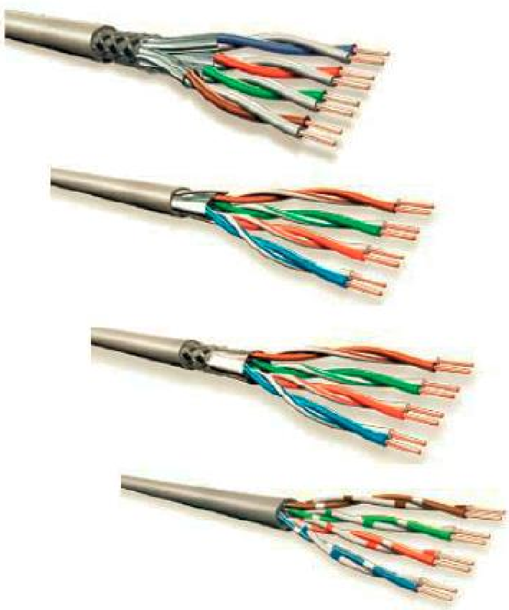


Figure 9. Twisted Copper Cable (RLMD Technical 2019)

Twisted pairs can be used for transmitting either analog or digital information. The bandwidth depends on the thickness of the wire and the distance traveled. Due to their adequate performance and low cost, twisted pairs are widely used and are likely to remain so for years to come. (Tanenbaum & Wetherall 2010, Chapter 2.)

5.2.1 Twisted pair copper cable insulation.

With the aim of providing a reliable connection between electronic devices, selecting a proper shielded twisted pair cable is basic to the network using twisted pair copper cables. There are mainly four types of shielded TPCs (Figure 10).



- S/FTP=Screen braided overall (S), foil screened twisted pairs (FTP)

- F/UTP= Foil screen overall (F), unscreened twisted pairs (UTP)

- SF/UTP=Screen braided and Foil screen overall (SF), unscreened twisted pairs (UTP)

- U/UTP=Unscreened overall (U), unscreened twisted pairs (UTP)

Figure 10. Types of shielding for Twisted Cooper cables (Gosnet 2019)

5.2.2 Pin Connections for Twisted-Pair Cable

T568A and T568B are the main color standards implemented for wiring eight-position RJ45 connectors. Both are under the ANSI/TIA/EIA wiring standards (Figure 11).

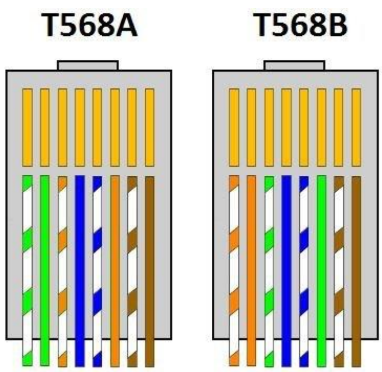


Figure 11. T-568A and T-568B cabling diagram (Hossain 2019)

The only difference between the two wiring standards is which pair is used to transmit data and which pair is used to receive data. In the EIA/TIA 568A standard, the green pair is used to transmit and the orange pair is used to receive. In the EIA/TIA 568B and AT&T 258A standards, the orange pair is used to transmit and the green pair to receive (Table 1). (Lowe 2018, 47.)

Table 1. EIA/TIA 568A and EIA/TIA 568B wiring standards (Gosnet, 2019)

Pin Number	Function	EIA/TIA 568A	EIA/TIA 568B AT&T 258A
Pin 1	Ethernet transmit +	White/green	White/orange
Pin 2	Ethernet transmit –	Green	Orange
Pin 3	Ethernet receive +	White/orange	White/green
Pin 4	Used for Gigabit	Blue	Blue
Pin 5	Used for Gigabit	White/blue	White/blue
Pin 6	Ethernet receive –	Orange	Green
Pin 7	Used for Gigabit	White/brown	White/brown
Pin 8	Used for Gigabit	Brown	Brown

5.2.3 Twisted Pair Cable Categories

Twisted-pair cable grades are categories specified by the ANSI/TIA standard 568. ANSI stands for American National Standards Institute; TIA stands for Telecommunications Industries Association. The higher the number, the faster the data transfer rate (Table 2). (Lowe 2018, 42.)

Table 2. Copper Media Type categories. (Gosnet, 2019)

CATEGORY	BANDWITH	THROUGHPUT	COMMENTS
Cat5	100MHz	100Mbps	Up to 100m
Cat5e	100MHz	1Gbps	Up to 100m
Cat6	250MHz	1Gbps	10Gbps up to 55m
Cat6a	500MHz	10Gbps	Up to 100m
Cat7	600MHz	10Gbps and above	Up to 100m

5.3 Fiber Optic

In order for optical fibers to work properly within a system or network, they must meet certain minimum standards established by standards organizations. The Telecommunications Industry Association (TIA) and the International Telecommunications Union (ITU). These organizations publish many different standards on optical fiber, fiber-optic cable, and testing. (Oliviero & Woodward 2009, 569.)

While TIA and ITU publish many standards on optical fiber, the key standards that you should be familiar with are ANSI/TIA-568-C.3, ITU-T G.652, ITU-T G.655, and ITU-T G.657. The ANSI/TIA-568-C.3 standard is applicable to *premises* optical fiber cabling components. The ITU standards are applicable to single-mode optical fiber and cable.
Here are their descriptions:
ITU-T G.652: Characteristics of a single-mode optical fiber and cable
ITU-T G.655: Characteristics of a dispersion shifted single-mode optical fiber and cable
ITU-T G.657: Characteristics of a non-zero dispersion-shifted single-mode optical fiber and cable. (Oliviero & Woodward 2009, 540.)

Optical fiber cable transmits data over longer distances and at higher bandwidths than any other networking media. Unlike copper wires, fiber-optic cable can transmit signals with less attenuation and is completely immune to EMI and RFI. (Cisco Networking Academy 2016, 4.2.3.1.)

Fiber-optic technology is different in its operation than standard copper media because the transmissions are “digital” light pulses instead of electrical voltage transitions. Very simply, fiber-optic transmissions encode the ones and zeroes of a digital network transmission by turning on and off the light pulses of a laser light source, of a given wavelength, at very high frequencies. The light source is usually either a laser or some kind of light-emitting diode (LED). The light from the light source is flashed on and off in the pattern of the data being encoded.

The light travels inside the fiber until the light signal gets to its intended destination and is read by an optical detector. (Oliviero & Woodward 2014, 255.)

Similar to coaxial cables, optical fiber cables have a cylindrical layout. The three concentrics are the core, the cladding, and the buffer (Figure 12). The core consists of several very thin fibers, each of which is surrounded by its own cladding. Each cladding also has a glass or plastic coating but different from that of the core. This difference is the key mechanism that confines the light in the cable. Basically, the boundary between the core and cladding reflects the light into the core and runs it through the cable. (Mir 2014, 74.)

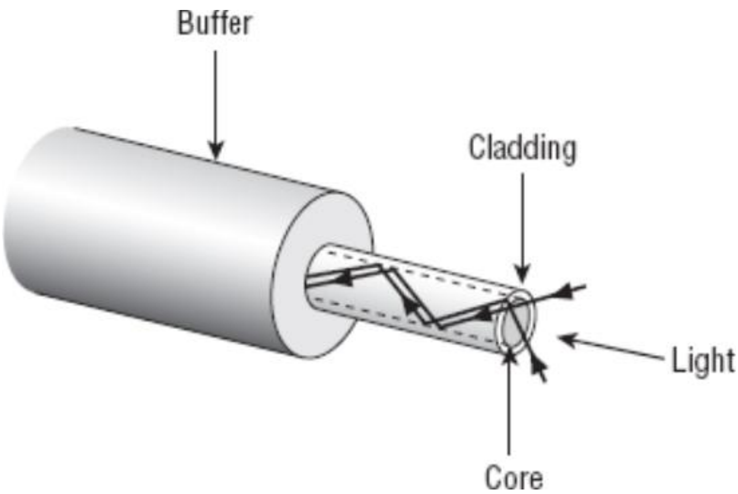


Figure 12. Opctic fiber cable components (Oliviero & Woodward 2014, 255)

5.3.1 Advantages of Fiber Optic cable

The following advantages of fiber over other cabling systems explain why fiber is becoming the preferred network cabling medium for high-bandwidth, long-distance applications:

- Immunity to electromagnetic interference (EMI). Fiber-optic cabling is immune to crosstalk because optical fiber does not conduct electricity and uses light signals in a glass fiber, rather than electrical signals along a metallic conductor, to transmit data. So it cannot produce a magnetic field and thus is immune to EMI. Fiber-optic cables can therefore be run in areas considered to be "hostile" to regular copper cabling

- Higher data rates. Much higher data rates are possible with fiber-optic cabling technologies than with traditional copper systems. Multimode is the preferred fiber-optic type for 100–550 meters seen in LAN networks
- Longer maximum distances. single-mode fiber-optic cables can span distances up to 75 kilometers without using signal-boosting repeaters. (Oliviero & Woodward 2014, 258.)

