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|  | INTERNATIONAL TELECOMMUNICATION UNION**TELECOMMUNICATIONSTANDARDIZATION SECTOR**STUDY PERIOD 2017-2020 | **Focus Group on Machine Learning for Future Networks including 5G** |
| **ML5G-I-237-R6** |
| **Original: English** |
| **Question(s):** | N/A | 9th meeting, (e-meeting) 2-3 June 2020 |
| **INPUT DOCUMENT** |
| **Source:** | FG ML5G |
| **Title:** | A compilation of problem statements and resources for ITU Global Challenge on AI/ML in 5G networks (formerly ML5G-I-223) |
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| **Keywords:** | AI, Challenge, ML, Sandbox, Data, Resources |
| **Abstract:** | This contribution compiles the list of problem statements and resources contributed by the Focus Group members and partners towards the ITU AI/ML5G Global Challenge. The resources are intended to be a reference list to be used for pointer towards data, toolsets and partners to setup sandboxes for the ITU AI/ML5G Challenge. The problem statements are intended to be analysed, short-listed and used for the challenge to be solved by participants. |

## References

[ITU-T AI Challenge] ITU AI/ML in 5G Challenge website <https://www.itu.int/en/ITU-T/AI/challenge/2020/Pages/default.aspx>

[[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)] [ITU AI/ML 5G Challenge: Participation Guidelines](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU_AI_ML5G_Challenge_Participation_guidelines_v25.docx) (11th May, 2020)

[ITU AI/ML Summary] [ITU AI/ML 5G Challenge: Summary Slides](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20Challenge%20Summary-23-April-2020.pptx)(23rd April, 2020)

[ITU AI/ML Mngt] [ITU AI/ML in 5G Challenge Management Guidelines](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/Challenge_Management_Guidelines_v1.docx) (18th May, 2020)

# 1. Introduction

[[ITU AI/ML Participation Guidelines​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)] described the proposal for ITU Global Challenge on AI/ML in 5G networks.

Problem statements which are relevant to ITU and IMT-2020 networks are the backbone of the challenge. They should be aligned with the theme/tracks of the challenge and should provide enough intellectual challenge while being practical within the time period of the challenge. They should address short term pain points for industry while pointing to long term research directions for academia. In addition, many of them may need quality data to solve them. This contribution collates the problem statements from our partners in a standard format. Future steps for these problem statements are:

* analyse the submitted problem statements from our partners and colleagues,
* present them for selection by the challenge management team
* host the selected problem statements on the challenge website.

While discussing and disseminating the challenge with our partners, an important and frequent question posed to us is about the relevant resources. This document contains a collection of resources pointed to us by our members and partners in the context of ITU ML5G global challenge. This is an attempt to compile and classify them so that it is useful to all our partners. We invite our members and partners to add pointers to private as well as public resources which may be of relevance to the Challenge.

# 2. Summary of problem statements

1. Unrestricted Problem Statements

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| --- | --- | --- |
| **ID** | **Title** | **Contact** |
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| ITU-ML5G-PS-012 | ML5G-PHY: Machine Learning Applied to the Physical Layer of Millimeter-Wave MIMO Sytems | Universidade Federal do Pará (UFPA), Brazil - aldebaro@ufpa.br |
| ITU-ML5G-PS-013 | Improving the capacity of IEEE 802.11 WLANs through Machine Learning | Universitat Pompeu Fabra (UPF), Spain francisco.wilhelmi@upf.edu |
| ITU-ML5G-PS-014 | Graph Neural Networking Challenge 2020 | Barcelona Neural Networking Center (BNN-UPC), Spain jsuarezv@ac.upc.edu |
| ITU-ML5G-PS-018 | Compression of Deep Learning models | ZTE, yuan.liya@zte.com.cn  |
| ITU-ML5G-PS-019 | 5G+AI (Smart Transportation) | JNU, Delhi, preranam.jnu@gmail.com |
| ITU-ML5G-PS-020 | Improving experience and enhancing impressiveness of Video conferencing and collaboration | fauziyafarheen@gmail.com |
| ITU-ML5G-PS-021 | 5G+ML/AI (Dynamic Spectrum Access) | amit.oberoi@alumni.iitd.ac.in |
| ITU-ML5G-PS-022 | Privacy Preserving AI/ML in 5G networks for healthcare applications | C-DOT, Delhi, prashantchugh1234@gmail.com |
| ITU-ML5G-PS-023 | Shared Experience Using 5G+AI (3D Augmented + Virtual Reality) | Hike, India, neerajku@hike.in, ankur@hike.in  |

1. Restricted Problem Statements

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| --- | --- | --- |
| **ID** | **Title** | **Contact** |
| ITU-ML5G-PS-001 | 5G+AI+AR (Zhejiang Division)  | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-002 | Fault Localization of Loop Network Devices based on MEC Platform (Guangdong Division) | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-003 | Configuration Knowledge Graph Construction of Loop Network Devices based on MEC Architecture (Guangdong Division) | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-004 | Alarm and prevention for public health emergency based on telecom data (Beijing Division) | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-005 | Energy-Saving Prediction of Base Station Cells in Mobile Communication Network (Shanghai Division) | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-006 | Core network KPI index anomaly detection (Shanghai Division) | China Unicom liutf24@chinaunicom.cn |
| ITU-ML5G-PS-008 | Out of Service(OOS) Alarm Prediction of 4/5G Network Base Station | China Mobile jiazihan@cmdi.chinamobile.com  |
| ITU-ML5G-PS-009 | Radio signal coverage analysis and prediction based on UE measurement report | China Mobile xieyuxuan@chinamobile.com  |

