Artificial Intelligence and MCS Innovation

Thoughts Inspired by WG 7 N 387 on AIEN

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***Abstract*—Upon the request and guidance of SC 6/AG 4 Convenor Kingston ZHANG, a research group has been formed for study the potential impact of Artificial Intelligence on MCS Innovation and to evaluate how can AG 4's work contribute to the next stage of SC 6/WG 7's Future Network standardization program. This is a preliminary report.**

Keywords- AIEN; Future Network;MCS Efficiency; Terminology

I. INTRODUCTION

On 23 Feb. 2024, AG 4 posted a document N 166 which was a document from ISO/IEC JTC 1/SC 6/WG 7 N387 entitled "Harmonious collaboration between base station modulation and user applications." In the cover page of N 166, AG 4 Convenor Kingston ZHANG attached the following note:

The impact of AI on Modulation and Coding Scheme innovation has not been touched in AG 4. WG 7 N387 presents an initial study on the use of AI to achieve harmonious collaboration between base station modulation and user applications. Considering the relevance, this document is posted as an AG 4 document for review and comments. It will be listed on AG 4 10th meeting agenda.

A brief survey on the history of AG 4 indicate that despite its short history (about 17 months since its first GD document released in October 2022), a remarkable number (167) of documents have been generated and many technical issues have been discussed. However, most of the technical discussions have been on MCS gap analysis of different application fields. With this background, AG 4 N 166/WG 7 N 387 brings a new perspective to AG 4 research.

- It provides information that leads to discovery that there are interests and resources in SC 6 about AI technology which has not been considered by AG 4.
- It indicates that AI can be applied to the improvement of MCS efficiencies and is thus a relevant field for AG 4.
- The idea of AI enabled networking (AIEN) indicates AI is an enabler and not "gap", thus the current Gap Analysis focus does not include AI. It should be covered in the second phase of MCS Innovation research which is expected to start in 2024.
- AG 4 needs to include AI into its research scope.

This document hopes to start the discussion in AG 4 on the impact and applicability of AI in the development of MCS innovation.

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II. SCOPE

This document provides a preliminary analysis on the relevance of AI with MCS Innovation focusing on the follow issues:

- An survey on AI research in SC 6.
- Analyzing relevance of AI with MCS Innovation.
- Thoughts and comments on WG 7 N 387
- Future directions for AG 4 on AI research

Exclusion: This document is a research work, which could lead to preparation for AI related MCS standard proposals. But it does not present an PWI or NP project proposal.

III. ACRONYMS

AI	Artificial Intelligence
AIEC	Artificial Intelligence Enabled Communication
AIEN	Artificial Intelligence Enabled Networking
DL	Deep Learning
EE	Energy Efficiency
FN	Future Network
IS	International Standard
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MF-RIS	Multi-Functional Re-configurable Intelligent Surface
MFN	Modulation for Networking
NP	New Project
PHY	Physical
PWI	Preliminary Work Item
QoS	Quality of Service
RIS	Re-configurable Intelligent Surface
SE	Spectral Efficiency
SUE	Spectral Utilization Efficiency
TR	Technical Report
WD	Working Draft

IV. THE DEVELOPMENT OF AIEN WORK IN SC 6

A. Relevance

This document intends to analyze AI impact on MCS Innovation and assess the possibility of opening up a research field in AG 4 to study AI enabled MCS Innovation. As advisory group for SC 6, AG 4 should first understand what has been done in SC 6 in AI related research to avoid duplication/ contradictions and to make better use of existing resources.

B. AI Research in SC 6

The research of AI in SC 6 started with the concept of AIEN "Artificial Intelligence Enabled Networking" in 2019. It is a research project in SC 6 WG 7. It is also the only such project so far in SC 6. It has a long history of development and had gone through several major changes in concept.

