Survey on the LAN MCS Gap Analysis (LMGA)

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***Abstract*—This survey paper can fill a literature gap in LAN/Ethernet modulation and coding scheme. During the past several decades, even though there were many technical papers on MCS technologies in the IEEE 802.3 Ethernet standard development process, those papers are only technical discussions for specific technical proposals and analysis for special application scenarios. There is no paper providing a historical overview of IEEE LAN/Ethernet MCS system. This paper is proposing to establish a research project to cover MCS deficiency gap analysis in the application field of LAN (Ethernet) communications systems. Research on LMGA is a mission to collect information on LAN MCS technologies, conduct analysis on the gaps between MCS practices and market needs so that in the future MCS Innovation development stages including technical requirements and proposal selections， LAN MCS gaps can be filled and to facilitate quick application and adoption into the field for new MCS technologies.**

Keywords-Ethernet Modulation Schemes; Spectral Efficiency; Power Efficiency; Coding Deficiency LAN; MCS

I. INTRODUCTION

On 13 December 2022, ISO/IEC SC 6 Secretariat circulated 6N17882 Liaison of IEEE 802.3 Working Group to share IEEE 802.3-2022 standard under the PSDO agreement. The paper contains 7026 pages of technical specifications of LAN (Ethernet) standard.[1] As the title of 6N17882 indicates, it is not a formal submission for 60-day ballot under the PSDO paper, but to share the paper with ISO/IEC SC 6 for information and comments. Therefore, members of ISO/IEC SC 6 committee are expected to provide comments for consideration of IEEE 802.3 Working Group. [2] As a working group of ISO/IEC 6, AG 4 and its members are entitled to make comments on 6N17882.

At about the same time as IEEE's submission of 802.3-2022, ISO/IEC SC 6/AG 4 on MCS Innovation posted a paper (AG 4/N 22) entitled "Execution Plan for Industry Survey on MCS Deficiencies". [3] The paper is a follow up to AG 4/N10, a contribution from Chinese Hong Kong expert YIM Wai Ning proposing an Industry Survey on MCS Deficiencies. AG 4/N 22 listed ten application fields including WLAN, Mobile Communications, UAS/UAAN, Ultra-Short-Wave Radio, WIA-FA, Maritime Satellite, TETRA, Beidou, HDTV. [4] From the list, notably missing is LAN/Ethernet application field. The circulation of 6N17882 provides a good opportunity for AG 4 to consider including LAN MCS Gap Analysis （LMGA） into the scope of industry survey.

The subject of LMGA emerged in AG 4 in the very beginning of this year. [5] On 6 Jan., 2023, Convenor Zhang wrote to IEEE 802 Liaison Officer Andrew Myles and IEEE 802.3 Chair

David Law, informing them that the idea of studying LMGA has emerged in ISO/IEC SC 6/AG 4 and inviting IEEE participation in AG 4 meetings (AG 4 N30). IEEE responded positively by registering two representatives in AG 4 Global Directory (AG 4 N42).

In the 3rd AG 4 meeting, there were brief discussions between Convenor and IEEE representative Dr. George Zimmerman regarding the issue the interest of AG 4 on LMGA and how can IEEE help on the task. [6] The interest and need for an LMGA was confirmed and the remaining question was how to proceed. Convenor Zhang promised to provide a question list as a base to work on.

After the conclusion of ISO/IEC SC 6 Plenary Meeting on 24 March 2023 and with the extension of AG 4 to the 2nd term, Convenor Zhang spent some time to work out this paper to fulfill his promises.[7]

This paper contains analysis and comments on IEEE 802.3-2022 as contained in 6N17882.

II. METHOD AND TECHNIQUE

A. Overview of LAN Techology

Local Area Network (LAN, also known as Ethernet) is a network technology connecting computer systems through wired communication channels such as copper wires and fibre optical cables but with limited range not exceeding 40 kilometers. [8] The technology is mainly developed by IEEE 802.3 group and adopted into International Standards system through bilateral PSDO agreement with ISO. [9] Another local area network technology is connecting systems through emission of electromagnetic waves. It is called Wireless Local Area Network (WLAN) and is also mainly developed by IEEE and enters international standard through ISO.