1. Problem Statements which are under progress

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| **ID** | **Title** | **Contact** |
| ITU-ML5G-PS-010 | UE Moblity Analytics in 5G network | China Information and Communication Technologies (CICT) aiming@catt.cn |
| ITU-ML5G-PS-011 | Intelligent spectrum management for future networks | Vodafone AbdAllah.Mahmoud-Eissa@vodafone.com  |
|  ITU-ML5G-PS-016 | Radio network traffic prediction | China Telecom xudan6@chinatelecom.cn  |
| ITU-ML5G-PS-017 | User-Specific Demand Prediction | Lenovo guoxin9@lenovo.com  |
| ITU-ML5G-PS-015 | DL-based RCA (Root Cause Analysis) | KT, Korea s.baik@kt.com |

# 3. Template for problem statements

The table below is a template that can be used for submission of new problem statements for the ITU AI/ML Challenge.

|  |  |
| --- | --- |
| Id | ITU-ML5G-PS-TEMPLATE |
| Title | Do not modify this particular table, this serves as a template, use the one below. |
| Description | NOTE 3- include a brief overview followed by a description about the problem, its importance to IMT-2020 networks and ITU, highlight any specific research or industry problem under consideration. |
| Challenge Track | NOTE 4- include a brief note on why it belongs in this track |
| Evaluation criteria | NOTE 5- this should include the expected submission format e.g. video, comma separated value (CSV) file, etc.NOTE 6- this should include any currently available benchmarks. e.g. accuracy. |
| Data source | NOTE 7- e.g. description of private data which may be available only under certain conditions to certain participants, pointers to open data, pointers to simulated data. |
| Resources | NOTE 7- e.g. simulators, APIs, lab setups, tools, algorithms, add a link in clause 2. |
| Any controls or restrictions | NOTE 8- e.g. this problem statement is open only to students or academia, data is under export control, employees of XYZ corporation cannot participate in this problem statement, any other rules applicable for this problem, specific IPR conditions, etc. |
| Specification/Paper reference | NOTE 9- e.g. arxiv link, ITU-T link to specifications, etc. |
| Contact | NOTE 10- email id or social media contact of the person who can answer questions about this problem statement. |

# 4. List of problem statements

NOTE 1- the structure of the list below is derived from the many discussions that we had with partners across the globe.

NOTE 2- this list is in no specific order.

NOTE- some problem statements are “**restricted problem statements**”. These are available in this document with red title but the registration to the regional host’s website to such problem statements and data are subject to conditions set forth by the Regional host. E.g. currently the problem statements offered by AIIA-ITU challenge are restricted problem statements and are available only to Chinese citizens with authorized Chinese identification.

NOTE- some problem statements use “**restricted data**” which is available only under a certain conditions set forth by the Regional host.

|  |  |
| --- | --- |
| Id | ITU-ML5G-PS-001 |
| Title | 5G+AI+AR (Zhejiang Division) |
| Description | **Background**: Augmented Reality, which enriches the real world experience through digital means. Its realization depends on a variety of technical means such as multimedia, three-dimensional modeling, real-time tracking and registration, intelligent interaction, and sensing. It simulates computer-generated virtual information such as text, images, three-dimensional models, music, and videos, and then applies it to the real world. The two kinds of information complement each other to achieve "augment" of the real world.The final breakthrough of AI technology comes from the rapid development of big data and computing power. The combination of AI and AR is based on data and hardware to improve perception recognition, knowledge calculation, sameness and interaction fidelity, so that virtual objects and real environment can have natural, continuous and in-depth interaction with users. The deep integration of AI and AR will enable the virtual world to be seamlessly connected to the real world, and ultimately enable digital applications in various industries.**Problems**: Focusing on the intelligence application demand of industry, the artificial intelligence technology and augmented reality technology are applied to the digital upgrade of the industrial Internet. It can be expanded around the following two topics:**Direction 1: AI+AR entertainment application**"AI + AR Entertainment" combines 5G, AI, and AR technologies with the consumption, entertainment, and business fields. It empowers the entertainment market through technological means, changes existing communication methods, strengthens the participation and interaction of audiences, and brings people an immersive sensory experience."AI + AR Entertainment" includes rich industrial scenes such as city landmarks, business district interaction, games, and digital venues. Participants can choose any scene to play their creativity and imagination and combine science and technology to achieve the purpose of improving the audience experience, innovating the communication and marketing methods, and enhancing the cultural and entertainment content. This helps to ensure that the solution is innovative and accessible and uses technology to help the development of the entertainment industry.**1.AI+AR city landmark interaction：**The tourism supply side reform is shifting from relying heavily on large resources, large capital and large commercial district to focusing on differentiation, innovation, experience and operation. As the showcase project of the city, the city landmark is not only the name card of the city, but also the display window of city multiculturalism. In the city landmark scene, the technologies of combination of virtual and reality are introduced to provide rich and diverse interactive experience for different groups of people, strengthen the digital operation value of urban landmarks, rebuild the relationship between people and city, and make the city identity more full and dynamic.**2.AI+AR commercial district interaction：**With the deepening of urbanization, the single shopping mall with a large serving range has gradually disappeared. More and more shopping zones and the impact of e-commerce makes it a new challenge for the business complex to attract more young customers with strong consumption ability and high consumption desire. In the era of 5G, digital empowerment enables the effective connection between online and offline. "Smart commercial district" will become a visible trend. AI+AR technology is likely to break the space limitation of shopping malls and create unprecedented experience upgrade and consumption upgrade by using new interaction and communication methods.**3.AI+AR games：**Gaming is the most widely used area of AR technology at present. Since Pokémon Go, the phenomenal-level AR interactive game, became popular all over the world, AR games have become popular among more and more players due to the high sense of immersion brought by the combination of virtual and reality. When compared to the high degree of homogeneity and repetitive patterns in traditional games, AI+AR has great potential to bring fresh gameplay, visual expression and new experience to games, realizing more creativity and imagination.**4.AR digital venues：**In the era led by digital technology, more and more digital interactive exhibition items are being used in the design of exhibition halls and pavilions, which has also become the new vane of the industry. The introduction of 5G and AR technologies further breaks the physical space constraints of indoor pavilions, bringing possibilities for the enhanced memory, experience and cognition of viewers, as well as new market benefits.**Direction 2: AI+AR industrial Internet application**Driven by 5G technology, the Industrial Internet will develop rapidly, and at the same time, it will bring opportunities for AI + AR applications that are involved in multiple parts of the Industrial Internet, and digital applications for vertical industries will emerge in succession. This "AI + AR industry application" competition theme is closely related to the theme of empowering the industry's digital upgrade and improving production efficiency. It calls for solutions and products that are innovative, useful and of practical value to industry needs.1. **AI+AR industry application - operation efficiency improvement**
* AI+AR is applied to long-distance industrial maintenance, intelligent maintenance, automation training, visual training and other operation and maintenance fields
* AI+AR is applied to intelligent inspection, visual troubleshooting, intelligent coordination and other inspection fields
* AI+AR is applied to intelligent research and development, remote interaction design, 3D spatial information tracking, 3D content interaction and other design and development display fields
* The application of AI+AR in intelligent storage, logistics transfer, intelligent volume, intelligent sorting, automatic delivery and other innovative applications
1. **AI+AR industry application – new media**
* Applying AI+AR to service media workers to improve work efficiency
* AI+AR is applied to web-live/video/live events to achieve high-quality mixed reality experience
1. **AI+AR industry application – urban governance**
* AI+AR is applied to urban security management, crisis identification, population control, vehicle management, community management and other fields
* AI+AR is applied to the daily operation and management of transportation junctions (such as airports, stations and ports), such as the innovative application of passenger guidance, public security management, staff management, material and equipment management, informed scheduling and other aspects.