C. Evolution of AIEN

The following table provides a highlight of the timeline of AIEN history:

TABLE I. AIEN HISTORY

Time	Event	Reference
2007	SC 6 Xi'an Resolution started Future Network project	6N 13307
2009-2010	SC 6 started TR 29181 series	6N 13602
2013-2014	ISO/IEC TR 29181 part 1-7 published	
2014	1st Draft of 29181-8 (FNQoS) presented	6N 15910
2016	ISO/IEC 21558 and 21559 (Future Network architecture and protocols) NP approved	6N 14601-14602

Time	Event	Reference
2017	ISO/IEC TR 29181-8 QoS published (problem statement and Requirement	6N 16519
2017	ISO/IEC 21558 and 21559 divided, 21558-8 and 21559-8 are assigned to FNQoS architecture and protocols	6N 16556
2018	WD for 21558-8 and 21559-8 submitted	6N 16573-16574
2018	ISO/IEC 21558 and 21559 reorganized, FNQoS become 21558-2 and 21559-2	6N 16850
2019	CD ballot for ISO/IEC 21558-2 and 21559-2	6N16958
2019	AIEN concept first proposed in SC 6	WG7 N 205-206
2020-10-10	PWI-AIEN proposed in SC 6	6N 17371
2021-09-10	SC 6 approved PWI-AIEN (PWI 5096)	6N 17599
2022	Final Text for publication of FNQoS (ISO/IEC 21558-2 and 21559-2) submitted	6N 17802 6N 17803
2023	FNQoS (ISO/IEC 21558-2 and 21559-2) published	
2023-08	In Chongqing Interim Meeting, five IS directions were proposed for AIEN	WG 6 N384-389
2023-08-07	Harmonious collaboration between base station modulation and user applications	WG 7 N 387
2024-02-05	AG 4 pays attention to WG 7's AIEN modulation discussion	AG 4 N 166

Above timeline can be categorized into four major stages

TABLE II. AIEN BACKGROUND

Stage	*Time*	*Events*
Stage 1	2007 ~2014	Future Network TR
Stage 2	2014 ~2017	FNQoS TR
Stage 3	2018 ~2023	FNQoS 21558-2 and 21559-2
Stage 4	2019 ~2024	AIEN

The first stage is from 2007 to 2014. During this seven year period, SC 6 founded Future Network project and completed the first phase of FN standardization by publish seven Technical Reports focusing on problem statement and requirements.

The second stage is from 2014 to 2017 in which ISO/IEC TR 29181-8 (FNQoS) was added and completed.

The third stage is from 2018 to 2023 in which FNQoS architecture and protocols (ISO/IEC 21558-2 and 21559-2) were developed and published.

The fourth stage is from 2019 to current which is almost parallel with the third stage and the scope has been extended.

D. Conceptual Changes of AIEN

1) FNQoS

In SC 6, AI work started with ISO/IEC TR 29181-8 focusing on QoS for Future Network. The technical concept was the use of proxy to make a more intelligent QoS for Future Network (FNProxy). The following paragraph from TR 29181-8 explains:

FNProxy is actually a software unit with a high degree of intelligence and autonomous learning ability. Adopting intelligent FNProxy technology to build the FNQoS architecture, the advantages are it can configure services for user through intelligent FNProxy server according to user QoS requirements, then provide expected services for user through proxy communication protocols, and speculate user's intention,customize and adjust services autonomously. FNProxy technology is an intermediate technology. Because FN is a converged network, it is difficult to design universal technology for each network. However, the concreteness can be shielded and the unified strategies can be implemented through the proxy technology.

From ISO/IEC TR 29181-8 to ISO/IEC 21558-2 and ISO/IEC 21559-2, Proxy based QoS is the main focus of adding intelligent functions to Future Network.

2) The Concept of AIEN

Starting from 2019, while ISO/IEC 21558-2 and ISO/IEC 21559-2 are still under development, the concept of AIEN has been proposed. It is an effort to expand the element of intelligence beyond FNProxy based FNQos and to explore more intelligent functions to support more networking protocols.

The following table offers a comparison:

3) Definition of AIEN

According to 6 N 17371, AIEN is defined as:

AIEN is the abbreviation of the process of machine networking which is given by certain intelligence by using AI learning reasoning method in the process of machine networking.

