Ethernet/TTEthernet

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***Abstract*—This paper is divided into two sections, one dealing with Ethernet in general - on topics like its technicalities, relevancy and usage - and another that delves into TTEthernet, as a direct continuation of the former topic.**

I. Introduction

Although Ethernet is one of the oldest forms of technology used for networking in the market today, it is also one of the most used through and through. Due to its reliability, speed, upgradability and relative inexpensiveness, Ethernet has cemented itself as the most popular networking technology for LAN connectivity. But its specific place and relevancy in the networking world, as well as its inner-workings must be understood first, if we are to make sense of its massive popularity and usage worldwide. Time-Triggered Ethernet adds synchronization capabilities to standard Ethernet devices, used primarily in safety-related and safety-critical systems.

II. OSI 7 Layer Model

Open Systems Interconnection model (OSI model/7 layer model) is a conceptual model, which came about in the late 1970s as a result of the diverse computer networking methods that were competing for application in the large national networking efforts in France, the United Kingdom, and the United States. It is necessary to pinpoint Ethernet's place in this model before the topic of Ethernet is discussed further. The 7 layer model characterizes and standardizes the communication functions of a telecommunication or computing system, regardless of what underlying technologies might be used in the systems it describes. It is the most widely used model in networking and it sets a standard for most networking devices today, although it falls short with more complex and abstract systems. The model is divided into, naturally, 7 abstract layers, namely:

1) The Physical Layer
2) The Data Link Layer
3) The Network Layer
4) The Transport Layer
5) The Session Layer
6) The Presentation Layer
7) The Application Layer

As is the nature of Ethernet, this paper will mostly be concerned with the physical layer. As the name suggests, the physical layer deals with the actual physical connections between devices for the purposes of transmitting raw data in the form of electrical, radio, or optical signals. And although Ethernet is heavily dependent on wiring and optical data transmission through that wiring, the paper might touch on some topics that belong in within the Data Link layer mentioned above, especially on the topic of TTEthernet. And even though the standard OSI model could delineate Ethernet as an object within the Physical layer, it would be more useful to conceptualize it within the bounds of the TCP/IP model, for the reason mentioned above. The TCP/IP model is composed of four layers:

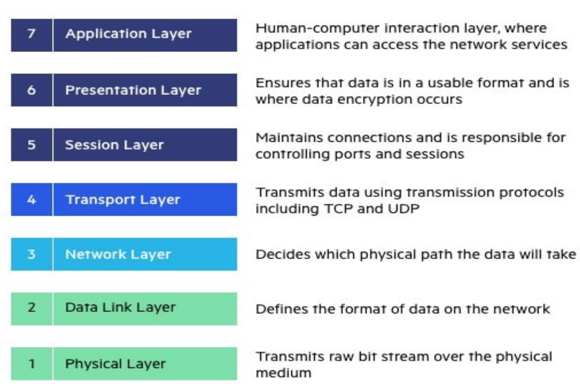

Fig. 1. OSI Model

A. Network Layer

The Network layer combines the Data Link layer and Physical layer, including the twisted pair cable, the Physical layer device (PHY), and the Ethernet Media Access Controller (MAC).

B. Internet Layer

The Internet layer consists primarily of a software implementation. The IP header is evaluated or generated by software.

C. Transport Layer

The Transport layer defines what should be done with the data. This layer is based on the following two popular protocols: UDP is a very simple protocol and is perfect for streaming sequences (e.g., audio or video). TCP is a highly reliable host-to-host protocol for a controlled connection. TCP is appropriate for applications that require guaranteed delivery.

D. Application Layer

The Application layer includes all available software implementations (e.g., FTP, HTTP, SMTP, DNS, ...) that make up the lower layers. These applications can work only in combination with the API of TCP or UDP, which form the software implementation of the Transport layer.

III. Basic Overview

Ethernet essentially works by chain reactions. One device generates and sends a signal, such as a UDP or a TCP signal, which passes through cables, and then through a connector, then to cables again and finally to their designated receiving device. Ethernet uses an algorithm based on random delay times to determine the proper waiting period between retransmission. Traditionally, the protocol used for broadcasting, listening and detecting collisions as CSMA/CD (Carrier sense multiple access/collision detection), but that was later rendered impractical and outdated for many devices. In the case of a collision, all transmitters would practically fail, meaning that the sender would have to retransmit the same message again, hindering performance as a result and requiring more resources, which would prove especially detrimental for smaller devices. However, some newer forms of Ethernet have been developed that use full duplex Ethernet protocols. This protocol supports point-to-point simultaneous transmission, sends and receives signals without any listening required during the entire process.