5.3.2 Singlemode and Multimode Optic Fiber

Fiber-optic cables come in many configurations. Most often, the fiber strands are glass, but plastic optical fiber (POF) exists as well. The cables can be strictly for outdoor use, strictly for indoor use, or a "universal" type that works both indoors and out.

The most basic differentiation of fiber-optic cables is whether the fiber strands they contain are single mode or multimode. A mode is a path for the light to take through the cable. The wavelength of the light transmitted, the acceptance angle, and the numerical aperture interact in such a way that only certain paths are available for the light. Single-mode fibers have a lower numerical aperture and cores that are so small that only a single pathway, or mode, for the light is possible (Figure 13).

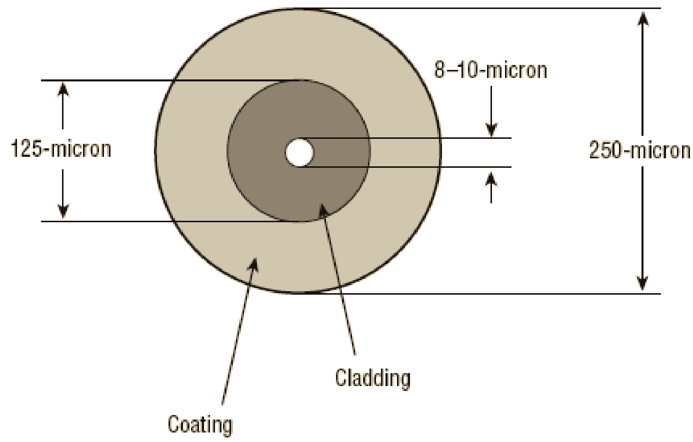


Figure 13. An example of single-mode glass-fiber core (Oliviero & Woodward 2014, 264)

Multimode fibers have larger numerical apertures and cores; the options for the angles at which the light can enter the cable are greater, and so multiple pathways, modes, are possible (Figure 14). Multimode fibers can accept light from less intense and less expensive sources, usually LEDs or 850nm vertical cavity surface-emitting lasers (VCSELs). In addition, connections are easier to align properly due to larger core diameters. Since the core diameters are larger than singlemode fiber, the tolerances required to manufacture these parts are less precise and less expensive as a result.

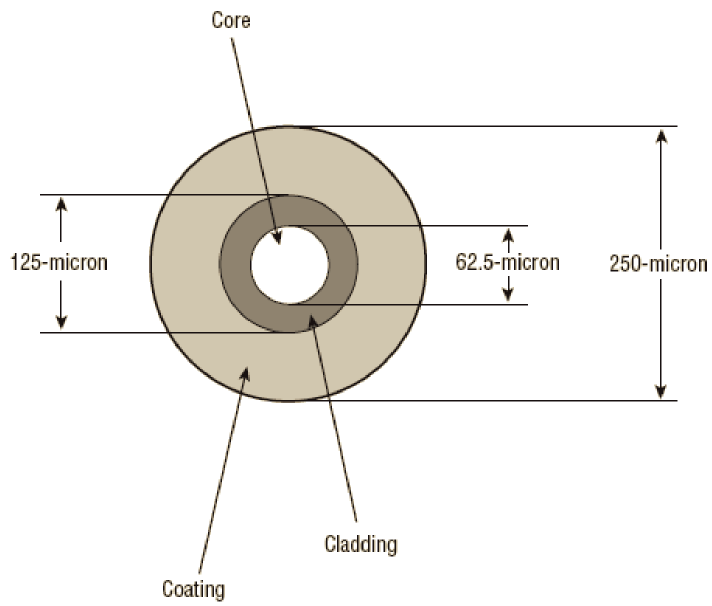


Figure 14. A sample 62.5/125 optical fiber (Oliviero & Woodward 2014, 269)

Single-mode fibers are usually used in long-distance transmissions or in backbone cables, so you find them mostly in outdoor cables. Multimode fibers are usually used in an indoor LAN environment in the building backbone and horizontal cables. They are also often used in the backbone cabling where great distances are not a problem. (Oliviero & Woodward 2014, 261-263.)

Multimode's advantage is that the light can be sent and received with inexpensive LED and VCSEL transceivers. Its disadvantage is its lower, 2km maximum range at 100MBit. Single mode, by contrast, requires expensive, laser-based transceivers to send and receive data. However, single mode data can travel 10 times further—20km. (NEUTRIK 2015, 27.)

5.3.3 Fiber Optic Standards

While optical fiber performance parameters may be mirrored in different standards (Table 3), the fiber designations typically are not. ISO/IEC 11810 uses the acronym "OM" to describe multimode optical fiber and "OS" to describe single-mode. IEC 60793-2-10 uses the letter "A" to describe multimode optical fiber and IEC 60793-2-50 uses the letter "B" to describe single-mode. In the ANSI/TIA-568-C standard optical fiber is designated using the ANSI/TIA-492 series of documents where the letter "A" after 492 designates multimode optical fiber and "C" designates - single-mode. ITU does not use letters only numbers; G.651.1 is a multimode standard while G.652, G.655, and G.657 are single-mode. These designations are broken out in Table 4 (Oliviero & Woodward 2014, 592.)

Table 3. Fiber Optic Standards (Gosnet, 2019).

	OS1	OM1	OM2	OM3	OM4
MODE	Single-Mode	Multimode	Multimode	Multimode	Multimode
DIAMETER	9/125µ	62.5/125µ	50/125µ	50/125µ	50/125µ
USUAL THROUGHPUT	10/100/1000Mbps – 10Gbps	100Mbps	100/1000Mbps	10Gps	10Gps
BANDWITH		200Mhz/km (850nm)	500Mhz/km	1500Mhz/Km (850nm)	3500Mhz/Km (850nm)
COLOR	Yellow	Orange	Orange	Aqua or Violet	Aqua or Violet

Table 4. Fiber designation by industry standard (Oliviero & Woodward 2014, 593)

Industry Standard	Multimode	Single mode
ISO/IEC 11810	OM	OS
IEC 60793-2-10/50	A	B
ANSI/TIA	TIA-492A	TIA-492C
ITU	G.651.1	G.652, G.655, G.675

5.4 Wireless Transmission

The wireless connection, known as Wi-Fi, is defined by the IEEE 802.11 standard and is continually being revised to keep up with the growing demand for wireless communication. Currently, IEEE developers are working on 802.11 standards that would provide even greater speed (throughput)—theoretically, up to 20 Gbps. (AVIXA Inc. & Ciddor 2019, 128.)

The open IEEE 802.11 “wireless Ethernet” standard revolutionized the portable computer market, and found many applications in our market as well, especially during the programming of a show. IEEE 802.11, which is also called “Wi-Fi”, offers high-speed, easy-to-use connections to mobile computer users (Table 5). Of course, that also means it can provide convenient access to us in the entertainment control, as long as we use the systems carefully and prudently. (Huntington 2017, 164.)

Table 5. 802.11 Standard Revisions (AVIXA Inc. & Ciddor, 2019)

Revision	Release Date	Frequency Band	Typical Throughput	Maximum Throughput
802.11a Wi-Fi 2	October 1999	5GHz	27Mbit/s	54Mbit/s
802.11b Wi-Fi 1	October 1999	2.4GHz	~5Mbit/s	11Mbit/s
802.11g Wi-Fi 3	June 2003	2.4GHz	~22Mbit/s	54Mbit/s
802.11n Wi-Fi 4	September 2009	5GHz and/or 2.4GHz	~144Mbit/s	600Mbit/s
802.11ac Wi-Fi 5	December 2013	5GHz	~433Mbit/s	3.5Gbit/s
802.11ad	December 2012	60GHz	~1.5Gbit/s	6.7Gbit/s
802.11ax Wi-Fi 6	December 2018	5GHz and/or 2.4GHz	~4.8Gbit/s	11Gbit/s
802.11ay	November 2019	60GHz	~6Gbit/s ?	20Gbit/s

A wireless access point (WAP) is a local area network device that allows wireless devices to connect to a link that connects to a wired network using a related standard. A WAP usually connects to a router via a wireline link as a standalone device, but it can also be an integral component of the router itself. With a wireless access point, users are able to add devices to the associated wireless network for accessing the network with no cables.
The actual range of WAPs can vary significantly, depending on such variables and factors as the weather, operating radio frequency, indoor or outdoor placement, height above ground, nearby obstructions, other electronic devices that might actively interfere with the signal by transmitting in the same frequency range, type of antenna, and the power output of devices. The range of operability of WAPs can be extended through the use of repeaters, which can amplify radio signals. (Mir 2014, 47.)