4) AIEN Current Status

The current status of AIEN study in SC 6 is reflected in SC 6 N 18186 circulated by SC 6 on 2023-12-14.

- AIEN is given PWI status and the official number is PWI 5096.
- The project is intended to produce a WD.
- There have been four updates on the project report. The last updated text of the report is given in WG 7 N 389 on 2023-08-07.
- The fourth report was accompanied by five new sub-field reports, including:
  - AIEN Network Object OID Arc Identification Registration
  - Harmonious collaboration between base station modulation and user application
  - Harmony Degree Calculation Calibration Method of AIEN
  - AIEN Based QoS for Vehicular Communications and Applications
  - Study of AIEN application in LEO satellite Mega-constellations
- These five sub-fields are treated as topics for future IS.
- Modulation was included in the five sub-fields which needs special attention from AG 4.

V. AIEN AND MODULATION

A. A New Direction

Among the five new AIEN proposals, WG 7 N 387 is related to AG 4 and needs special attention. The title of WG 7 N 387 is "Harmonious collaboration between base station modulation and user applications". here is a summary of the proposal:

- In wireless communications, spectral utility and economic considerations require new technologies.
- There are over service issue.
- A better coordination between end users and service providers can reduce over service.
- A better management of modulation can increase spectral utility efficiency.
- Solution is described as "Dynamic modulation and demodulation based on AIEN".
- The FNProxy protocol in ISO/IEC 21558-2 and 21559-2 provides some technical support.

In short, WG 7 N 387 is offering a new standard which is AIEN based modulation technology with artificial intelligent enabled functions to reduce over service and other benefits.

B. AG 4's Relevance

In many ways, WG 7 N 387 is closed related to AG 4 and requires attention.

WG 7 N 387 is the first document connecting AIEN with modulation. Its usage in the SC6 scope is universal.. Therefore, it needs help and support from AG 4 which is a dedicated group for Modulation and Coding Scheme innovation standardization research.

AG 4 has another useful resource. WG 7 N 387 is proposing modulation technology based on AIEN which is also based on published standard on Future Network. AG 4 convener Kingston ZHANG is one of the veteran expert of ISO/IEC Future Network standardization. He was an active

participant and made numerous contributions to SC 6 Future Network work and is one of the editors of ISO/IEC TR 29181-2 (Future Network Naming and Addressing).

A third advantage for AG 4 is its position. In SC 6, WG 1 is responsible for MAC and PHY layer standardization (communication) and WG 7 is specializing in Network layer standardization. Usually, modulation is considered a PHY layer technology. AG 4 is an SC 6 advisory group and therefore it is not restricted by the layer restrictions. AG 4 identifies and develops MCS technologies and can recommend standardization proposals to any SC 6 working groups.

C. Modulation for Networking

WG 7 N 387 is interesting to AG 4 also because it opens up a direction to work on "modulation for Networking, MFN".

Modulation is a PHY technology and its primary function is to facilitate communication. But when the communication equipment such as routers and switches is interconnected to form various networks, modulation also becomes the base technology for networking. The capabilities of modulation schemes will have direct impact on the performances of networks. Therefore, after a new MCS technology is identified and adopted as a SC 6 standard, apply it into networking standards can be done in parallel with works in communication.

In short, modulation technology is a work in PHY layer and primary application is to enhance communication efficiencies, but the work can be extended to cover networking. On the other hand, networking standard development may also find new requirement for enhanced Modulation services which is the case of WG 7 N 387.

D. Coordination Requirement

Since N387 is relevant to AG 4's work, some procedural rules need to be established for coordination and mutual support. AG 4 needs to establish positions on a few issues which will not only affect WG 7 N 387 but also AG 4's work.

The issues include:

- Should Artificial Intelligence be included in MCS Innovation research?
- Will Artificial Intelligence be able to help MCS Innovation to reach its objectives?
- Is the modulation technology presented in WG 7 N 387 (collaboration between network providers and end users in modulation service requirement) part of MCS Innovation?
- What will be the impact of MCS Innovation on networking?