Local Area Networks, in the beginning known as carrier sense multiple accesses with collision detection (CSMA/CD) access method and physical layer specifications was approved as an IEEE standard by the IEEE Standards Board in 1983 and subsequently published in 1985 as IEEE Std 802.3-1985. In 2012, the title of the standard was changed to Standard for Ethernet.

Communication speed is the major base to categorize IEEE LAN/Ethernet Standards. [10] The First version of LAN standard in 1985 had a 2.94 Mb/s data rate. IEEE Std 802.3u™ added 100 Mb/s operation (also called Fast Ethernet), IEEE Std 802.3z™ added 1000 Mb/s operation (also called Gigabit Ethernet), IEEE Std 802.3ae™ added 10 Gb/s operation (also called 10 Gigabit Ethernet), IEEE Std 802.3ah™ specified access network Ethernet (also called Ethernet in the First Mile) and IEEE Std 802.3ba added 40 Gb/s operation (also called 40 Gigabit Ethernet) and 100 Gb/s operation (also called 100 Gigabit Ethernet). [11] These major additions are all now included in and are superseded by IEEE Std 802.3-2022 and are not maintained as separate papers. Now, IEEE is working on Ethernet technologies capable of delivering 800 Gbps, 1 Tbps and beyond.

Comparing WLAN and LAN, there are some commonalities but also striking differences in the perspective of MCS Gap Analysis. The differences are summarized in the following table.

TABLE I. COMPARING WLAN AND LAN

Parameters	WLAN	LAN/Ethernet
Connection Method	*Wireless*	*Wired*
Communication Medium	*Air*	*Copper, Fiber, etc.*
Latency	*Low*	*High*
Mobility and Rooming	*higher*	*limited*
speed	*Gigabits*	*Higher speed over 400G*
Need for MCS	*required*	*required*
access	*Proximity required*	*Physical access required*
Sharing	*Shared*	*dedicated*
interference	*high*	*Much less*
Fluctuation vulnerability	*high*	*Much less*
Reliability	*Much Less*	*high*
coverage	*100 meters*	*Meters to kilometers*

With these differences, a lot of MCS related questions need to be answered:

- How the different application scenarios and conditions affect MCS systems in these two application fields?
- Does LAN/Ethernet face similar or same MCS challenges of WLAN?
- How much impact does MCS systems have on the development and performances of these two fields?
- Which one has higher efficiency MCS schemes and why?

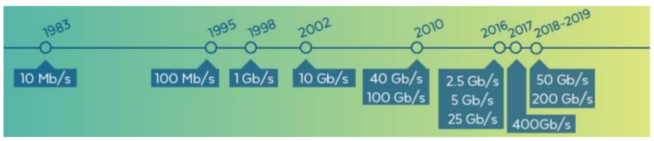


Figure 1. Date Rate Explosion

From the above brief summary, it shows a remarkable trend that over forty years since its start, the data rate of Ethernet has been increased from 10 Mb/s to over 400 Gb/s, which is 40,000 times.

Unlike Wireless LAN and Mobile Communications which transmits radio waves through the air, Ethernet transmits information signals through wired cables. Because of the physical, economic and other considerations in different application scenarios, Ethernet uses different cables and transmission protocols.

The evolution of Ethernet technology indicates that the increase of speed over the past three decades was primary due to the exploration of cabling technology like using different categories of twist pairs, using higher frequencies and optical transmission technologies.

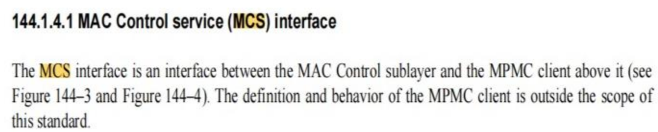
However, due to physical constraints, cable transmission also has maximum performance limits. Has Ethernet reached those limits? How far is from the limits? These questions are relevant to MCS gap analysis.

B. *MCS and LAN/Ethernet Technology*

In IEEE standard systems, there is no uniformed rule for the abbreviation of MCS. [12] It different standards it refers to different technologies.

In IEEE 802.16 for example, MCS is short form for “modulation and coding scheme”. In IEEE 802.11 WLAN standards, MCS is not included in the abbreviation list, but in the text it is clearly indicated that MCS refers to modulation and coding scheme.