Access points can operate on a variety of channels. When the coverage area of two access points overlaps substantially, they are typically configured to operate on different channels to avoid interfering with one another. If a large number of clients in the same area must be supported together (e.g. a densely packed office or auditorium), then multiple access points can also deployed over the same coverage area but each using a different channel. (Matthews 2005, Chapter 5.3.)

For devices to establish a wireless connection, the RF signals for transmission must maintain minimum signal strength. To maintain proper signal strength, the devices should be as close together as reasonably possible. Though some wireless systems claim distance limitations of 50 meters, the real distance limitations have more to do with the transmitting antenna, the receiving antenna, physical obstructions, and the power output of the transmitters on both ends. (Grimes & AVIXA Inc. 2014, 28).

5.5 Ethernet Physical Media Standards

The Physical Layer describes the way in which the network is electrically connected, the topology and the speed of operation. It also specifies the range of Media Types that can be used. Table 6 summarizes the options:

Table 6. Physical Media Standards (Howell 2013, 49)

Physical Layer	Specifications	
100BaseT	Minimal cable spec:	Cat5
	Maximum cable length:	100m
	Preferred cable spec:	Cat5e
	Maximum cable length:	100m
100BaseFX	Multi-mode fiber:	2Km
	Single-mode fiber:	10Km
1000BaseT	Minimal cable spec:	Cat5e
	Maximum cable length:	100m
	Preferred cable spec:	Cat6
	Maximum cable length:	100m
1000BaseLX	Multi-mode fiber:	2Km
LX=Long wavelength laser	Single-mode fiber:	10Km
1000BaseSX	Multi-mode fiber:	550m
LX=Long wavelength laser	Single-mode fiber:	220m
10GBaseT	Minimal cable spec:	Cat6
	Maximum cable length:	55m
	Preferred cable spec:	Cat6a
	Maximum cable length:	100m

Physical Layer Terminology: The first number refers to de data rate (100=100Mbps, 1000=1000Mbps, 10G=10Gbps). The word Base indicates that the electrical transmission method is Baseband. And the last letters, indicate what cable is it:

T=Twisted pair
F=Fiber optic
X=Full Duplex
S=Fiber optic – Short wavelength (850nm)
L=Fiber optic – Long wavelength (1310nm)

Baseband is a method of communication in which the entire bandwidth of the transmission medium is used to transmit a single digital signal. The signal is driven directly onto the transmission medium without modulation of any kind. Baseband uses the entire bandwidth of the carrier, whereas broadband uses only part of the bandwidth. Baseband is simpler, cheaper, and less sophisticated than broadband. (Oliviero & Woodward 2014, 1162.)

6 ENTERTAINMENT CONTROL SYSTEMS. PRACTICAL CASES

The network practical cases are explained by the people that designed the networks, programmed the equipment and operated the shows. The interviews go over the details of the networks and personal comments from perspective of the network designers.

6.1 Video Network for Iskelmä Gaala 2020

Name of the show: Iskelmä Gaala

Date of implementation: 21.2.2020

Place of implementation: Tampere Talo

Type of show: TV Show/Live music

Network designer: Matias Ojanen

> *We had on stage an ABSEN C30 LED back screen, a Hippotizer server rack with a network switch, main and backup servers, one BARCO ImagePro, a control rack with LED screen processors and a power distro for the LED screen* (Figure 16).

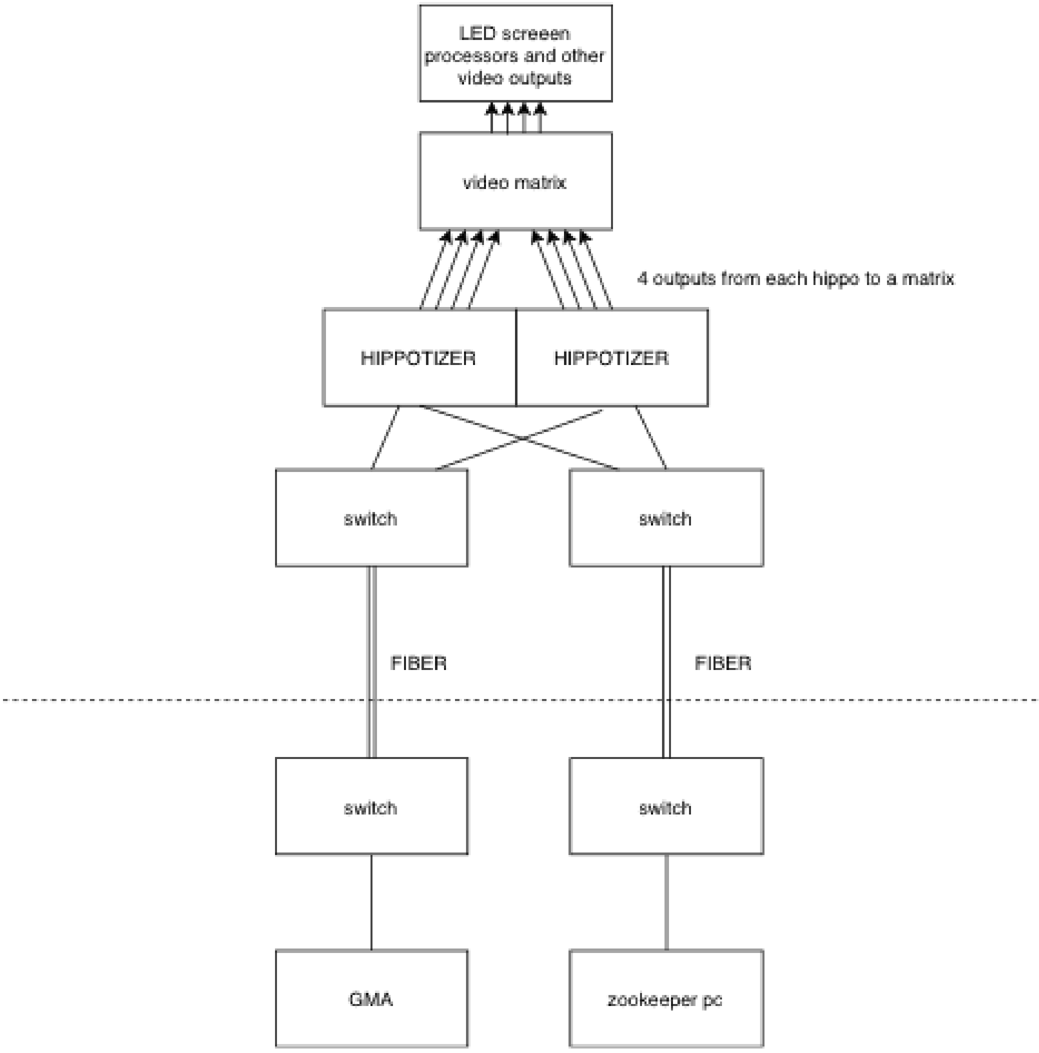


Figure 15. Video Network Diagram for Nenäpäivä (Ojanen 2020)

My first idea was to take a lighting desk to run cues to the Hippotizer servers, but then I realized that the video control room was so small that the GrandMA desk was not going to fit. I could only use two laptops max (Figure 16)*. At first, I was thinking, how can I do a cue list without a lighting desk? I realized that I could send OSC commands from QLab to the Hippotizer servers. So I decided to run the cues with QLab.*

Basically what I did, was to run all the nominee and winner videos, logos, trailers and inserts for the I-Mag (Image Magnification) screens from QLab at front of house because the camera department was also at front of house and they were sending the feed to the I-Mag screens; and the content for the LED screen came from the Hippotizer servers on stage.