VI. AI AND MCS INNOVATION

A. AI as an Industry Trend

AIEN is the first basic standard in SC 6 to apply AI technology to modulation. It can guide the usage of AIEN. SC 6 needs to take a broader survey of the academics and technologies to make the proposals more inclusive.

Before the emergence of AI as a popular technology, ICT sector has long history of applying intelligent operation into communication and networking operations. Typical applications include channel and frequency selections, automatic adjustment of transmitting power levels, and automatic hibernation in no use situations.

However, traditional concept of automation is not complicated. It is intelligent but not at the advanced level. The trend is moving from being intelligent to highly advanced Artificial Intelligence which can utilize deep learning and logical reasoning to perform more complicated duties. The conceptual evolution from FNProxy in Future Network to AIEN in PWI-5096 reflect this trend.

It is clear that AI can be applied to make MCS operations more efficiently. As to whether AI can help AG 4 find innovative MCS solutions to overcome the theoretic and physical berreier, it needs more assessment.

B. AI/DL Semantic Communication

Another direction is the emergence of Semantic Communication concept in the past decade which is hoping to rely on AI/DL technology to allow communication systems avoid the constraints of

classic information theories. This direction has not been analyzed in AG 4 but should be given attention because AG 4 does have the resources to evaluate the technical feasibility and future impact of this technology.

The semantics of the three elements (syntax, semantics and timing) of communication protocol can be represented by proper semantic coding, which can improve the communication effect and avoid the restriction of Shannon's law.

But one problem with semantic communication approach is that sending less information could lead to misunderstanding or misinterpretation on the receiving end. Proponent of this direction points to the growth of AI/DL (Artificial intelligence/Deep Learning) as the future tool to deal with this problem.

C. AIEC

Discussion on Semantic Communication and AIEN leads to a concept of Artificial Intelligence Enabled Communication (AIEC). The proxy mechanism in Future Network leads to the awareness that more intelligent solutions are needed for networking, the semantic communication technology also indicates the need for more intelligent solutions to improve communication services. This technical direction will continue to attract interests from the industry. The only uncertainty is about to what degree can AI impact communication performances.

There will be a race between AI and human wisdom to decide who can break the theoretical and physical limits in communication channel capacity.

D. AI Assisted RIS Modulation

RIS is the abbreviated term for Re-configurable intelligent surfaces, a new material based technology that is seen as have many benefits for enhanced communication and networking performances. The Surface material is capable of receiving, re-configuring, enhancing, and redirecting received radio frequency signals. Due to its potential to enhance the capacity and coverage of wireless networks by smartly re-configuring the wireless propagation environment, RIS is considered a promising technology for the sixth-generation (6G) of mobile communication, NFC and other wireless communication systems.

On 14 Dec. 2023, SC 6 circulated a Chinese contribution providing the first explanation on how RIS can enhance wireless communication and networking. The document introduced a new generation of RIS technology with abbreviated term of "MF-RIS". Each element of the MF-RIS is composed of an amplifier and a phase-shifter, which can be used to achieve signal amplification, reflection and refraction. The MF-RIS first amplifies the incident signals, and then divides them into reflection and refraction parts by power split circuits. Thus, all users around the MF-RIS can be served simultaneously.

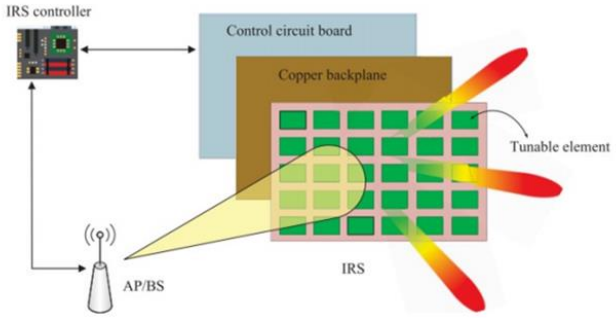

Figure 1. RIS Architecture

Clearly, RIS technology is intelligent and will most likely needs the support of Artificial Intelligence. On the other hand, from AG 4's perspective, RIS is capable of providing better and enhanced spectral utility rates and enhance user end efficiencies. Whether and how the technology can enhance MCS efficiencies or even provide an alternative direction different from AG 4's directions is unclear and is worthy more attention.