In IEEE 802.3, MCS is not listed in the abbreviations tables. [13] In 802.3:2022, MCS is not used to define “Modulation and Coding Scheme”， but as “MAC Control Services”.


144.1.4.1 MAC Control service (MCS) interface

The MCS interface is an interface between the MAC Control sublayer and the MPMC client above it (see Figure 144–3 and Figure 144–4). The definition and behavior of the MPMC client is outside the scope of this standard.

Figure 2. MAC Control Services

To avoid confusion with modulation and coding scheme, whenever the abbreviation of MCS appears in Ethernet standards, the full term “MAC control service” is included.

It is therefore necessary to restate that in AG 4 produced paper and in our discussion on LAN MCS deficiencies, MCS has always been defined as the abbreviation of “Modulation and Coding Scheme.”

During the discussion on WLAN MCS deficiency before the founding of AG 4, there were questions about the MCS related descriptors such as HT, HE-MCS, VHT and UHT in IEEE 802.11 standards. [14] This issue does not arise in Ethernet standards because of the following factors:

- Ethernet categorizes its technology into different speeds (throughput) such as 10M,100M, 10G, 100G, and 400G
- Each category has names with relevant prefixes such as 10MBASE, 10GBASE, etc.
- First suffixes are attached to the names to show media types.
- The evolutions of Ethernet are along the line of speed increases over the years.

- The most fundamental driving force behind the speed increase is the fast development of fibre-optical transmission capabilities.
- MCS technology does not have as much impact in Ethernet development as in WLAN and Mobile communications.
- Therefore, IEEE 802.3 neither use MCS to define its technologies no assign descriptors to MCS systems in the Ethernet standards.

IEEE 802.3 standard adopts a rate based classification system for its programs and standards. [15] In this system, from the titles of the groups, their missions and objectives are clearly indicated. The following list is from IEEE website:

The IEEE 802.3 Working Group develops standards for Ethernet networks. We have a number of active projects, study groups, and ad hoc cs as listed below:

- IEEE P802.3cw 400 Gb/s over DWDM systems Task Force.
- IEEE P802.3cy Greater than 10 Gb/s Electrical Automotive Ethernet Task Force.
- IEEE P802.3da 10 Mb/s Single Pair Multidrop Segments Enhancement Task Force.
- IEEE P802.3df 400 Gb/s and 800 Gb/s Ethernet Task Force.
- IEEE P802.3dg 100 Mb/s Long-Reach Single Pair Ethernet Task Force.
- IEEE P802.3dh Multi-Gigabit Automotive Ethernet over Plastic Optical Fiber Task Force.
- IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force.
- IEEE P802.3dk Greater than 50 Gb/s Bidirectional Optical Access PHYs Task Force.
- IEEE P802.3.1 (IEEE 802.3.1b) Revision to IEEE Std 802.3.1-2013 Ethernet MIBs Task Force.
- IEEE P802.3.2 (IEEE 802.3.2a) Revision to IEEE Std 802.3.2-2019 YANG Data Model Definitions Task Force.
- IEEE 802.3 New Ethernet Applications Ad Hoc.
- IEEE 802.3 PDCC Ad Hoc.

Figure 3. Rate Based Classification

C. *Ethernet Modulation Schemes*

There are two major types of modulation schemes in IEEE Ethernet standards, PAM and QAM. [16] PAM modulation was the major scheme in LAN standards and QAM modulation is introduced into Ethernet only for about five years and in limited application scenarios. In efficiency, PAM modulation belongs to the lower end and QAM modulation is considered as the choice for higher order solutions.

PAM modulation and Ethernet are considered as a perfect match. Most forms of Ethernet use pulse amplitude modulation (PAM) constellations. In PAM signal modulation, information is encoded in the amplitude of a series of signal pulses. [17] The advantages of PAM include simplicity of receiver and transmitter design and easy transmission over a pair of wires.