**Submitting:**Submission of works Our competition schedule is divided into two stages: preliminary and final. The two stages need to submit different competition works. |
| Challenge Track | Vertical-track (invite participant to make solutions for 5G, AI and AR application in vertical industries) |
| Evaluation criteria | **Evaluation Standard of preliminary：**

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| --- | --- |
| Project ( full mark: 100) | Evaluation Standard |
| Description of the project(10 marks) | Be concise, be able to effectively overview the entire solution; have the distinct individuality, have the creativity; Have clear ideas and goals; Be able to highlight their own unique advantages; The logic of the article is clear, the language is fluent, the content is comprehensive, systematic and scientific |
| Requirements analysis and program design(40 marks) | Accurately describe the demand pain point, market opportunity and development orientation of the project; The scheme involves the rationality and feasibility, the completeness and the forward-looking innovation |
| Operating mode/management(20 marks) | Reasonable operation mode, clear goal planning, clear focus; Accurately analyze the difficulty and resource requirements in the process of project implementation |
| Benefit evaluation(10 marks) | The economic and social benefits of the project to the industry |
| Team (10 marks) | Team members have relevant education and work background; Reasonable division of work; Rigorous organization; Proper division of property rights and equity rights; The team has a strong ability to work under pressure, and it is fully prepared for possible difficulties in starting a business. The team has a strong interest in the industry |
| Relevance with China Unicom business(10 marks) | Can become China Unicom's business partner, or can well support China Unicom's existing business, or can combine with China Unicom's key business, improve business competitiveness |
| Total | 100 marks |

**Evaluation Standard of final：**

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| Project ( full mark: 100) | Evaluation Standard |
| Description of the project(5 marks) | Be concise, be able to effectively overview the entire solution; have the distinct individuality, have the creativity; Have clear ideas and goals; Be able to highlight their own unique advantages; The logic of the article is clear, the language is fluent, the content is comprehensive, systematic, scientific |
| Requirements analysis and program design(20 marks) | Accurately describe the demand pain points of the project, analyze the market opportunities, elaborate the business model, and have certain quantitative data support; On the basis of preliminary scheme design, the key points and details of the scheme implementation are detailed |
| Operating mode/management (10 marks) | Reasonable operation mode, clear goal planning, clear focus; Accurately analyze the difficulty and resource requirements in the process of project implementation |
| Benefit evaluation (5 marks) | Estimate social benefits by combining with Demo project examples |
| Team (5 marks) | Team members have relevant education and work background; Reasonable division of work; Rigorous organization; Proper division of property rights and equity rights; The team has a strong ability to work under pressure, and it is fully prepared for possible difficulties in starting a business. The team has a strong interest in the industry |
| Relevance with China Unicom business (5 marks) | Can become China Unicom's business partner, or can well support China Unicom's existing business, or can combine with China Unicom's key business, improve business competitiveness |
| DEMO completion (50 marks) | the completion and experience of the DEMOFor AI+AR entertainment application, the adaptation of mobile phone terminal experience is the basic requirements, the completion of smart glasses terminal adaptation can get 5-20 points bonus.For AI+AR industry-Internet industry application, the adaptation of smart glasses terminal experience is the basic requirement, the adaptation of multiple terminals to achieve cross-terminal platform applications can get 5-20 points plus |
| Total | 100 marks |

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| Data source | NO |
| Resources | Not sure[TBD]. |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)]. |
| Specification/Paper reference | [1], [2], [3], [4] from Appendix I. |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn; |