Figure 16.Video control room for Iskëlmä Gaala 2020 (Ojanen 2020)

In every gig I like to use some sort of cue list (Figure 17)*, which is already programmed and running smoothly. That is why I really like when a customer brings us a very good running script for the show. It does not matter if it is for a corporate event or theatre.*

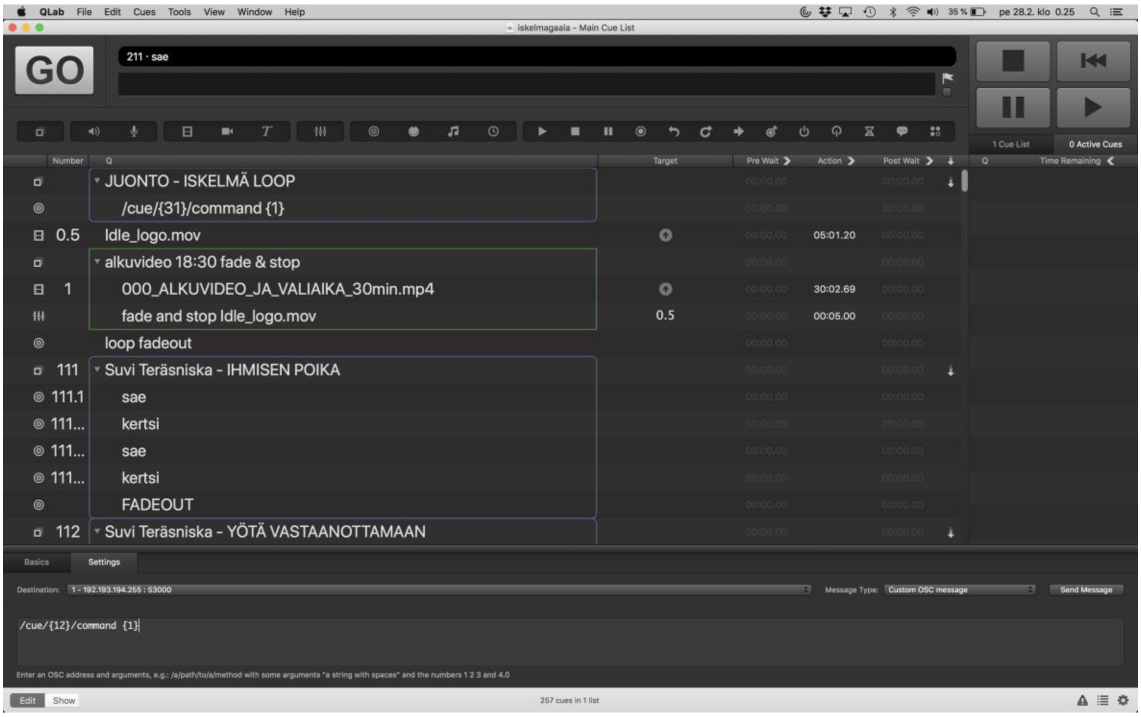


Figure 17. Cue list in QLab (Ojanen 2020)

In QLab I did a cue list with the I-Mag screen videos, but to trigger the LED screen content I was running OSC commands also from QLab to the Hippotizer servers. By sending OSC commands you can control the content and timelines on the media servers. I also had a control laptop with the Zookeeper software to setup, adjust the screens and program the timelines on the media servers using HippoNet (Figure 18).

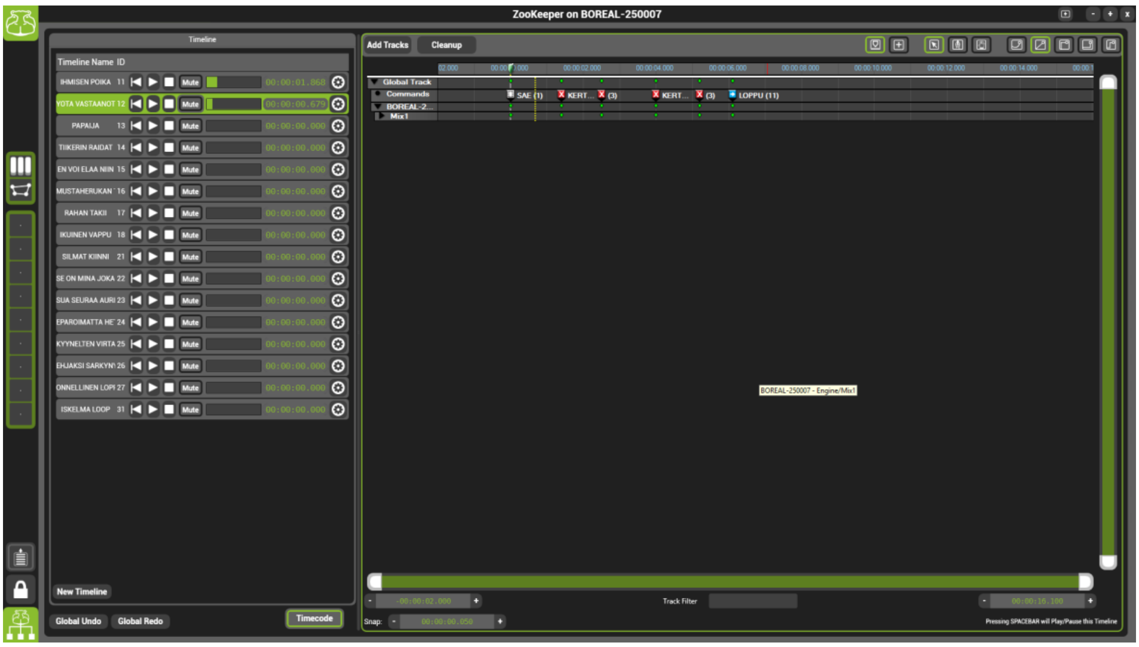


Figure 18. Zookeeper timeline (Ojanen 2020)

For Iskelmä Gaala, the video network was setup like this: At the front of house I had two laptops, one was the QLab Mac and the other one was the control laptop with Zookeeper, both connected to a network switch. On stage, both servers were connected to a network switch, and both network switches (front of house and stage) were connected together with an Ethernet cable. Both media servers and both laptops were in the same network.

The only challenge for me was to send the OSC commands to both media servers (main and backup) without duplicating all the cues in QLab. The solution was to send the OSC commands to the broadcast IP address that ends in 255. So I sent the OSC command to that address and it was broadcasting to all computers in the network, but only those devices that were listening to the OSC were responding to them.

I had the BARCO ImagePro switcher close to the servers so in case the main server crashes, someone on stage could switch it to the backup server.

6.2 Audio Network for Tampereen Työväen Teatteri

Name of the Project: Sound Network Installation

Year of implementation: 2010

Place of implementation: Tampereen Työväen Teatteri – Suuri Näyttämö

Type of shows: Theatre/Musicals

Network designer: Jarkko Tuohimaa & Kalle Nytorp

In the theatre's audio network we have three consoles. One is the main front of house console which is the DiGiCo SD7, the secondary front of house console is a DiGiCo SD10 used only for band mixing during musicals and the third one is a DiGiCo SD9 that is located on the side of the stage used for monitoring the stage and musicians.
We have one SD-Rack at front of house; on stage we have two SD-Racks, one D-Rack and one SD-MiNi Rack. All these are connected together through OPTOCORE, which is unique standard for networking. Is very rarely used but it works perfectly for large installations like this one because it can handle up to 1008 channels at 48kHz in the network. All of the consoles can use any input signal that comes into the network through any rack or through any console. Usually consoles and racks are connected through a LAN but our network is using optic fiber.

We also have UB-MADI sound cards that are used for QLab playback and external sound check recording for virtual sound checks. We mirror the wanted channels and then record what comes into the network to an external computer, so we can play back later when we want to have a sound check with out the band. We can have a 48 multichannel recording.

The Matrix, which is the YAMAHA DME64N, drives the PA system and is also connected to the main console with MADI. All the matrix signals are converted with one RME M-32 DA and one RME ADI-6432 to suit the desired input and output formats. The outputs from the matrix are connected with multicore cables to the DiGiCo racks that are in the OPTOCORE network. This matrix drives everything that goes into and out of the consoles. We decide where it goes and how it is processed. Inside the network everything is OPTOCORE but when we go outside the network then we use MADI or analog audio cables (Figure 19).