The following table shows Ethernet PAM modulation types and application scenarios:

TABLE II. PAM MODULATION

Modulation	Application
PAM 3	100BASE-T1 100BASE-T4 1000BASE-T1
PAM 4	400G
PAM 5	10BASE-T 100BASE-T2 1000BASE-T
PAM 16	2.5GBASE-T 5GBASE-T 10GBASE-T 25GBASE-T 50GBASE-T

- PAM 3 and PAM 5 modulation schemes are implemented in sub-G rates applications.
- Higher order PAM 16 is used for gigabit systems.
- There is a tendency to move back to lower order modulation (PAM 4) in standards providing over 100 Gb/s Ethernet systems.
- Emphasis on reliability in some other advanced communication fields is also reflected in Ethernet.

In IEEE Std 802.3™-2015, there was only one reference to QAM in 62.3.1 PMD Overview: "The bytes within the frame are encoded to a set of QAM constellation points that are used to modulate the carriers of the DMT symbol. [18] The time-domain symbol is cyclically extended and then windowed to reduce side lobe energy." And, QAM was not even included in the abbreviation list.

On 22 Nov. 2016, IEEE approved 802.3bn-2016 Physical Layer Specifications and Management Parameters for Ethernet Passive Optical Networks Protocol over Coax (EPoC ）.The new amendment contains 169 references to QAM.

Three years later when IEEE released IEEE Std 802.3™-2018, QAM was cited 209 times. In IEEE Std 802.3™-2022, QAM was cited 202 times.

TABLE III. M-QAM APPLICATION

Modulation	Standard
M-QAM	10GPASS-XR 1000BASE-RHx Management Data Input/Output (MDIO) Interface EPoC (802.3bn-2016)

- 10GPASS-XR is a collection of IEEE 802.3 EPON Protocol over Coax (EPoC) Physical Layer specifications for up to 10 Gb/s downstream and up to 1.6 Gb/s upstream point-to-multipoint link over a coax cable distribution network.
- 1000BASE-H comprises a Physical Coding Sublayer (PCS) and a Physical Medium Attachment (PMA) sublayer that supports Physical Medium Dependent (PMD) sublayers for operation at 1000 Mb/s over duplex plastic optical fiber (POF) as the transmission medium. The following three port types with different PMDs are defined: 1000BASE-RHA, 1000BASE-RHB, and 1000BASE-RHC (collectively referred to as 1000BASE-RHx).
- EPoC operates over a point-to-multipoint (P2MP) topology composed of passive segments of coaxial media and passive taps/couplers, optionally interconnected with active coaxial amplifiers, and/or analog optical links creating a tree-and-branch topology.

Because EPoC is the first IEEE Ethernet standard that adopts QAM modulation, the development time line is needed to indicate the exact time of QAM enters Ethernet.

TABLE IV. EPOC AND QAM MODULATION

Time	Event	QAM Modulation
2011-11	Call for Interest	Modulation was not mentioned
2012-08	PAR Approved	Modulation was not mentioned
2012-10-28	Motion 11 Approved	Support multiple downstream modulation orders up to 4096QAM. Support multiple upstream modulation orders up to 1024QAM.
2013-01-25	Motion 3 Approved	The downstream PHY Link Channel shall use a fixed modulation order of 16 QAM to carry PHY Link
2013-03-21	Motion 4 Approved	The E PoC standard shall support multiple modulation profiles for the bursting DS and US PHY and a single modulation profile for the continuous DS PHY.
2014-01-22	Motion 11 Approved	Support for 2048 and 4096 QAM in the TDD upstream shall be mandatory, using the same QAM constellation mapping as the FDD downstream.
2014-09	1st draft	
2015-03	2nd draft	
2015-10	3rd draft	
2016-11	IEEE Standard	
2018-12-11	ISO/IEC Standard	ISO/IEC/IEEE 8802-3:2017/A md 6-2018

- From current highest data rate perspective, LAN/Ethernet has advantage with top speed 40 times of WLAN.
- From the timing of adoption of QAM modulation perspective, WLAN has the advantage, adopting 64-QAM modulation in 1999, two decades ahead of LAN/Ethernet.
- In 1999, WLAN had given up QPSK and implemented 64-QAM modulation, nowadays PAM 4 (equivalent to QPSK) is still the main choice for Ethernet modulation scheme.
- Ethernet has one advantage over WLAN in the highest mandatory order with 4096-QAM compared with WLAN’s 1024-QAM.
- Ethernet has also an advantage over WLAN in the highest optional order with 16384-QAM compared with WLAN’s upcoming 4096-QAM in IEEE 802.11be.
- Ethernet probably has reached the highest possible QAM order in 16384, while WLAN has no plans for QAM orders over 4096.
- Ethernet has these advantages because of the favorable transmission medium.
- Facing unfavorable application and medium conditions, WLAN develops other modulation technologies such as 8 spatial stream operation which is unavailable to LAN/Ethernet systems.