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| Id | ITU-ML5G-PS-002 |
| Title | Fault Localization of Loop Network Devices based on MEC Platform (Guangdong Division) |
| Description | **Background**: As an information highway, the influence of network fault is expanding constantly. The development of 5G technology brings the benefits of large bandwidth and wide access to this highway, but it also makes the information highway more complex. Moreover, multi-generation technologies coexist for a long time, which brings great challenges to network operation. Similarly, the progress of science and technology also brings us MEC technology. MEC can be deployed in three locations: eNodeB, C-RAN and convergence ring. It can not only obtain the operation data of the equipment in the corresponding location directly, but also load the applications developed by the third-party developers. As a result, operators can provide IaaS / PaaS for the development of special-purpose applications that need MEC features (such as super delay).On the one hand, the fault localization of loop network devices based on MEC platform solves the problem of the decentralized resource management of network equipment. The decentralized devices do not form an end-to-end support for business, and the basic foundation is weak. The information technology level of the supporting process is low, and the supporting work depends on an offline mode, with low efficiency. On the other hand, this fault localization solves the problem of large-scale network events will trigger a large number of single point alarms at the same time, leading to great trouble to the fault repair people, requiring engineers to check one by one, which is time-consuming and labor-consuming. It is difficult to locate cross-domain complex scenes, long fault handling time and low efficiency of cross discipline linkage, which are the pain points of current operation and maintenance attention. It is of great significance to enhance the network usage awareness of MEC platform customers.All network equipment will generate logs in the process of operation to record the running status of the devices in real time. With the help of MEC platform, the ability of data collection and analysis of edge devices and the ability of AI to analyze network logs are very worthy of study, especially for 5G network, collect the log from the terminal and conduct real-time analysis, use AI technology to carry out intelligent evaluation and decision-making on the operation state of the network, and quickly and accurately define the hidden/display fault of the current network. Thus enabling MEC platform can provide customers with a better service.**Problems**: In order to find out the problem and find the root cause, the participants are expected to focus on the analysis of the characteristics of the log data provided. Combined with the network topology information provided, it is necessary to analyze the association relationship described in the network equipment log, extract the log template, predict the Key log, search the keyword Association, find out the fault points that affect the normal operation of the network, determine the cause of the fault, and realize the network fault event playback through the analysis of the fault transmission.**Submitting:**Preliminaries: participants need to submit two parts: one is the algorithm model and analysis results (in csv format); the other is the source code with annotations and descriptive documents (separately attached with a file, in pdf format). All files are packed and compressed into zip file, which is submitted through the email of AIguangdong1@163.com.1. Field description of submitted results

|  |  |  |
| --- | --- | --- |
| FIELD NAME | MEANING | WEIGHT |
| Flag | Test data dentification | A/B |
| RCF\_device | Root cause fault device | 60 |
| F\_time | Fault time | 10 |
| FC\_log1 | key log 1 | 15 |
| FC\_log2 | key log 2 | 8 |
| FC\_log3 | key log 3 | 4 |
| FC\_log4 | key log 4 | 2 |
| FC\_log5 | key log 5 | 1 |

2. Submit . csv format sampleFlag,RCF\_device,F\_time,FC\_log1,FC\_log2,FC\_log3,FC\_log4,FC\_log5A,”XXX-X”,20200XXX,"xxxxx","xxxx","xxxxx","xxxx","xxxxx"B,”CSG-1,CSG-2”,20200219,"xxxxx","xxxx","xxxxx","xxxx","xxxxx"All files (including csv\pdf\zip) are named in the format of participants’ title + team name, for example: " fault localization of loop network devices based on MEC platform\_China Unicom Network Research Institute.csv". |
| Challenge Track | Network-track（MEC） |
| Evaluation criteria | The evaluation criteria are whether the prediction results of relevant schemes are consistent with the real results. It is divided into three parts for comprehensive scoring: The first part is the evaluation criteria F1 of root cause fault device location; the second part is fault time point evaluation criteria F2; the third part is fault critical log evaluation criteria F3.Where the root cause fault device is located accurately, F1 = 60, and inaccurate F1 = 0. If the positioning time is within 5 minutes before and after the standard time, then F2 = 10; if the positioning time is within 1 hour before and after, F2 = 4; if the positioning time is more than 1 hour before and after, F2 = 0. There are 5 key logs, 5 logs in the standard answer are assigned scores according to the importance of 1, 2, 4, 8 and 15, and the corresponding scores are obtained when the positioning results exist in the logs in the standard answer.The analysis and processing data objects are divided into two parts: A and B. the test data analysis results of the two parts are scored respectively: FA = F1A + F2A + F3A, FB = F1B + F2B + F3B .Final score: F = 0.5 \* ( FA + F2B ). |
|
| Data source | In this contest, A and B data are provided. These two data are generated by network devices of different manufacturers, and the data structure will be slightly different.**1.Network topology information**The occurrence of network fault usually has the characteristics of propagation, and the topology related equipment will carry out fault diffusion, which leads to the phenomenon that many devices have faults, but usually the root cause of a fault is only one device, so it is very necessary to analyze the fault for the network which is in constant change.**2.Historical training log + failure time log**The log is composed of unstructured text information. Although the neighboring logs are not the same, there are always the same or similar logs printed repeatedly. Moreover, there is a logical relationship between different types of logs. Therefore, it is necessary to analyze the similarity and relevance of historical logs. In addition, after the log is transformed into structured data, statistical characteristics can be analyzed, so as to grasp the change of equipment operation state, which is very necessary for fault analysis. Most importantly, with the occurrence of faults, some special logs are often printed, in which the key information related to faults is stored. |
| Resources | No |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)]**.** Data is under export control and employees of partners cannot participate in this problem  |
| Specification/Paper reference | No |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn;  |