E. AI for MCS Innovation

How AI can be used to promote MCS Innovation has not been studied in AG 4, but some positions can be stated:

- Traditional automation control technologies can help communication and networking become intelligent and is useful in modulation and coding scheme services. But usually the technology is used to make micro-management of available resources.

- The MCS technology presented in WG 7 N 387 is not in the main direction of AG 4's research. But AG 4 can help AIEN program find more application scenarios for AI enabled management of MCS operations.
- The application of AI/DL in semantic communication is mainly for the purpose of restore original information but requires advance knowledge and availability of material support.
- Semantic Communication is pursuing a direction which is totally opposite of SC 6's MCS Innovation program because it put emphasis on transmitting less data, which SC 6's effort is to break through the limit and continue long term expansion of spectral and energy efficiencies.
- Due to the fact that MCS innovation shall try to break not only theoretic limits but also physical constraints such as in-channel and inter-channel interference, learning and reasoning capabilities of AI does not offer much help. Human mind will still be the main driving force for MCS Innovation.
- AG 4 should pay more attention to the development of Semantic Communication technology. And a special report on the topic should be developed. Since there is no committees in ISO/IEC involved in Semantic Communication standardization research, this work has to be carried out by AG 4.

VII. MCS Innovation for Networking

A. *Networking into Scope*

The discussion on AIEN is beneficial because it raised an overlooked perspective on MCS Innovation. In AG 4 research so far, MCS Innovation are exclusively treated as a communication technology. WG 7 N 387 revealed a situation that networking also needs the support of advanced modulation technologies. MCS Innovation thus needs to consider the gaps and requirements of MCS operations in the perspective of networking.

Before discussion the relationship between MCS innovation and Networking, the relationship between MCS Innovation and communication needs to be first explained.

B. *Defining Communication*

In SC 6, there is no definition for "communication." A simple definition of communication is that it is a process of exchanging information between two entities. In ICT sector, communication is also known as telecommunication as shown in JTC 1/SC 6 title. Communication can take many forms and mediums such as gesture, voice, music, writing, drawing, etc. Adding prefix "tele" to communication indicates that the exchange of information can take place in long distances.

Communication requires at least two entities, one to send and the other to receive information. MCS is a key technology involving both end offering modulation and demodulation, coding and decoding of messages.

Because the MCS modulation-demodulation and coding-decoding procedures take place below the MAC layer it is designed as PHY layer technology and belongs to SC 6/WG scope.

According to SC 6 Business Plan, the work of WG1 is closely related to all sorts of physical communication technologies.

SC 6/WG 1 is to deliver the standards on services and protocols in the physical and data link layers. As new types of communication technologies emerge, it extends the working boundary and delivers the standards the market requires.

C. *MCS Innovation for Communication*

MCS Innovation technical objectives have not been clearly defined, but based on previous SC 6 and AG 4 documents, the following principles should be established:

Rule 1: MCS Innovation's objective is to find a way for long term advancement and improvement for communication efficiency.

Rule 2: MCS Innovation's primary focus is on the design of wave forms that

Rule 3: MCS Innovation shall not be bound by classic information theory but shall strive to find ways to surpass the channel capacity limits and boundaries.

Rule 4: MCS Innovation shall develop a plan for continued growth of spectral efficiency for communication systems for the next two-three decades.

Rule 5: MCS Innovation shall overcome the conflict between spectral efficiency and energy efficiency as reflected in classic information theory.

Rule 6: MCS Innovation shall develop an evaluation scheme to evaluate capabilities and impact of new MCS technologies on communication systems.

D. Defining Networking

The definition of "network" can be found in ISO/IEC standards including:

- A collection of interconnected elements that provides connection services to users (ISO 1745:1975)
- The ensemble of equipment through which connections are made between terminal installations. These equipment operate in real time and do not introduce store and forward delays. (ISO/IEC 12139-1:2009)

If compared with "communication", networking can be viewed as an advanced form of communication. Networks can not only provide service to one to one communication, but also one to many communication (broadcasting) and many to many communication (meetings). Because of the more diversified application scenarios, networking is more complicated and sophisticated information system.