A. Half Duplex

Half duplex is a mode of operation with CSMA/CD support of a local area network (LAN) in which Data Terminal Equipment (DTEs) contend for access to a shared medium. Multiple, simultaneous transmissions in a half duplex mode CSMA/CD LAN result in interference, which requires resolution by the CSMA/CD access control protocol.

B. Full Duplex

Full duplex is a mode of operation of a network or Physical Medium Attachment (PMA) that supports duplex transmission as defined in IEEE 100. Within the scope of this standard, this mode of operation allows for simultaneous communication between a pair of stations, provided that the Physical Layer is capable of supporting simultaneous transmission and reception without interference (without CSMA/CD). The different modes are described in these IEEE specifications: Half Duplex: 10 MBit/s (IEEE 802.3) Full Duplex: 100 MBit/s (IEEE 802.3u) Full Duplex: Gigabit-Ethernet (IEEE 802.3ab) is Full-Duplex transfer with all four pairs

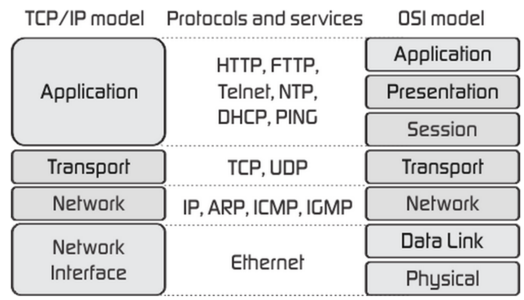

Fig. 2. TCP/IP vs OSI Model

IV. Technicalities

Ethernet stations communicate by sending each other packets, a formatted unit of data. Data packets are composed of a header and a payload. Headers typically transmit information similar to a file's metadata, which enables the device to interpret the data correctly. The payload would simply be the data being sent from the sending device, for example: UDP or TCP messages. As with other IEEE 802 LANs, adapters have their own globally unique 48-bit MAC address, which must differ from each other. The MAC addresses are used to specify both the destination and the source of each data packet. Ethernet establishes link-level connections, which can be defined using both the destination and source addresses. On reception of a transmission, the receiver uses the destination address to determine whether the transmission is relevant to the station or should be ignored, not least due to the type of transmission being receipted. A network interface normally does not accept packets addressed to other Ethernet stations. Ethernet connections are, outwardly, physically limited in the number of senders/receivers in parallel to the number of actual devices being used, but there is an effective workaround. An EtherType field in each frame is used by the operating system on the receiving station to select the appropriate protocol module (e.g., an Internet Protocol version such as IPv4 or IPv6). Ethernet frames are said to be self-identifying, because of the EtherType field. Self-identifying frames make it possible to intermix multiple protocols on the same physical network and allow a single computer to use multiple protocols together. Despite the evolution of Ethernet technology, all generations of Ethernet (excluding early experimental versions) use the same frame formats. Mixed-speed networks can be built using Ethernet switches and repeaters supporting the desired Ethernet variants.

A. Virtual MAC Addresses

In order to go past the obstacle of the limited number of physically available devices at hand, virtual mac addresses

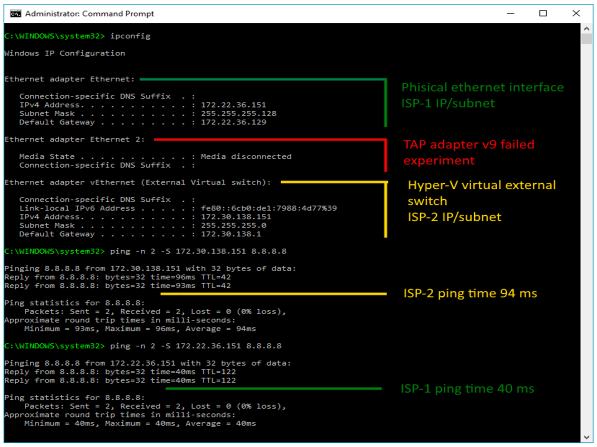

Fig. 3. An Example of a Virtual Instance

could be attributed to programmed virtual adapters to essentially increase the number of possible senders and receivers, with unique attributes if necessary, but at the cost of the hardware's resources availability. In parallel, it is naturally possible to establish virtual LAN networks on top of the virtual adapters.