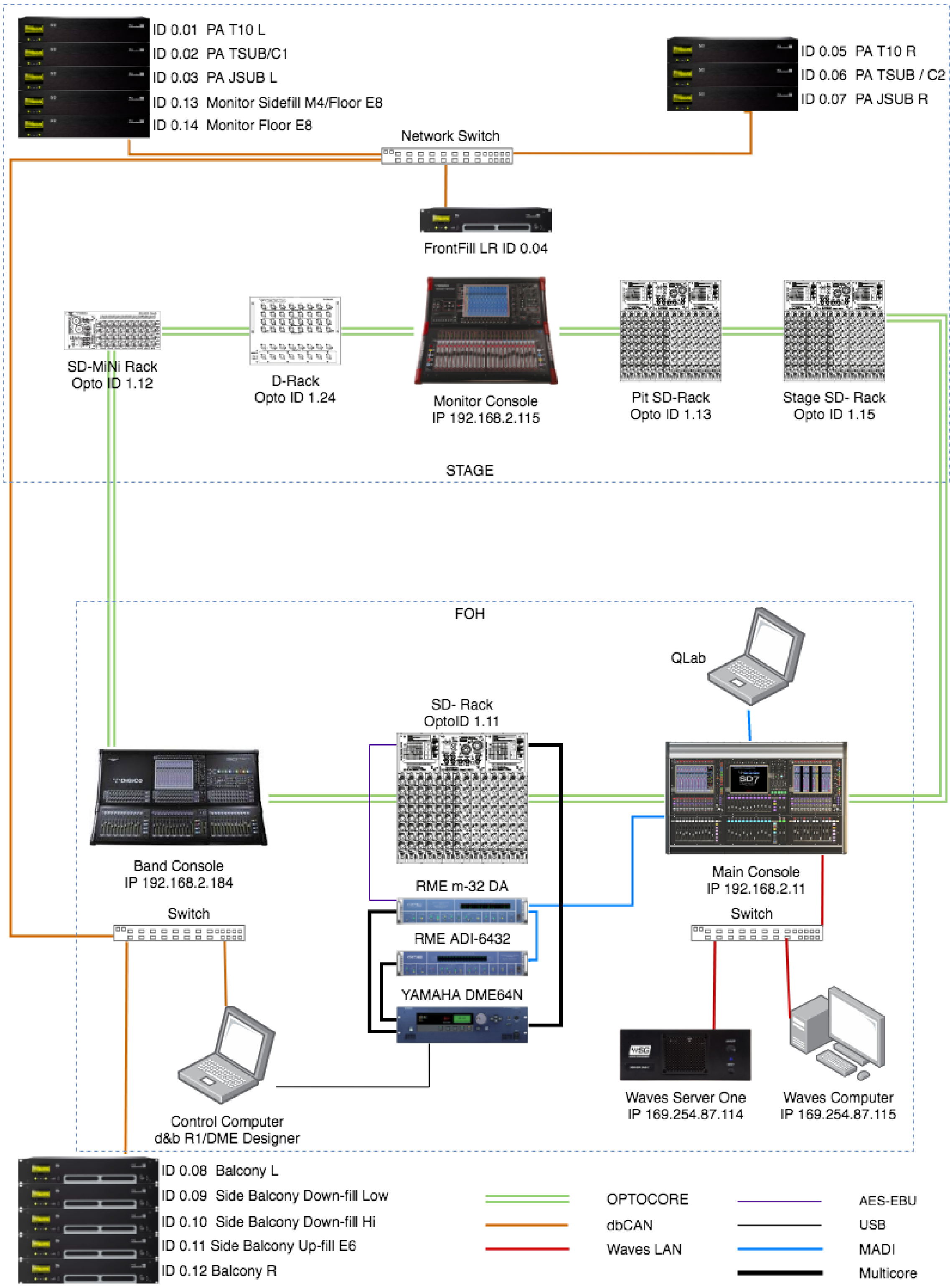


Figure 19. Sound Network Diagram at TTT (Portilla 2020)

In addition to that, we have Waves Effects MultiRack, which is a very recent installation. We have two SoundGrid One servers and a computer using the basic Waves audio plugins. The server and computer are connected with a network switch to the console via

LAN so all the processing happens in the server and not the computer that has the plugins. The second server is a spare.

We also have a computer with d&b audiotechnik R1 remote control software that we use to control all the settings inside the amplifiers. This is connected with an Ethernet cable that runs from the front of house computer to the sides of the stage where the amplifiers are located. This way we can control all the aspects of the amplifiers from front of house with out physically going to the amplifiers.

Appendix 1 provides the interview with Kalle Nytrop. Details about the network and equipment are mentioned here. Considerations on the planning phase as well as difficulties on the implementation are also commented. Possible changes and considerations for improvement are also expressed in the interview.

6.3 Lighting and Video Network for Tampereen Työväen Teatteri

Name of the Project: Lighting and Video Network Installation

Year of implementation: 2010

Place of implementation: Tampereen Työväen Teatteri – Suuri Näyttämö

Type of shows: Theater

Network designer: Sami Rautaneva

There are two main parts in the network, the control booth and the tower near the stage. At the control booth, we have one Full size Hog 4 console and a computer with Hog 4 PC software as a backup, both connected to the front of the house network switch. There is also a possibility that we might connect two consoles to that switch. When we did the play "Mestaritontun seikkailut" in 2015, I was a video designer, and we had two lighting consoles. The lighting designer was doing the lights on the main console and I was programming the video at the same time on the second console. We were working on the same show file but with two consoles.

The front of house network switch is connected to a HIGH END SYSTEMS DP8000 processor via CAT cable. We are not using the DMX outputs from the processor. It's just processing all the Art-Net data and sending it from its network port to a Zyxel GS-2024 switch via ethernet cable. Both the processor and Zyxel GS-2024 switch are at the front of house. Connected to the Zyxel GS-2024 switch at *front of the house, we have an optic fiber cable that goes to the tower.*

At the tower, we have another Zyxel GS-2024 switch connected to the end of the fiber that comes from the front of house, which at the same time is connected via ethernet cable to a patch panel that sends the data to all the outlet ports on stage. So from the patch panel, all the Art-Net is distributed to the stage via ethernet.

Plugged to various ethernet outlet ports on stage we have multiple LUMINEX Luminode 4 and Luminode 2 nodes that convert the Art-Net to DMX that go to the fixtures, dimmers and haze machines (*Figure 20*).

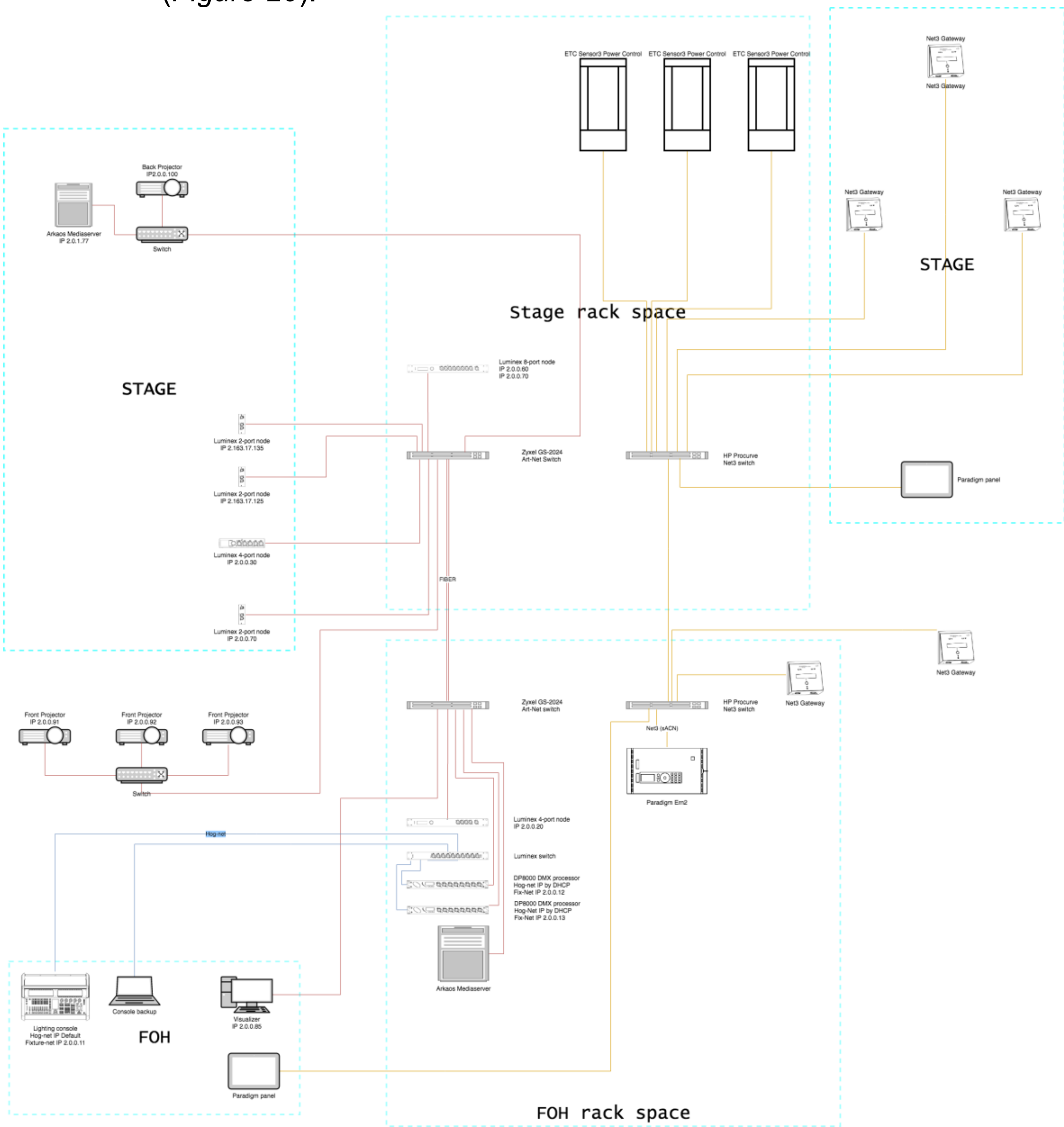


Figure 20. Lighting/Video Network Diagram at TTT (Rautaneva 2020)

We also control projectors with Art-Net. We take the Art-Net signal from the stage patch panel directly to the projectors. It's really easy because you can make your projector profile in the lighting console and from there you control the projector, just like the media server control. Usually, we only control the shutter of the projectors, so it's one DMX channel only. Same with the media server, the Art-Net goes straight to the network port of the media server so it doesn't have to be converted to anything, the media server just reads the Art-Net.