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| Id | ITU-ML5G-PS-003 |
| Title | Configuration Knowledge Graph Construction of Loop Network Devices based on MEC Architecture (Guangdong Division) |
| Description | **Background**: If knowledge is the ladder of human progress, knowledge graph is the ladder of AI. In the past few years, Google, Microsoft, Facebook, Alibaba, Baidu and other major companies have announced their own knowledge graph products. Knowledge graph is the premise of intelligence. The knowledge graph is trying to make the computer think like human brain, which provides a new perspective and opportunity for the interpretable AI. By virtue of MEC's edge access capability and a large number of local distributed computing capabilities, it is easier to build a "knowledge graph of loop network devices configuration", "knowledge graph of loop network devices configuration" integrates the unstructured data information from multiple dimensions, and collects the status data of network equipments based on the text analysis algorithm (Real time log and network equipment alarms), configuration information, and knowledge data (fault book, manufacturer's documents, alarm handling book, etc.). By digitally cloning of real networks, abnormal events driven by network changes, automatical event root cause analysis，precise control of risks, both symptoms and treatment. The network risks and hidden dangers can be mitigated significantly. So as to provide high-quality network services for MEC platform customers.**Problems**: We hope that the participants will focus on the construction of network operation knowledge graph, based on real network equipment operation data. The framework of knowledge graph is designed according to the logic of network structure. Analyze the relationship between network devices, the internal protocol and business function of the devices. According to the change of network state, the database of knowledge graph is updated in real time, and the keyword search is supported for knowledge interaction. **Submitting:**Preliminaries: participants need to submit two parts: one is the algorithm model and analysis results (in csv format); the other is the source code with annotations and descriptive documents (separately attached with a file, in pdf format). All files are packed and compressed into zip file, which is submitted through the email of AIguangdong2@163.com.1. Field description of submitted results

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| FIELD NAME | MEANING | WEIGHT |
| Flag | Test data identification | A/B |
| Core\_set | Device role classification - core device set | 0.4 |
| Converge\_set | Device role classification - converging device set |
| Access\_set | Device role classification - access device set |
| Relations | Relationship between and within device | 0.6 |

2. Submit . csv format sampleFlag,Core\_set,Converge\_set,Access\_set,RelationsA,"A-23,A-14,…","A-09,A-16,…","A-25,A-32,…","A-23&A-14,A-04&ospf,…"B,"B-23,B-14,…","B-09,B-16,…","B-25,B-32,…","B-23&B-14,B-04&ospf,…"All files (including csv\pdf\zip) are named in the format of participants’ title + team name, for example: "configuration knowledge graph construction of loop network devices based on MEC architecture\_China Unicom Network Research Institute.csv".  |
| Challenge Track | Network-track(MEC) |
| Evaluation criteria | The evaluation criteria are whether the analysis results of relevant schemes are consistent with real results, whether the role identification of equipment and the relationship between them is correct. The weighted mean value of the two aspects is used as the evaluation criteria in this competition.Based on the given equipment data, the participants need to classify and identify the equipment roles. The specific calculation formula of evaluation criteria F1 is as follows: P=TP/(TP+FP), R=TP/(TP+FN), F2=2\*P\*R/(P+R). Where TP represents the set of devices identifying the correct role, FP represents the set of devices discovering the wrong role, FN represents the set of devices not discovering the role, P represents the accuracy rate, and R represents the recall rate.The specific calculation formula of evaluation criteria F2 is as follows: P=TP/(TP+FP), R=TP/(TP+FN), F2=2\*P\*R/(P+R), where TP represents the set of correct association relations, FP represents the set of discovered incorrect association relations, FN represents the set of undiscovered association relations, P represents Precise, and R represents Recall.The analysis and processing data objects are divided into A and B, and the analysis results of the two data are scored respectively: FA = 0.4F1A + 0.6F2A, FB = 0.4F1B + 0.6F2B .Final score: F = 0.5 \* ( FA + F2B ).  |
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| Data source | **1.Network device configuration information**The configuration file contains the device instructions, which guides a series of protection actions carried by the device to the service, and saves all the parameter information that the device follows during operation. It not only describes the relationship between various business protocols within the device, but also describes the logical and physical relationship between devices. Through the extraction of key information and association relationship in the configuration file, we can build a perfect network knowledge graph and manage the network in the form of graph database. **2. Data example**In this contest, A and B data are provided. These two data are generated by network devices of different manufacturers, and the data structure will be slightly different.A data: network 192.168.0.1 mask 255.255.255.0This line of configuration command indicates: the IP address range allocated dynamically. At the same time, when the command in this line is under different interfaces, it indicates the configuration restrictions on different interfaces.1. B data: router-id 10.0.0.1

This line of configuration command indicates: configure the router ID of OSPF process. |
| Resources | No |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control and employees of partners cannot participate in this problem  |
| Specification/Paper reference | No |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn;  |