B. A Point on the Unique Practicality of Ethernet

This sheds significant light on the significant practicality of Ethernet over, say, Wireless Networking. The stability, speed and the adaptability of being able to switch between different devices without sacrificing compatibility all give Ethernet a justification of its long historical usage throughout the past few decades. The stability of Ethernet is more or less self-explanatory, especially compared to that of Wi-Fi, but it would be negligent to gloss over its major advantage in the field of cyber-security. The raw data sent is limited to the confines of the cables/wires themselves, forcing anybody acting in bad faith to require some form of physical access to the devices used. In the context of its speed, the use of light as the primary point of data transfer allows the devices to be fed packets at enormous sizes at great speed.

	WiFi	Ethernet
Speed	Slow data transfer speed	Faster data transfer speed
Reliability	Suffers from signal interference due to many environmental factors	Delivers a consistent speed
Security	Data flow needs to be encrypted	Data doesn't require to be encrypted
Latency	Higher	Lower
Deployment	Easy to install and deploy	Cable installation infrastructure is required

Fig. 4. Ethernet vs Wi-Fi

V. Communication Methods

Due to the nature of the wired set-up, any and all raw data sent through Ethernet will be received by every device connected to the same wire. That means that if only one cable is used, per se, the data bandwidth will be shared, such that, for example, available data bandwidth to each device is halved when two stations are simultaneously active, similar to the limitations that virtual adapters impose. Although the receiving devices get hold of every single bit of data sent through its respective Ethernet cable, the header frames help the device differentiate between useful and ignorable data. The raw data itself is not capable of interrupting a devices CPU without its header frames being checked and approved first. A collision happens when two stations attempt to transmit at the same time. They corrupt transmitted data and require stations to re-transmit. The lost data and re-transmission reduces throughput. In the worst case, where multiple active hosts connected with maximum allowed cable length attempt to transmit many short frames, excessive collisions can reduce throughput dramatically. Not all stations share one channel through a shared cable or a simple repeater hub; instead, each station usually communicates with a switch, which in turn forwards that traffic to the destination station. This reduces the load on a device's CPU, having the frames filtered before they reach their destination. In this topology, collisions would only be possible if stations and switches attempted to communicate with each other at the same time, and collisions are limited to this link particularly.

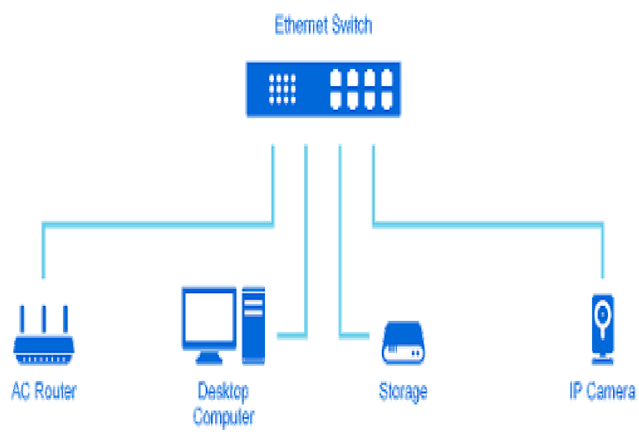

Fig. 5. Ethernet Switches Example

VI. Frame Structure

In IEEE 802.3, a datagram is called a packet or frame. Packet is used to describe the overall transmission unit and includes the preamble, start frame delimiter (SFD) and carrier extension (if present). The crucial difference between frame and packet is that frame is the serial collection of bits, and it encapsulates packets whereas packets are the fragmented form of data and it encapsulates segment. The frame begins after the start frame delimiter with a frame header featuring source and destination MAC addresses and the EtherType field giving either the protocol type for the payload protocol or the length of the payload. The middle section of the frame consists of payload data including any headers for other protocols (for example, Internet Protocol) carried in the frame. In this instance, an ARP request (Address Resolution Protocol), or alternative methods if necessary, could also determine and then appropriately filter for VLAN (Virtual Local Area Network) configured frames. The frame ends with a 32-bit cyclic redundancy check, which is used to detect corruption of data in transit. Notably, Ethernet packets have no time-to-live field, leading to possible problems in the presence of a switching loop.

VII. Time-Triggered Ethernet

The European Space Agency gives a perfect delineation of TTEthernet: "TTEthernet (defined by SAE AS6802) is a scalable, open real-time Ethernet platform used for safety-related applications primarily in transportation industries and industrial automation. It is compatible with IEEE 802.3 Ethernet and integrates transparently with Ethernet network components. This technology offers deterministic real-time scheduled communication and conventional asynchronous traffic in parallel on the same Ethernet network. There are two types of devices: switches and end systems.