E. Network Standardization

In ISO/IEC, network standardization is the duty of JTC 1/SC 6 whose title includes "information exchange between systems" which is another way to refer to "networking". In SC 6, the work of networking standardization is the responsibility of WG 7 whose title is described as "Network, Transport, and Future Network".

WG 7 had developed lots of protocols on OSI network and transport by the early 1990s. Currently, WG 7 has been working on Future Network including, other emerging networking issues, to prepare the future of the networks. Considering recent market requirements and activities of other SDOs on 5G/6G network technologies, WG 7 plans to challenge this important technical area as well as future networking technologies including multi-access edge computing, communication protocols in low earth orbit inter-satellite networks and application of AI to networks to support emerging new applications and services such as Blockchain, and metaverse.

The challenge is that almost all new emerging application and services have dedicated committees to handle International Standardization. WG 7 needs to possess unique resource and advantage to attract interest in seeking support for networking standardization. In this perspective, MCS Innovation could possibly be the new driving force.

F. MCS Innovation For Networking

On this subject, there are a few issues needing clarification and understanding:

- Modulation and Coding Schemes are considered PHY layer protocols.
- In SC 6, WG 1 is responsible for MAC and PHY layer protocol standardization.
- Therefore, if it is strictly about MCS technological specifications and used in communication systems such as WLAN, Radio and PLC etc., the standardization projects should be processed in SC 6/WG 1.
- On the other hand, networks are composed of communication systems such as routers, access points, switches, servers etc., all with MCS systems embedded. Therefore, innovative MCS technologies if successfully identified, standardized and implemented, will not only enhance communication efficiencies, but also have an impact on networking capabilities and performances. Network designers and operators should be aware of the advances of MCS technology so that they can

integrate innovative MCS technology into their planning.

- AG 4 is a SC 6 advisory group and can recommend proposals to all SC 6's WG's according to their scopes.

G. MCS Innovation For Future Network

1) Natural Connection between AG 4 and WG 7

MCS Innovation has some natural linkage with the Future Network standardization activity in WG 7 and can also make significant contribution for its future development.

The MCS Innovation initiative was started by Kingston ZHANG in August 2021 when he submitted a contribution to WG 1 on the MCS challenges faced by WLAN. He is also the convenor of AG 4 on MCS Innovation since its founding on 2022-07-01.

On the other hand, Kingston ZHANG is also a senior expert member of SC 6 since 2004. Ever since the first SC 6 meeting creating a study project on Future Network, Mr. Zhang had been a key member of the Future Network standardization expert group. He is one of the editors of ISO/IEC TR 29181-2 on FN naming and addressing. He also contributed many WG 7 reports on Future Network planning and outlooks.

2) MCS Innovation's Potential Impact on Future Network

According to SC 6 Business Plan:

The current network has become an essential communication infrastructure for data transfer and social applications. Even though the current network is such an essential infrastructure, SC 6 notices many concerns, such as scalability, security, robustness, mobility, Quality of Service (QoS), reconfigurability, context awareness, etc. Since 2010, SC 6 has studied and published nine parts of ISO/IEC TR 29181 Future Networks-Problem statement and requirements: General aspects, Naming and addressing, Switching and Routing, Mobility, Security, Media transport, Service composition, Quality of service and Networking of everything. Driven by emerging application requirements, SC 6 has developed International Standards on Architecture for future networks (ISO/IEC 21558 series) and the corresponding protocols and mechanisms (ISO/IEC 21559 series).

ISO/IEC's Future Network has had significant impact on global ICT standardization and industry. Examples include the Decimal naming and addressing impact on digital identifiers standards in other SDO's and ISO/IEC TR 29181-5's impact on "Zero-Trust Security Architecture" which is becoming a hot field in information security. Furthermore, since ISO/IEC Future Network in the very beginning had set the year of 2020 as the time for commercial deployment, China has designated Future Network as one of the several "future industries" to devote more resources for its implementation and deployment.