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| Id | ITU-ML5G-PS-004 |
| Title | Alarm and prevention for public health emergency based on telecom data (Beijing Division) |
| Description | **Background:** In recent years, the worldwide outbreak of Covid-19, Ebola, MERS and SARS posed grievous and global affects on human beings and seriously challenged WHO as well as the health department of many countries. Apart from the effort of health department, modern informational technologies and data can help in health emergencies. In this problem statement, competitors should use the tracking data of telecom users’ geographical movements and DPI information, technologies including machine learning and big data, to propose comprehensive solutions, product developing or advises on infrastructure for serious public health emergencies. All these works can be considered on aspects of epidemic surveillance, spread monitoring, precise prevention, resource allocation, effect evaluation for health incidents.**Problems:** This topic focuses on epidemic surveillance, spread monitoring, precise prevention, resource allocation, effect evaluation by telecom users’ tracking data and DPI information while the outbreak of Covid-19. Participants should propose related products or solutions by using the data, resources and developing environment provided by the competition organizer. If participants use the data from anywhere else, it should be taken in account that the accessibility and scalability of the data. **Submitting:**Participants do mining and modeling based on the data provided by the organizer and yield corresponding solutions or products. The final submission should cover the following aspects:Detailed introduction of the solutions or products.The source code of mining and modeling, as well as the completed zip file of applications; The model and explanations. The product prototype, website or APP (optional, plus). |
| Challenge Track | Vertical-track |
| Evaluation criteria | **Full marks 100****Problem analysis (10 marks):** Whether it has a good understanding of the core of the topic and key elements which affect the final results.Application prospects: Whether there are demands, prospects and potentials for the proposed solutions or products.**Solutions (25 marks)**: Whether the solutions are reasonable and feasible, and meet the demand.The use of data: Whether the data provided by organizer is fully used in an effective way.Innovation: Whether the works are innovative and different from matured solutions in current industries, and whether it performs better.**Implementation (25 marks)**: Whether the solutions or products can be implemented or used as a clear pattern in realistic situation and have prospects in future.Technical foundation: Whether it has a solid technical foundation to carry out the solutions or products and improve them in future.Social effect: Whether it has social effects and the ability to avoid the risk of data breach.**Completion (40 marks)**: Whether the work is complete within the allotted time and schedule and meet all the requirements. |
| Data source | The tracking data including geographically locations and time (directional offset) of sampled users (encrypted) in a city, the app use data and the ownership information.Detailed description: The format, parameter, field of the data, etc. More details can be found in the zip file of the topic. |
| Resources | None |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control and employees of partners cannot participate in this problem |
| Specification/Paper reference | None |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn; |

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| Id | ITU-ML5G-PS-005 |
| Title |  Energy-Saving Prediction of Base Station Cells in Mobile Communication Network (Shanghai Division) |
| Description | **Background:** With the arrival of the era of mobile Internet + artificial intelligence, Internet giants have occupied the forefront of AI in the era of AI and IoT. Operators need to think deeply about how to give play to their professional advantages, accelerate cross-industry integration and enhance industry value.**Problems:** The service load of the base station is unevenly distributed in time and space, and the power supply of the base station cannot follow the service load of the base station, resulting in energy consumption waste. Base station AI energy saving project is aimed at the accumulated operation and maintenance data of operators. Taking AI as the starting point, the base station is modeled and analyzed based on the historical data of base station and base station cell, and the energy saving optimization strategy is generated on the premise of ensuring the service carrying capacity and coverage.**Submitting:**Contestants need to submit two parts of content in the preliminary competition: one is to submit the algorithm model and the analysis results (submitted in. CSV format); The second is the annotated core code and documentation (a separate attached file submitted as a.pdf file). Finally, all the files are packaged and compressed into a zip file for submission. |
| Challenge Track | Network-track |
| Evaluation criteria | TP (True Positive): 1 for True and 1 for prediction; FN (False Negative): true 0, predicted 1; FP (False Positive): true is 1, prediction is 0; TN (True Negative): 0 for True and 0 for prediction.According to the following formula, the scores of the contestants are calculated. According to the accuracy rate (formula 1) and recall rate (formula 2), F1-score (formula 3) is calculated. Finally, all the contestants are ranked according to F1-score.P = TP/(TP+FP) （1）R = TP/(TP+FN) （2）F1-score = 2\*P\*R/（P+R） （3） |
| Data source | This contest provides the resource data of the base station (eci, enodeb, antenna, carrier frequency, etc.), the resource data of the base station cell (flow, coverage, PRB, etc.), the cell phone bill information of the base station cell, the perception data, etc.In order to protect users' privacy and data security, the data has been sampled and desensitized. There are null values or junk data in the data table, and the participants need to handle it by themselves. |
| Resources | None |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control and employees of partners cannot participate in this problem |
| Specification/Paper reference | None |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn; |

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| Id | ITU-ML5G-PS-006 |
| Title |  Core network KPI index anomaly detection (Shanghai Division) |
| Description | **Background:** The core network occupies a pivotal position in the entire mobile operator network. Once the fault occurs, the service quality of the whole network will be greatly affected. Therefore, it is necessary to quickly discover the risk of the core network and timely eliminate the fault before the influence scope is expanded.**Problems:** Key performance indicators (KPIs) reflect network performance and quality. Analysis and mining of KPI can timely find the risk of network quality deterioration. The organizer will provide the real data of a certain operator's core network KPI during the competition, with sampling interval of 1 hour. Contestants are required to train the model and detect anomalies in the following 11 days (test data set) according to the KPI data (training data set) with a history of two and a half months, including normal labels and abnormal labels.**Submitting:**Contestants need to submit two parts of content in the preliminary competition: one is to submit the algorithm model and the analysis results (submitted in. CSV format); The second is the annotated core code and documentation (a separate attached file submitted as a.pdf file). Finally, all the files are packaged and compressed into a zip file for submission. |
| Challenge Track | Network-track |
| Evaluation criteria | TP (True Positive): 1 for True and 1 for prediction; FN (False Negative): true 0, predicted 1; FP (False Positive): true is 1, prediction is 0; TN (True Negative): 0 for True and 0 for prediction.According to the following formula, the scores of the contestants are calculated. According to the accuracy rate (formula 1) and recall rate (formula 2), F1-score (formula 3) is calculated. Finally, all the contestants are ranked according to F1-score.P = TP/(TP+FP) （1）R = TP/(TP+FN) （2）F1-score = 2\*P\*R/（P+R） （3） |
| Data source | 1.Documentation of core network KPI and its meaning.2.Training data set: data list file of 23 KPIs under different scenarios, label 1 at abnormal moments.3.Test data set: data list file of 23 KPIs in subsequent 11 days.In order to protect users' privacy and data security, the data has been sampled and desensitized. There are null values or junk data in the data table, and the participants need to handle it by themselves. |
| Resources | None |
| Any controls or restrictions | **This problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control and employees of partners cannot participate in this problem |
| Specification/Paper reference | None |
| Contact | liutf24@chinaunicom.cn; Tel +86 15652955883; wechat: yudajiangshan wangw200@chinaunicom.cn; weijx29@chinaunicom.cn; |