TABLE V. LAN AND WLAN MODULATION COMPARISON

Parameters	LAN/Ethernet	WLAN
Highest data rates	400G	10G
QAM modulation	2018	1999
Highest order (Mandatory)	4096-QAM	1024-QAM
Highest order (Optional)	16384-QAM	4096-QAM （planned)
Highest possible	Upto 16384-QAM	No more planned beyond 4096-QAM
Adoption	Limited application	System wide
Spatial Streams	None	8

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III. RESEARCH RESULTS AND FINDDINGS

A. SPECTRAL EFFICIENCY

Spectral Efficiency is one of the most important indicators of the capabilities of MCS system. [19] It affects the data rates (throughput) and bandwidth utility efficiency. In different application scenarios, however, the weight of Spectral Efficiency in the development of communication capacity varies.

IEEE Ethernet standard does not offer spectral efficiency tables for PAM modulation schemes. The following table is based on theoretical estimates:

TABLE VI. PAM MODULATION TYPES AND APPLICATION SCENARIOS

Modulation	Application	Spectral Efficiency bps/Hz
PAM 3	100BASE-T1 100BASE-T4 1000BASE-T1	<2
PAM 4	400G	<2
PAM 5	10BASE-T 100BASE-T2 1000BASE-T	<2
PAM 16	2.5GBASE-T 5GBASE-T 10GBASE-T 25GBASE-T 50GBASE-T	3.125

This table reveals a fact that Ethernet PAM modulation has lower Spectral Efficiencies (SE) with highest SE not exceeding 4 bps/Hz.

Comparing the two major Ethernet modulation schemes, PAM modulation has much lower Spectral Efficiency rates, and QAM modulation can deliver several times higher Spectral Efficiency thus could significantly increase the capacity of Ethernet communication systems.

One observation is that in other applications fields, the evolution of MCS technology is through the path of FSK/PSK to QPSK, 16-QAM, 64-QAM, 256-QAM and 1024-QAM. [20] In Ethernet, the evolution of MCS technology is from PAM, to PAM 4, PAM 5 and PAM 16 and then to M-QAM. However, not only older Ethernet protocols continue to rely on PAM technology, the newer groups such as IEEE P802.3dcw 400 Gb/s over DWDM systems, IEEE P802.3df 400 Gb/s and 800 Gb/s Ethernet, IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet all adopt PAM 4 as the modulation scheme.

The major reason for not adopting higher order QAM modulation in systems over 200Gb/s Ethernet standards are the complexity factor. [21] It is not clear how long this factor will remain a barrier since higher order modulation schemes such as 256-QAM and 1024-QAM have because state of the art MCS technology and Ethernet is adopting M-QAM since 2018. It is likely that Ethernet will follow the main-stream in higher order MCS applications.

B. Power Efficiency

During the pre-AG 4 discussions between August 2021 and July 2022 over the issue of WLAN MCS deficiency, the trend of higher and higher MCS power consumption was one of the major factors demonstrating the need for MCS Innovation.

In IEEE 802.3 Ethernet standard, the term Energy Efficiency (EE) was used instead of Power Efficiency (PE) .The purpose of Energy Efficiency is to lower power consumption of Ethernet systems, so the term of Energy Efficiency and Power Efficiency are interchangeable.

Look at the history of 802.3 Ethernet, it is noticeable that IEEE 802.3 standard is very dedicated to achieve Energy Efficiency for Ethernet motivated by the following factors:

- Legislative pressure: legislative action worldwide is demanding improvements in energy efficiency of networked systems.
- Market pressure: energy consumption and efficiency will become a major factor in the choice of network solutions, especially in data centers.
- Cost saving: Energy costs are a major component of operating cost. The Energy efficiency solutions will not materially impact component or installation costs, and may provide cost savings opportunities.