Based on this observation, it is safe to say that ISO/IEC Future Network has reached its objective set for the past 15 years. Looking to the future, what will Future Network be after 15 years later? Is Future Network looking for increase its technological strengths and expand its capabilities? What will be the directions?

3) Future Directions for Future Network

From WG 7 N 387 and related proposals on AIEN, it gives a sign that WG 7 experts are planning to expand Future Network technological outreach capabilities, and Artificial Intelligence has been identified as one direction. In SC 6 Business Plan, WG 7 also shows intention to further build on Future Network's success to look for standardization opportunities:

Due to the new idea and expertise are required for future network project, WG 7 plans to invite experts from liaison organizations to participate in the relevant WG 7 activities, as well as contributions to be submitted from 'in-active' P-member national bodies. For the successful achievement of WG 7 work on Future Network related subjects, close collaboration with other SDOs, especially ITU-T SG11 (protocols) and SG13 (requirements and architectures) on Future Networks, IMT-2020 networks and beyond, should be strengthen. Also, considering recent market requirements and activities of other SDOs on 5G/6G network technologies, WG 7 needs to challenge this important technical area as well as

future networking technologies including multi-access edge computing, communication protocols in low earth orbit inter-satellite networks and application of AI to networks to support emerging new applications and services such as Blockchain, and metaverse.

4) Future Network 2.0

Besides the new directions such as AI, 6G, Blockchain and Metaverse, this document offers another perspective based on AG 4's works on MCS Innovation. Over 15 years ago, SC 6 experts set a few performance characteristics for Future Network including better performances in scalability, ubiquity, security, robustness, mobility and heterogeneity. Looking at the current situations and long-term objectives, a new and quite significant capability is network capacity.

Over the years, the quantity of information transmitted through networks has gone through explosive growth. This trend will continue as more application scenarios are emerging such as Big Data, AI, Cloud Computing and Metaverse which transmit huge amount of data through networks. In the meantime, network capacities have also expanded with the fast expansion of Fiber-optical transmission technology. However, due to the hard to overcome barriers of information capacity limit and physical constraints, communication systems are facing slowing down and even stagnation in MCS efficiency which forms bottle necks in networking systems.

Some technical development strategies try to bypass the barriers with ideas to reduce the volume of information as in Semantic Communications or to put the computing work load on the perimeters to reduce reliance on network (Edge Computing).

In SC 6, there are two promising technical directions. One is Future Network with its potential in clean slate network structural design and new ideas such as AIEN. The other is AG 4's MCS Innovation program which aims at breaking information channel capacity limit and continuous increase of spectral and energy efficiencies of future communication and network systems.

Therefore, based on AIEN, MCS Innovation and some other innovative technologies such as Stealthy Defense Information Security technologies, SC 6 may consider starting "Future Network 2.0" standardization initiative.

VIII. MCS Innovation Terminology

A. General

WG 7 N 387 has several definitions related to Modulation and Coding Scheme efficiencies. Some of the terms are also used in AG 4 technical research documents, but the meanings are different. AG 4 has not started offering terms and definitions in MCS Innovation standardization. The analysis below indicates that AG 4 needs to start working on definitions in order to avoid confusions.

B. Defining Spectral Efficiency

WG 7 N 387 offers this definition: "Spectral Efficiency (bps/Hz/cell, bps/Hz/Km2): Throughput provided by unit spectrum resources per cell or unit area."

The following offers some observations and brief comments regarding this definition:

- N 387 definition of Spectral Efficiency is different from the definition used in MCS innovation programs.
- MCS Innovation defines Spectral Efficiency as bps/Hz without concern for "cell" or "Km2".
- The reason of leaving out "cell" or "Km2" is that MCS Innovation focuses on MCS efficiency which is deployed in all communication systems.
- In many communication and networking scenarios, there are no performance measurement requiring factors of "cell" or "Km2". For example, for WLAN, NFC, Radio, Scatter communications etc., the communication is basically point to point and does not involve many cells or square kilometer calculations.
- The "bps/Hz/cell, bps/Hz/Km2" definitions for Spectral Efficiency is a terminology used in Mobile or cellular communications.