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| Id | ITU-ML5G-PS-008 |
| Title | Out of Service(OOS) Alarm Prediction of 4/5G Network Base Station |
| Description | At present, the operation and maintenance of 4/5G BS(base station) follow a passive pattern, repairing orders will not be generated until the out of service(OOS) fault occurs. Once the BS is out of service, users will not be able to connect to the wireless network, and their regular communication will be affected. In general, there are some secondary alarms before the major alarm (OOS alarm). Therefore, in this challenge, the participants are expected to train an AI model using historical alarm data with labels of major ones. By excavating the relationship between alarms, one may use the secondary alarms to predict the probability of the important alarm happening in a future period, so that the operation and maintenance personnel can solve the fault in advance and avoid network deterioration. Due to the similar operation and maintenance mode of 4G/5G network, after the large scale commercial use of 5G network, the AI model can be smoothly transferred as a pre-trained model. |
| Challenge Track | Network-track |
| Evaluation criteria | Submit a comma separated value (CSV) file. The content includes whether the given base station will have an out of service alarm in the next 24 hours (or other period). The accuracy of the current prediction model has reached 78% |
| Data source | 4/5G network fault alarm data from China Mobile.The data is fault alarm data of several months, including alarm start time, alarm name, base station name, base station ID, vendor name, city, etc. |
| Resources | None |
| Any controls or restrictions | **This is problem statement is restricted** [[ITU AI/ML Primer](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control and employees of partners cannot participate in this problem |
| Specification/Paper reference | None |
| Contact | jiazihan@cmdi.chinamobile.com Tel +86 13810024426 |

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| Id | ITU-ML5G-PS-009 |
| Title | Radio signal coverage analysis and prediction based on UE measurement report |
| Description | Multiple frequency bands are usually deployed in the commercial network to increase the network coverage and capacity. With the increasing number of bands, inter-frequency measurements by UEs may cause amount of signaling overhead and cost huge UE power consumption and severely impact on running service by the data interruption for inter-frequency measurement gap. It takes too long time for UE to choose the proper cell to reside in. This will degrade the network performance and UE experience. So quick inter-frequency measurement is desired. One way to obtain the coverage information of UEs' radio signal quickly is to divide the cell into the grids by serving cell’s and neighboring cell’s radio signal levels, then locate the UE’s grid and perceive UE’s coverage information based on statistical analysis or directly predict the inter-frequency measurement based on the intra-frequency measurement, which can largely reduce the numbers of UE inter-frequency measurement and benefit for mobility based handover, load balancing, dual connection and carrier aggregation. |
| Challenge Track | Secure-track |
| Evaluation criteria |  Solution, criteria hasn’t been determined |
| Data source | Training data from commercial LTE network with feedback on UE MR data including RSRP,RSRQ,Earfcn,PCI of serving cell and neighboring cells. |
| Resources | No |
| Any controls or restrictions | **This is problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)]. |
| Specification/Paper reference | No |
| Contact | xieyuxuan@chinamobile.com |

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| Id | ITU-ML5G-PS-010 |
| Title | UE Mobility Analytics in 5G network |
| Description | **Background:** In 3GPP, the NWDAF is the AI related network function (NF), which collects data from NFs, OAM and to feedback around 9 categories analytics to requested NFs (Please refer to TS23.288). Within the category “UE related analytics”, the UE mobility analytics or predications could be utilized by NFs, e.g. AMF, SMF, EIR for some purposes, such as mobility management parameter adjustment, detect UE been stolen, and etc.The detailed content of “UE Mobility information” collected from 5G network, the output analytics including “UE mobility statics” and “UE mobility predictions” could be found in TS23.288.**Problem:** However, how 5GC NFs utilize aforementioned output analytics in real 5G network would not be standardized in 3GPP now, and has been leave to NF implementation (but how?), and the benefits of such implementation for real network is still not clear.It is very important to find out “how” and demonstrate the benefits. This would help operator to deploy the NWDAF related and make real 5G networks more intelligent. |
| Challenge Track | Operator and vendor -track? |
| Evaluation criteria | 1. Every team needs to provide output analytics including “UE mobility statics” and “UE mobility predictions”, according to the input “UE Mobility information”.
2. Every team needs to provide the description of their implementation on how to use the output analytics, and corresponding benefits.
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| Data source | 1. Every team itself needs to provide the “UE Mobility information” from real 5G network or find equivalent from 4G network.
2. Are there operators could possibly kindly provide the “UE Mobility information” all the teams?
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| Resources | TBD |
| Any controls or restrictions | This problem statement is open to all participants. |
| Specification/Paper reference | TS23.288 |
| Contact | aiming@catt.cn |