TTEthernet's foreseen main utilization is for safety-critical fail-operational applications and launchers, meaning that the system remains fully functional even if a failure occurs (supporting a single or double-fault hypothesis)."

Modern Ethernet systems run into compatibility issues when it comes to combining them with older versions of Ethernet networks, devices and services. The scalability of these systems is limited and the network solution is tailored for a specific application area. The use of Real-Time and Safe Ethernet systems, outside typically engine and plant construction, is no option. The industry is striving to reduce the number of networks and to cut costs on effort and resources. And a possible realistic alternative is TTEthernet, which aims to combine the proven determinism, fault-tolerance and real-time properties of time-triggered technologies with the flexibility and dynamics of Ethernet.

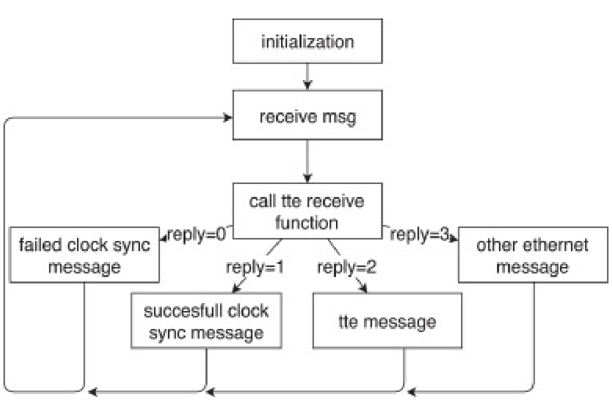

Fig. 6. TTEthernet Outline

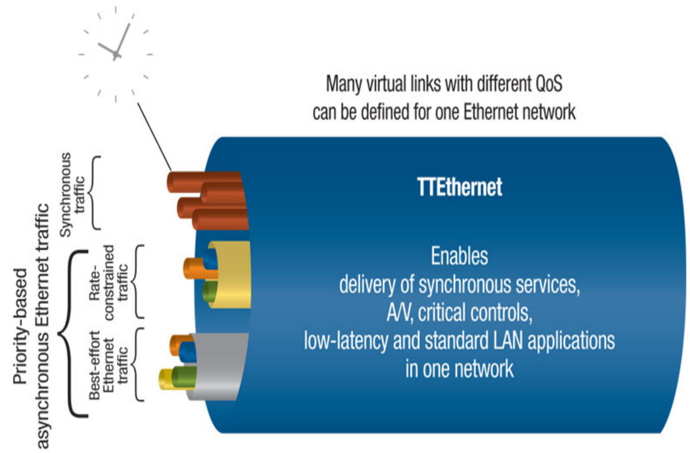

Fig. 7. TTEthernet Model

VIII. The Purpose Behind TTEthernet

Conventional PCs, web and office devices, multimedia systems, real-time systems and safety-critical systems typically use the same standardized network models. A single network that is completely compatible with the IEEE Ethernet 802.3 standards is suited for data transmission among different applications with various requirements and this exact characteristic could thus be used in an attempt to bring about a more universal solution to, for example, safety-critical applications in airplanes, ranging from the entertainment programs utilized in the airplane, to board supply, digital navigation and guidance systems, and so forth. This airplane example can be used to detail some critical areas that must accordingly be made fail-safe or fail-operational. Fault tolerance mechanisms avoid the fault propagation in the system and prevent potential failures from creating risks. TTEthernet's scalability essentially would allow existing Ethernet systems to transmit real-time data in such safety-critical areas. Existing applications do not need to be altered when the network is extended, in terms of its functionality. Time-critical messages always take precedence over less important messages. This, however, does not affect conventional applications, thus compatibility is of no great concern. The temporal behavior of the time-critical messages is predictable (deterministic) and can be accordingly characterized (depending on the required quality). System are made to remains fully functional even in the instance of any form of failure (supporting a single or double fault hypothesis). These fail-safe and fail-operational features extend to nodes, switches, or a network branch, which is one of the particularities that differentiates it from other proposed solutions of a similar type. This paper will delineate some properties and examples of TTEthernet in an attempt to showcase its wide-ranging usability as a potential practical approach to working with the above mentioned issues.

IX. TTEthernet Properties

TTEthernet has characteristics that enable time-triggered communication over the trivial Ethernet model. These time-triggered services establish and maintain a global time, which is realized by close synchronization of local clocks of the devices. These global time forms provide useful information about the basis for system properties such as temporal partitioning, a precise diagnosis, efficient resource utilization, and, notably, composability (composability is a system design principle describing the inter-relationships of components).