Green Ethernet is a common name for a set of features that is designed to be environmentally friendly, and to reduce the power consumption of a device. [22] The Green Ethernet feature can reduce overall power usage in the following ways:

- Energy-Detect Mode: On an inactive link, the port moves into inactive mode, saving power while keeping the Administrative status of the port Up. Recovery from this mode to full operational mode is fast, transparent, and no frames are lost. This mode is supported on both GE and FE ports.
- Short-Reach Mode: This feature provides for power savings on a short length of cable. After cable length is analyzed, the power usage is adjusted for various cable lengths. If the cable is shorter than 30 meter for Ten gigabit ports and 50 meter for other type of ports, the device uses less power to send frames over the cable, thus saving energy. This mode is only supported on RJ45 GE ports; it does not apply to Combo ports. This mode is disabled by default.

In addition to the above Green Ethernet features, the 802.3az Energy Efficient Ethernet is found on devices supporting GE ports. EEE reduces power consumption when there is no traffic on the port.

The differences between EEE and Green Ethernet are that the later is enabled on all devices whereas only Gigabyte ports are enabled. [23]. With EEE. [24] 802.3az EEE is designed to save power when there is no traffic on the link. And, in Green Ethernet, power is reduced when the port is down but when using 802.3az EEE, systems on both sides of the link can disable portions of their functionality and save power during periods of no traffic.

From MCS perspective, there are some observations:

- The Green Energy and EEE are out of scope, just as the Target Wake Time (TWT) energy saving technology in WLAN. [25] The Ethernet power saving technologies such as disabling port LEDs when not needed are Port Management functions irrelevant with MCS operations.
- The MCS technologies in Ethernet are similar to those employed in other applications such as WLAN in terms of power consumption in transmission of data.
- There is no power saving mechanism to reduce MCS power consumption in Ethernet standards.
- The constraints in power deficiency faced by other application fields such WLAN are also affecting Ethernet operations.
- For example, PAM 4 modulation can double the speed of Ethernet transmission, but also causes 4-5 dB penalty which has to be compensated by other technical measures such as optical amplification or FEC coding systems with higher code gains. [26] Higher order modulations schemes such as PAM 16 and M-QAM results in

more power penalties harder to compensate with other measures.

- Power consumption is one of the major factors blocking Ethernet's utilization of higher Spectral Efficiency modulation schemes. [27] Higher SNR modulation schemes for WLAN systems may be affordable due to the distributed deployment scenario. For Ethernet, in many situations such as operation centers and data storage hubs, higher power consumption may be a cost inhibitor for higher order modulations schemes.
- Ethernet may further cut operation costs if innovative MCS technologies can reduce power consumption while maintain or even increase spectral efficiency.

C. Coding Deficiency

In conventional MCS technology, the C means channel coding and usually refers to FEC coding system. [28] The deficiency of FEC coding has been discussed in 6N 17675 but a through analysis is needed to fully understand the issue and to provide guidelines for coding scheme innovation.

In Ethernet, there are three FEC coding systems used in different application scenarios. Coding gains, latency and complexity are the factors considered in Ethernet FEC coding selections.

- LDPC has higher coding gain (only 0.66 dB gain) but higher latency and complexity.
- Small code size such as RS code has lower latency.
- LDPC was used in delay insensitive network/system such as broadcast, home network, residential access network.
- LDPC is mostly used in copper and wireless system due to its good performance in these channels.
- RS has been used in fiber optical communication system, long-haul, metro and access.

MCS Coding deficiencies is a general and theoretical issue having impact over almost all ICT fields, LAN/Ethernet is no exception. AG 4 needs to have a special study on this topic. IEEE does not have a work plan to work on MCS Coding theory and innovation. There are coding related technical proposals but they are related to specific application scenarios.

IV. DISCUSSION

LMGAR is the abbreviation for LAM MCS Gap Analysis report.[30] It will be the final gap analysis for LAN/Ethernet MCS deficiencies. The current paper is only an initial work providing some basic information as basis for further analysis.