The good thing in this network setup is that the computer we have in the control booth can run the visualizer and we can also configure all the nodes here. I can change any port address of the nodes from the computer.

And of course, we have one more network for control of the house lights and relays. We have the ETC Unison Paradigm system which it has its own separate switches that are distributing sACN and PoE throughout the house to the ETC nodes.

When we are working with LED pixel strips, we program them with ArKaos LED Mapper extension, which uses the Kling-Net protocol. The ArKaos media server can output by itself a total of 256 universes, so you can have a lot of LED pixel strips when you use the media server to control them. And Kling-Net has its own separate protocol. It doesn't have anything to do with Art-Net or sACN or any other protocol. Kling-Net is a protocol that you can run in the same network as your lighting control protocol. We feed to the same Art-Net network so we can get both Art-Net and Kling-Net from all the outlets.

The Appendix 2 presents the interview done with Sami Rautaneva. In the interview Sami explains the importance of networks in video and lighting show control for theatre and the need of permanent revision and updates to the network.

6.4 Lighting Network for an Award Show

Name of the show: Award Ceremony

Year of implementation: 2018

Type of show: Corporate event

Network designer: Esko Ansami

In the award show we had two stages facing opposite directions. There was a script so the timetable didn't overlap between the stages and the audience could keep track of what was going on in both stages. There was also a lounge area on the other side of the venue, which was like a separate area in the hall. We ended up having three front of houses. One for the main stage, another one for the secondary stage and our own lighting front of house for the lounge area.

We were running on GrandMA2 systems. We had two GrandMA2 light consoles in the big front of houses for the main and secondary stage and then we had the grandMA2 onPC setup on the lounge area. We were running all of the desks on one show file, different stations and different users, but all of them with the same show data.

We had four Ethernet switches, one on the main dimmer city. The main dimmer city was the central hub of the network. One network switch on the lounge area and then we had two network switches on the main front of houses, one for each console (*Figure 21*).

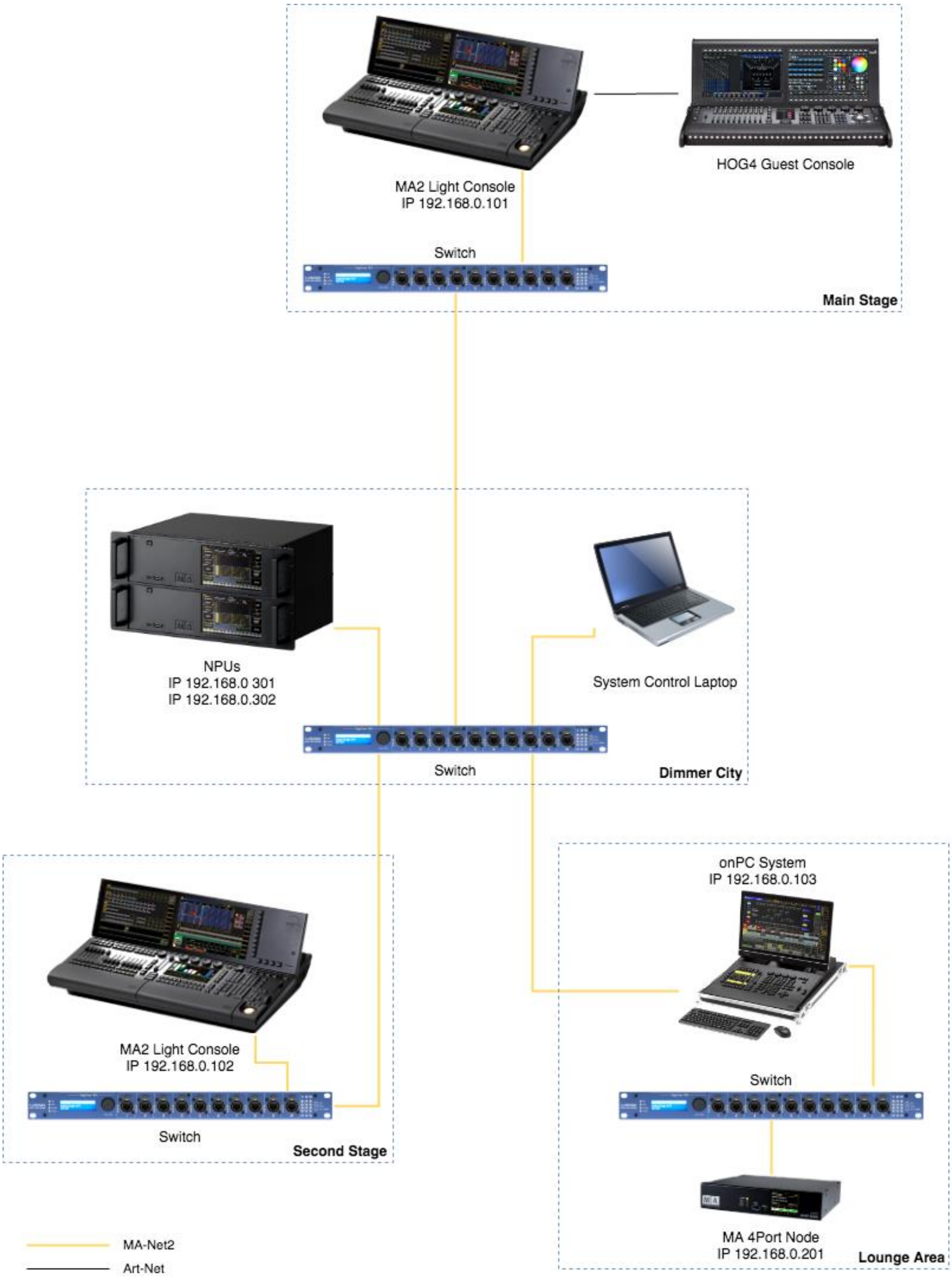


Figure 21. Award Ceremony Lighting Network layout (Portilla 2020)

Our idea was to control each area locally so we could have a front of house for each stage, but also we could go and do the programming for the lounge area near the lounge area, so it was just practical. I was doing all the front of houses because there was no time-

table overlaps, there was only happening something in one stage at a time.

Because of our network, I could go to any station I found practical and do whatever there. I could go to the lounge front of house and program the lights there, but I could also control the front lights of the main stage there. I had as much flexibility as I wanted. When I was walking around the venue I could do the programming on whatever console and store it globally, always on the same cue no matter on what station I was.

It was a very handy way to do it, because usually I've found that in corporate events you want the front of house to be in a good place and very often it doesn't happen like that. When there are a lot of lights around venue, and the venue is be very large, the programming can be very difficult because you can't actually see what you are doing.

We were running MA-Net2 through the consoles and NPUs. Our system engineer had a laptop at main dimmer city from where he had the control of the system. So we could control everything from anywhere, from the dimmer city or from any of the front of houses.

We had multiple VLANs setup on the network but we didn't used any. We only used MA-Net2, and on MA-Net2 we had everything because there were no media servers where you usually use some other network like HippoNet.

The signal was pretty basic. We were running on trunk etherCON cable. We had 2Gb links in each desk, but we would have been fine with 1Gb as well. We didn't use optic fiber because we had multiple front of houses and the distances were less that 75 meters between them.

We also had to take care of merging a guest console. There was a band coming to the event with their own technicians. We had sixteen universes of DMX running all over the place and of course, the lighting engineer of the band only wanted to have control of the main stage, and we also wanted him to have control only of the main stage because on the venue, there were several things you could not touch when the band was playing.

We had MA-Net2 and the engineer had HOG console and the HOG console doesn't have an idea about the MA-Net2. Basically, what I did, was to create an input for MA-Net2, so we were inputting Art-Net from the HOG console to the GrandMA2 console, and then, it was sent from my console as MA-Net2 to the system. In that way we could first convert the signal from Art-Net to MA-Net2 but also filter the signal to what the guest engineer could do, so I only created an input for those universes he needed and we were good to go.