- According to ITU-R, "bps/Hz/cell, bps/Hz/Km2" is the format to describe "Spectral Utilization Efficiency" (SUE) which is quite different from MCS spectral efficiency (ITU-R SM1046-3).
- Furthermore, a SC 6 document (6N 17676) pointed out in 2022 that it should be further noted that Spectral Efficiency and Throughput are two different terms. They are not interchangeable terms. They represent different technical aspects even though having close relationship. Higher Spectral Efficiency can lead to higher throughput. On the other hand, use of higher frequencies can also lead to higher throughput.

More analysis on Spectral Efficiency terminology is needed.

C. Defining Energy Efficiency

Energy Efficiency is also a key vocabulary frequently used in MCS Innovation. WG 7 N 387 offers this definition: "Energy efficiency (bit/J): The number of bits that can be transmitted per joule of energy."

The following offers some observations and brief comments regarding this definition:

- N 387 definition of Energy Efficiency is different from the definition used in MCS innovation programs.
- In MCS Innovation, energy efficiency is equivalent to power efficiency.
- For calculation of MCS energy efficiency, the format is SNR/SE or SRN/bps/Hz. It shows how much energy is used to raise every bit of Spectral Efficiency.
- This format is useful to evaluate whether an innovative MCS system can offer better energy efficiency than legacy MCS systems and whether the new technology can break classical information capacity limit. The format can also be used to evaluate different innovative MCS proposals and to make long term technological road maps.

More analysis on Energy Efficiency terminology is needed.

D. Cost Efficiency

WG 7 N 387 offers a definition for Cost efficiency：

"Cost-efficiency (bit/dollar): Number of bits transmitted per Unit cost. Compared with 4G system, 5G system needs to be significantly improved in Spectral efficiency, energy efficiency and cost efficiency. Spectral efficiency needs to be increased by 5~15 times; Energy efficiency has increased by over a hundred times. Cost efficiency has increased by over a hundred times."

- This definition for cost efficiency applies to Mobile communications.
- In MCS Innovation studies, a format to calculate the cost efficiency of innovative MCS proposals has not been developed.
- It is unclear whether the bit/dollar format in WG 7 N 387 can be used in MCS Innovation.
- Probably, in MCS innovation, there is no need to set cost efficiency criteria. It can be treated as collateral benefits associated with a new generation of MCS technologies that possess extraordinary high Spectral and Energy Efficiencies.

E. AG 4 Terminology

Above discussions have revealed discrepancies about some key terms such as Spectral Efficiencies and Energy Efficiencies. These discrepancies will cause confusions and misunderstanding if they are not effectively resolved.

Since WG 7 N 387 definitions are based on well established Mobile communication standards and in special application scenarios, AG 4 does not need to request changes from other organizations. What AG 4 can and should do is to establish its own system of terminologies with clearly defined definitions for terms used in MCS Innovation standard systems. For start, AG 4 can work out definitions for:

- MCS
- Innovative MCS
- Spectral Efficiency
- Energy Efficiency

- Over-capacity Communications
- Over-limit Communications
- Spectral Efficiency Rating System
- Energy Efficiency Rating System

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IX. Recommendation for More AG 4 Actions

- AG 4 should pay attention to the AIEN concept in WG 7 and contribute to the study of AI enabled modulation services.
- AG 4 should conduct a comparative research on Semantic Communications and develop a special report to compare different approaches on MCS technology development.
- AG 4 should continue watch on the development of AI/DL to evaluate its applicability in MCS technology development.
- AG 4 should consider the application of MCS innovative technologies to networking, with special attention to how the new technologies can make Future Network perform better.
- AG 4 should start a research project to provide terms and definitions for key MCS terminologies including the vital important Spectral Efficiency and Energy Efficiency.
- After the review and discussion at the 11th meeting on 2024-05-15, AG 4 needs to send this document (with revisions if suggested) to SC 6/WG 7 for their review and consideration at its Interim meeting 28~31 May 2024 in Hong Kong, China.

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