LMGAR should be an AG 4 report with about 60 pages.[31] It will be submitted to ISO/IEC SC 6 to be reviewed at at the 47th ISO/IEC SC 6 HoDC and plenary meetings in the fall of 2024. LMGAR should be mature enough to possess the potential to be converted into a Technical Report. There are several options to develop LMGA. The following provides evaluation of each option. The industry survey contained in 6N17975 is one option to gather industry data of MCS systems. However, the industry survey is not a good option because AG 4 has enough resources for more detailed information. IEEE is the leading Standard Development Organization of LAN technology and has close cooperation with JTC 1/SC 6. If IEEE is interested in providing resources to help out with this work, it would be of great help. AG 4 can solicit contributions from the industry and researchers who can provide practical experiences, market needs and academic theoretic work to help make the analysis more accurate reflection of the gaps between technology and social demand. The final option is to work it out within AG 4. This option has one advantage: because AG 4 is working on MCS gap analysis in several other application fields, LMGA can derive comparative knowledge from other fields. IEEE is the only standard development organization relevant with LMGA project and has already assigned liaison representatives to AG 4 who are senior experts in LAN technology standardization. Therefore, no matter what option is chosen, the process will benefit from collaboration with IEEE.

Because the LMGA report will cover not only technical specifications but also broad issues such as market demands and future directions, collaboration from IEEE and other relevant entities are vital for the success of this project.

In feasibility assessment, LMGA report is more practical than other fields because of the following factors:

- Already has the complete specification （6N17882）
- Historical papers
- IEEE Liaison with ISO/IEC SC 6 and AG 4
- WLAN as comparative technology
- AG 4's resources on other fields.

TABLE VII. TIMELINE

Time	Work	Objective
2023-08-01	Proposal	LMGA proposal is submitted
2023-08-08	6th Meeting	LMGA proposal is revised or approved
2023-12-11	AG 4 Report	LMGA is included in AG 4 report and recommendations to SC 6
2024-04-01	LMGAR	1st draft of LAN MCS Gap Analysis Report is presented to AG 4
2024-07-01	Revision	2nd draft of LMGAR is presented to AG 4
2024-09-01	Completion	Final Report on LMGAR is approved and submitted to SC 6

V. CONCLUSIONS

Technical requirement and proposal evaluation is not in the scope of this paper. However, due to the special situation of Ethernet MCS technology, it is proper here to offer some observations and thoughts on the future cooperation on technical development between IEEE 802.3 group and ISO/IEC JTC 1/SC 6.

LMGA fills a gap in the execution plan for industry survey on MCS deficiencies. And it will provide valuable insights into the application scenarios and conditions of wired modulation and coding schemes. It can also help modulation and coding scheme innovation researchers to understand the limitations of LAN technology and market requirements. And can help modulation and coding scheme innovation development more suitable for LAN applications. LMGA can not only be used by AG 4 to help future MCS innovation activities, but can also be published by ISO/IEC (if the content is mature enough) for general audience since this is the first comprehensive introduction of LAN/Ethernet MCS technology.

This paper proposes a research topic on LAN MCS Gap Analysis for AG 4 and provides an outline as a base paper for the end product "LAN MCS Gap Analysis Report". The work will be significant because of the wide application of LAN technology and the different and complicated application scenarios and challenges for MCS systems.

An overview of the LAN/Ethernet MCS systems does reveal the complexity of Ethernet application scenarios and many differences with other ICT fields such as WLAN. Even though over the past several decades, the data rates of Ethernet has shown remarkable increase and much higher than WLAN, the spectral efficiency performance lags far behind some other ICT fields. One of the major driving force behind Ethernet date rates increase if the fast expansion of fibre-optical cable capacities. As the demand for fast data rates will continue for more decades and as fibre-optical technology is also reaching theoretical and physical limits, deployment of higher order MCS technology will be the way for the future.

On the other hand, IQ based classical Modulation technologies including M-QAM are also facing theoretical and physical limitations. Unlike other advanced fields such WLAN and Mobile Communications which are already reaching the ceiling of MCS capabilities, LAN/Ethernet still has some rooms (moving from lower order to higher order MCS) to operate. If the barriers of higher order MCS complexity and power consumption are mitigated through MCS Innovation, it will be easier to convert Ethernet into higher Spectral Efficiency systems.

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