> *It was a pretty solid way to do it. We new about the band and agreed with the guest lighting engineer before hand that we do the Art-Net merging, so we had three universes that we could give him without getting in trouble. The key is that when you do merging, you should give whole universes to the guest engineer.*
>
> *Even though we had three front of houses with three different areas, from the dimmer city perspective we only had one system. We only had one MA-Net2 signal coming in instead of three. By doing his, we could run the cables more freely and handy to do because you have only one data system. It doesn't matter if you have multiple front of houses. From the system perspective, the NPU is sending out the data and that is it.*
>
> *Usually the networks in the lighting world are pretty simple because in most cases there are multiple stations running in an MA-Net2 session and then they are just working with each other on a single show file. Or if Art-Net is used, it is even simpler. On the technical side of the network, I would say that in most cases lighting networking is simpler than in the audio world.*

Appendix 3 refers to the interview done to Esko Ansami regarding the Award Ceremony lighting network setup. On it Esko explains the main reasons of using a network in these kind of events. Esko also emphasizes on the importance of planning, preproduction and verification of the network system before the actual event.

7 CONCLUSIONS

Throughout the years we have seen changes in the technology used on live events. The arrival of the ethernet and its implementation on show control systems allowed the entertainment industry to use the advantage of moving more data through simpler setups.

With more and more usage of digital consoles, moving fixtures, media servers, etc., show control systems require more capacity and speed. Now days we need our data in all areas of our event production.

With networks, there is virtually no limit to the number of devices that can be connected. Extra nodes, switches and more cable will be needed but all the devices will be able to communicate to each other.

One of the main benefits of using networks is its scalability. A network can be as small as two devices connected to each other or as large as a stadium concert. The larger the setup gets, the more complicated it turns and more knowledge about the designing, setting it up and operating the networks is needed.

There is a bright future for networking in the live event industry. Networking has enabled a lot of things for live event technology and with the recent arrival of optic fiber and the development of new standards, we will see a lot coming to the industry in the near future.

But the key factor of having a successful network system is the knowledge of the technicians and engineers that know how it works and most important, make it work. This industry is a never-ending path of learning. As more technologies are developed and implemented, the more we need to know how to use them. The beauty of live events is the amount of work and knowledge that technicians put to events for the enjoyment of the public. And having that final cue running while you start hearing the crowd, it just makes it all worthwhile.

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9 APPENDICES

9.1 Appendix 1. Kalle Nytrop interview

1. What is the main purpose of the audio Network?

Ease of use. The possibility it creates to connect all consoles together. All the consoles can use all the information that it is available in the network. Sending audio signals from the main console to the monitor console with regular XLR cables is a lot of hassle and risk, and there is a lot of installation and work needed. Instead, you can just tap the console's screen and take an input channel and route it, and that is it. It is easy.

2. What systems are connected to the network?

Only audio, but we can also work in interaction with the lighting console via MIDI, but so far that is the only way we are connected to the lighting department. So we can send MIDI to lighting console and lighting console can send MIDI to our audio console

3. What control devices are connected to the network?

Consoles, network switches, computers, audio matrix, audio amplifiers and stage racks. We are currently working on getting WAVETOOL, which is an RF recording software where we can find out things that happen in the RF spectrum. That will be on the network too.

4. What software is needed to trigger cues to run the shows?

QLab will be the software running playback cues, and triggering the cues is a MIDI signal from the audio console to the QLab computer. It's just a MIDI command on a single cue on the console that sends it to the computer that runs the QLab software.

5. What networking standards or protocols are used in the audio network?

Optocore, MIDI and Linear Time Code.

6. How many people have access to make changes or adjustments to the audio network?

During musical rehearsals there are three people maximum. Basically anyone that has access to use the console is instantly on the network. Sound designer, FOH engineer and monitor engineer.

7. Is there a fully dedicated person managing the Network?

No. It's part of everyone's responsibility.

8. What are the important factors to consider when planning an audio network for a theatre?

Ease of use and versatility, because we have a lot of different shows with different settings and configurations. We wanted to click few buttons so the settings are changed for the different plays that are going to be running. We also want to have as much control as possible in every aspect of the audio system.

9. What physical layers were chosen for the Network?

It is the OPTOCORE standard, 2 Gbit with optic fiber.

10. How many network switches are used in the network?

Just one. It is used to connect the Waves effect server, waves computer and the console.

11. What were the safety/backup considerations for the Network design?

Very little. We only have one spare engine for the main console. Nothing else is backed up. We will back up QLab and waves servers later this month

12. How is the bandwidth of the Network estimated/measured?

There is a way to check it from the console but we don't really do that. We don't have any problems. It's just in case we have a problem, then we start investigating what happened.

13. Were there any difficulties or limitations encountered during the designing phase of the Network?

Yes. Well, this is a large installation, even worldwide. It's not something that happens everyday, even from the manufacturers of these consoles. So when we starting setting up this network a decade ago, we didn't have much help from the distributors because it was not easy to build this network. We had an idea of how it was done, but when we asked, they didn't know. I mean, they knew everything about the consoles, but when you start adding console after console and rack after rack, they also started scratching their heads. So the difficulty came, as the work got more specialized. It's not something that anyone, even in the larger fields of this industry often came across with. So when we asked the question, it's was probably a question that nobody knew the answer to, or there was *no definite answer, and you have to wait for someone to figure it out and then continue with the work, so it was challenging.*

14. What type of control is implemented in the shows?

It is a linear control. The shows run in the same order every time. It is always executed as rehearsed.

15. What cueing methods are used for the shows?

Event cues and time based cues. Sometimes, there is a group of sixteen cues that happened with one trigger.

16. Is there any network monitoring tools used to oversee the performance of the Network?

Through the DiGiCo console we can monitor the network. It tells us the resources that have been used and what are the free resources. It doesn't go into detail. It kind of "sniffs" if there is a problem or overuse somewhere, or if the network is reaching its capacity. But so far, we've had zero problems with it, so that is why we haven't had the needed to use it.

17. Did you encounter any difficulties or last minute changes during the Network setup?

Yes. We had some problems with the console engines. For this network to work, the biggest challenge seemed to be the redundancy of two engines in one console.
For the network to understand that the redundant engine is not active, but it will be at some point, it really created a lot of problems. It took a lot of time and a lot of maintenance to get it to work.
At this moment the redundant engine is not working because the new update that we had to install made it very dangerous to use as we had it setup.

18. Did the Network meet the requirements for the Theatre?

Yes, the network itself works.

20. Are there any changes that could improve the performance of the Network?

Stability, stability, stability. That is all. I mean, I'm fine with less parameters and less controls and less things that I can do, because I'm well aware that things can sound spectacular without half of the parameters that I have here, but what I can not take is instability. That is something that is unacceptable. In a live performance you have to be able to trust the network and everything around you *completely. And if you can't, everything suffers. Even if nothing brakes, the work suffers. It's not nice and because this is something that you can not just do technically with out thinking, you have to have your heart in it, you have to be interested in what happens and if you are fearing that something might brake your work is not good, it's never going to be. So that is the main thing. To have it completely stable is the main goal for me. If I could just have one ting, that would be it.*

21. What other considerations can be taken into account in the future to redesign the audio network in the Theatre?

DANTE. It just simplifies everything. It just collects everything into one group. We now have one unity and then we have to have an extension to that, and an extension to that, and an extension to that, and then everything is brought into this circle, but with DANTE in a way, everything is inside the circle already. Now we have multiple circles that are connected into one network.

9.2 Appendix 2. Sami Rautaneva interview

1. Why did TTT require a video and lighting network?

A network is a core thing nowadays in theatre because you can distribute anything through a network. Anything can be converted to go into a network. So it's efficient and kind of cheap, and a good way to layout enough ethernet cable and fiber throughout the infrastructure of the theatre and then you just need switches and converters and a good guy to set up the network so it will work. You can run anything through an ethernet cable or fiber nowadays, so why would you use anything else?

2. What was the main purpose of the Network?

In the past, they had only two DMX cables coming from the front of house to the tower. At that time I saw there was going to be a lot more moving lights, media servers, video extenders. So it was an immediate thing to upgrade to a network system. There is no case in running ten DMX cables. And of course, if you think of theatre, there are also things like fire protection. You can't drill a big amount of holes in the theatre building. It's much easier to take a single fiber cable to the tower than ten or sixteen DMX cables made of copper. It's easier to install. And also the good thing about networking, everything can be set up via a software. You don't have to hard-patch things with the DMX cables. You can change the port outputs just by using your computer and you can have a quite clear *picture of what those ports are outputting if you look at the control program for the nodes. They are very easy to set up nowadays.*

3. What systems needed a connection to the network?

Lighting and video.