A. Temporal Partitioning

The global time can be used as a powerful isolation mechanism when devices become faulty; The global time essentially operates as a "temporal firewall", as a simple way to describe it. The way it is structured, in cases of failures, faulty applications are blocked from gaining untimely access to the network. Depending on the location of the failure, either the communication controller itself or the switch will block faulty transmission attempts, the latter introducing a bit more flexibility. Failures of the switch can potentially be masked by powerful end-to-end arguments such as CRCs or by high-integrity designs.

B. Resource Utilization

The global time contributes to efficient resource utilization in several ways. Time-triggered communication allows minimizing the memory buffers in network devices as the time-triggered communication schedules are free of conflicts. Hence, switches do not have to be prepared for bursts of messages that have to be delivered over the same physical link, distressing the load on the bandwidth. A minimal time-triggered switch design could even use multiplex media access logic. An alternative way of effective resource utilization would be to use buffer memory in the nodes, which usually are minimized. as the sensor values are acquired according to the global time, the moment before the message is sent to the receiver. Finally, a third way of effective resource utilization is power management in which energy can be seen, and saved, analogous to memory.

C. Precise Diagnosis

A global time stamping service simplifies the process of reconstructing the chains of distributed events. The synchronous capturing of sensor values allows snapshots to be built of the state of the overall systems, which is an infinitely advantageous characteristic, as compared to the classical Ethernet method, in which alternative methods would have to be employed in order to achieve the same goal.

D. Composability

: The global time is not limited to the specification of devices in the value domain, but also extends its capabilities in the temporal domain. This means that actively during the design process of the devices, the access pattern to the communication network can be defined in parallel. Upon integration of the individual devices, it is guaranteed that prior services are stable and that the individual devices operate as a coordinated whole.

X. Examples of TTEthernet in Practice

TTEthernet is a transparent synchronization protocol, i.e., it is able to co-exist together with other traffic, potentially legacy traffic, on the same physical communication network. Due to its fault tolerance capabilities, a multitude of devices can be configured to generate synchronization messages. The devices generating the synchronization messages may be distributed with a high number of intermediate devices between each other. TTEthernet defines basic building blocks that allow the transparent integration of the time-triggered services on top of message-based communication infrastructures such as standard Ethernet. For this, TTEthernet defines a novel application of the transparent clock mechanism that enables the concept of the permanence point in time, which allows re-establishing the send order of messages in a receiver.

A. Transparent Clock Mechanism

: All devices in the distributed computer network that impose a dynamic delay on the transmission, reception, or relay of a synchronization message, add this dynamic delay into a dedicated field in the synchronization messages used for the synchronization protocol.

B. Permanence Point in Time

: The application of transparent clock mechanisms allow for a precise re-establishment of the temporal order of synchronization messages. In the very first step, the worst case delay is calculated off-line. In the second step, each synchronization message is delayed for "worst case delay minus dynamic delay" upon reception of the synchronization message, where the dynamic delay is the delay added to the synchronization message, as the synchronization message flows through the communication channel. At this specific point, the reception point in time is called the permanence point in time. For fault-tolerant algorithms in general, and fault-tolerant synchronization algorithms in particular, the message send order is of highest importance. The re-establishment of the send order of synchronization messages is required for any fault-masking synchronization protocol that ensures synchronization of local clocks in a distributed computer network.

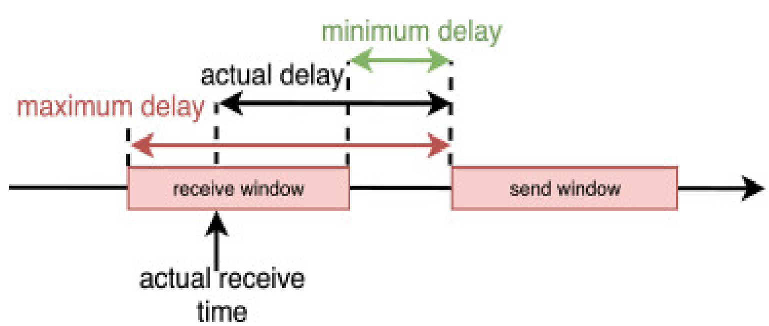

Fig. 8. TTEthernet Showcase

XI. Final Remarks

TTEthernet's rather simple nature in actuality provides for some substantial significant potential improvements in many areas where traditional Ethernet connections do not suffice. TTEthernet is most likely to be used progressively more in the networking market, as its use becomes increasingly requested, although it is yet unclear whether it will stand the test of time and eventually become the standard model for the issues of its nature.

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