4. What control devices had to be connected to the network?

Consoles, switches, computers, processors, nodes, media servers and projectors. But for this spring we are upgrading the dimmers, which will be taking sACN straight so we don't need to send DMX anymore to them. We will also have a monitoring and controlling software for the dimmers in that network because those dimmers are going to have a relay, so it can be switched between a dimming line or straight power output.

5. What softwares trigger the cues to run the shows?

We basically trigger the lighting cues from the lighting console, but from the audio department, we also receive MIDI cues from QLab and Linear Time Code.

6. What networking standards or protocols are used for the shows?

Art-Net, sACN, MIDI, Linear Time Code, Kling-Net and NDI.

7. How many people have access to make changes or adjustments to the Network?

Three people. The lighting designers.

8. Is there a fully dedicated person managing the network?

Not at the moment. But hopefully, in the near future, we can have someone.

9. What were the main elements considered to start designing the network?

We just needed to have enough bandwidth and enough ways to distribute the signal. That was the core idea of the network design. You just need to know what you will be running through the network and from where to where of course.

10. What physical layers were chosen for the Network?

Optic fiber and twisted pair cables. Both at 1Gbit/s. We chose optic fiber because it's the easiest way to have enough bandwidth for the future. And it's not that expensive for a permanent installation.

11. Was it necessary to configure different VLANs in the network?

We used to have VLANs when we were using the Hippotizer Media Server. But now we have a dedicated network for Art-Net and a dedicated network for the Hog-Net.

12. What kind of Dynamic Host Configuration Protocol (DHCP) was needed in the Network?

The processors get their IP addresses from the console with DHCP, but all the nodes have fixed IP addresses because is easier to control and set them up when you know the IP addresses. I have the addresses as a bookmark on the computer web browser.

13. How many network nodes were used in the network?

Two network switches, two optic fiber Gigabit switches, various LumiNodes and one access point.

14. What were the safety/backup considerations for the Network design?

We have a computer with the Hog 4 PC software running all the time as a backup for the lighting console connected to the main processor too. Each processor can distribute sixteen universes. So if we count the processor at the front of house, the one on the tower and the spare one, we can have up to forty-eight universes, but we are using only six-teen. If we would use the whole capability of the media server, it would eat a lot of uni-verses, so we are thinking of using the spare processor only for running the media server. The media server could easily take five or six universes if you have thirty layers on it.

15. Were there any difficulties or limitations encountered during the designing phase of the Network?

Yes. The price of the equipment. I think the only restriction was money. I mean, our dream would be to have more nodes and more places where you can get the DMX out. But the only thing that it's limiting us now is the money.

16. What type of control is implemented in the shows?

Linear. The cues are run in the same order every time. It is always executed as rehearsed.

17. What cueing methods are used in the shows?

Event-based and time-based.

18. Are there any network monitoring tools used to oversee the performance of the Network?

We run a program called ArtNetominator. It's a good program for the Art-Net monitor-ing. You can see what universes are used in the network and what is outputting. This is a free program to see what is going on in your network and it is good for troubleshoot-ing. You can see if you have something wrong with your setup. If the Art-Net would be going into the wrong universe, you could instantly see what should be the right universe. We are running the Art-Netominator with the PC that is running the lighting visualizer.

19. Did the Network meet the requirements for the SHOW?

No. We still don't have a good network to distribute the video signal with. That is our bottleneck right now. And there are not enough ethernet outlets on stage. We should have at least twice as much as we have right now. We also need ethernet outlets in the pit under the stage. There is no way to distribute DMX signal using Ethernet cable there at the moment.

9.3 Appendix 3. Esko Ansami Interview

1. What was the main purpose of using a lighting network for this event?

There are a few main reasons. The main reason in most cases is that it makes it easier to build different kinds of setups. You can run huge amount of data only in one cable, so you can get many universes of data in one cable, and usually is better to have more universes than a less universes. For example, we had sixteen universes but I don't think we had fixtures worth of sixteen universes. So all universes absolutely were not full.

The second reason is the concept of having backups and users. Now days there are many occasions when the sessions are so big, that you need to have multiple programmers working, so it helps to have a network so everyone can work on the same show file at the same time. The backup is also important because the consoles are computers, and computers get broken. We are on the rental business, so our gear is always loaded on and off from trucks. They live a hard life and they get broken occasionally. So it's very useful to have backup solutions on site.

The third reason I would say is, if needed, you can do all kinds of cool tricks with network, it's not on a day-to-day basis, but we can merge Art-Net inputs or monitor the output of the guest consoles.

And when it comes to this, network nodes play major role when doing this stuff. For example Luminex-nodes, which are used in Finland a lot, are capable of doing per-channel merging, re-routing etc.

2. What are the key elements you need to start planning the network?

   In this case, I suppose it was planned when the floor plan for the event was made. It had to be like that, because there was no other place in the venue where one front of house would have done the same as the three front of houses did. It was pretty obvious from the start that it would be the way to go.

3. What systems needed to be connected to the network?

   It was just the lighting system on the network.

4. What control devices had to be connected to the network?

   Consoles, computers, network switches, NPUs and MA 4Port Nodes

5. What device triggered the cues to run the event?

   Only the consoles and the onPC computer triggered the cues during the event.

6. What networking standards or protocols were used during the event?

   We used MA-Net2 to control everything and Art-Net for the guest console.

7. How many people had access to make changes or adjustments to the Network?

   Two. The system engineer and myself.

8. What are the main elements you considered to start designing the network?

   Usually the first thing to consider is whether to go with Ma-Net2 or Art-Net. In this case we had a choice to go with MA-Net2 so we were instantly thinking in doing it that way. And then we were testing the parameter count, checking how many channels we would need and then making sure to have some headroom, so in the case that something would break we could still get the control of everything.

9. What physical layers were chosen for the Network?

    1Gb Ethernet cables in trunk.

10. What factors where considered to determine the physical layer of the Network?

    The switches we had are 2Gbit. The link aggregation is built in and is used in that way weather we need it or not. MA-Net2 network runs on a 1Gbit network, it doesn't require more. But we usually build it to be 2Gbit because if you are using VLANs or something else, you might need the headroom of 2Gbit.

11. What was the IP addressing scheme used in the Network?

    We had the consoles being one after each other starting at 192.168.0.101. Then we had the nodes one after the other starting at 192.168.0.201. And processors from 192.168.0.301

12. What kind of Dynamic Host Configuration Protocol (DHCP) was needed in the Network?

    We used static IP addresses

13. Why?

    We didn't have any DHCP server

14. How many network nodes were used in the network?

    Four network switches, two MA NPUs and one MA 4Port Node.

15. What were the safety/backup considerations for the Network design?

    This type of setup is very good for backup. If something happens to brake or if one station dies, it doesn't matter because the other consoles have the same data and the output will remain the same. All the consoles were a backup in a way.

16. Were there any difficulties or limitations encountered during the designing phase of the Network?

    No. I believe that we were fortunate enough that the configuration we ended up having, was the actual the one we were hoping for.

17. What type of control was implemented in the show?

    Everything was cued. We had some basic looks for the entire venue and then we had some expanding control to it. The stages could be operated separated from each other but also as one. We had the chance to run effects on both stages if we wanted to. The load in to the venue was three days before the show and we had one day of training, so on that day I basically programmed everything.

18. Were there any network monitoring tools used to oversee the performance of the network?

    Command-line interface was used from the dimmer city to monitor the MA-Net2 network and with the main console I was monitoring the incoming signal from the guest console.

19. Did you encounter any difficulties or last minute changes during the Network setup?

    Not really. We actually built the whole system at the warehouse two days before going to the venue. The dimmer guy built everything on the Nivtek decks so we had the switches in place and then we tested everything, checked the software versions, make sure everything was running and then we even had the Ethernet cable reels ready on the same system. So we had literally everything in the same way we had on the venue. It's a very useful way to prep the equipment because something you really don't want to have during the load in, is to have problems with the DMX signal. It's the most useless thing to have because you can test it before hand and then when the load in starts there are better things to do other than setting any IP addresses. It is better to have the network like pug and play at the venue.

20. Did the Network meet the requirements for the show?

    Yes. We had zero problems with it.

21. Was the Network beneficial to other technical elements of the SHOW that were not considered at the beginning of the planning process?

    Yes. The possibility of having multiple front of houses was even more useful than what we thought. Everything related to programming was like super quick like that. For example, when the guest lighting engineer started his programming, I could be at the second front of house doing any other programming I wanted to. So it turned out even more useful than what we thought.

22. What other considerations can be taken into account in designing a Network for a future event like this?

It relates to the guest Art-Net signal. We could have run from the main front of house a separate Ethernet cable to the dimmer city and plugged the Art-Net cable on a different VLAN and then send it to all the consoles. In that way we could have continued with the Art-Net merging even though the master console would have died. We could have bypassed that problem in that way.