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| Id | ITU-ML5G-PS-011 |
| Title | Intelligent spectrum management for future networks |
| Description | **Background:** Future networks are heterogeneous, e,g, Multi-RAT (5G, 4G, licensed, unlicensed, fixed, mobile), Multiple platforms (edge cloud vs. centralized cloud, VNF vs. PNF, Multiple levels/domains (Access Network vs. Core, network slices with varied KPI demands, various management and orchestration layers). Also there several potential data sources e.g. (Peer-to-peer networks, NF, applications, UEs.**Problem:** In thatcontext**,** spectrum management for future networks is challenging. There is an expectation from end-customer for coexistence and mobility across different networks (see above).Interference management and seamless user experience across different frequency bands used by the network is expected.Power management in the base station and UE is a challenge in future networks with multi-bands.Current methods for spectrum management has the following disadvantages:* The existing techniques for spectrum management are technology specific, partly standardized + vendor-specific algorithms implemented in scheduler.
* Intra-RAT (radio access technology) standards available (e.g. X2)
* Operator control is lesser, mainly driven by vendor differentiation (scheduler and resource management algorithms).
* Suited to less-dynamic network conditions of 4G than to future networks of 5G and beyond.

In future networks, we would like schemes which:1. Exploit the upcoming open interfaces and data in RAN and CN
2. Flexible to optimize the on-demand spectrum access in tomorrow’s networks.

In this context, the spectrum management for future networks is proposed to be:* Data-driven: Use data from different parts of the network (based on VF contribution to ITU FG ML5G, Supplement 55 to Y.3170 series)
* Federated: Cross-domain exchange of data for ML (based on ITU Y.3172, 3174)
* Self-x: Adaptive, Distributed ML, decisions at the edge (to reduce latency, communication overhead).
* Level 5 intelligent: demand mapping, based on plug-in models from operator ML marketplaces (based on ITU Y.3173).

Advantages of this approach:* Data driven, at the same time, reduces latency, communication overhead
* Based on operator KPIs (e.g. interference reduction)
* Standard (ITU-based) architecture and interfaces for interoperability
* Take advantage of best ML mechanisms - Plugin models from researchers

Challenge problem statement:* Given a set of network bands for various types of future networks, implement intelligent dynamic spectrum management for future networks including IMT-2020 based on data from multiple domains in the network.
* Emphasises self-x strategy of VF.
* Implements pluggable intelligence (AI models).
* An optimal solution should have a model which reduces interference between various networks, uses standard interfaces (e.g. ITU), enables optimal operator KPIs and imposes minimal communication overhead.

[More details, including the VF sandbox setup (lab), will be shared later with interested participants] |
| Challenge Track | Network track (private VF data) |
| Evaluation criteria | In a testbed chosen by VF, shortlisted models and solutions will be evaluated by:1. Comparison with existing benchmarks for operator KPIs
2. Accuracy of models
3. Latency
4. Amount of communication overhead for the model
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| Data source | Private data from VF (available only to VF approved candidates) |
| Resources | TBD: Lab set-up / simulator (available only to VF approved candidates)VF Sandbox will be setup using data and tools from VF. It will be accessible only to selected participants nominated by VF. Data will be hosted in a place of choice by VF. Only the data and tools relevant to the VF problem statement will be hosted in the VF Sandbox. Regular meeting and monitoring of participants having access to the VF Sandbox will be done by ITU. |
| Any controls or restrictions | Data privacy: No data should be moved from the region.Private data from VF (available only to VF approved candidates) |
| Specification/Paper reference | ITU-T Y.3172 and Y.3174 |
| Contact | AbdAllah.Mahmoud-Eissa@vodafone.com |

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| Id | ITU-ML5G-PS-012 |
| Title | ML5G-PHY: Machine Learning Applied to the Physical Layer of Millimeter-Wave MIMO Systems |
| Description | The increasing complexity of configuring cellular networks suggests that machine learning (ML) can effectively improve 5G and future networks. One of the technologies for applications such as vehicular systems is millimeter (mmWave) MIMO, which enables fast exchange of data. A main challenge is that mmWave, as initially envisioned for this application, requires the pointing of narrow beams at both the transmitter and receiver. Taking into account extra information such as out-of-band measurements and vehicles positions can reduce the time needed to find the best beam pair. Beam training is part of standards such as IEEE 802.11ad and 5G, and has also been extensively studied in the context of wireless personal and local area networks. Hence, one of the tasks focuses on beam-selection. Another task is channel estimation, which is challenging due to mobility, strong attenuation in mmWave and other issues. This challenge uses datasets obtained with the Raymobtime methodology. The data consists of millimeter wave (mmWave) multiple-input multiple-output (MIMO) channels, paired with data from sensors such as LIDAR. |
| Challenge Track | Network-track, as the challenge consists of use cases related to signalling or management. |
| Evaluation criteria | Top-K classification for beam selection and normalized mean squared error for channel estimation |
| Data source | Raymobtime datasets - <https://www.lasse.ufpa.br/raymobtime/> |
| Resources | None |
| Any controls or restrictions | This problem statement is open to all participants. |
| Specification/Paper reference | [7] 5G MIMO Data for Machine Learning: Application to Beam-Selection using Deep Learning, 2018 - http://ita.ucsd.edu/workshop/18/files/paper/paper\_3313.pdf[8] MmWave Vehicular Beam Training with Situational Awareness by Machine Learning, 2018 - https://ieeexplore.ieee.org/document/8644288[9] LIDAR Data for Deep Learning-Based mmWave Beam-Selection, 2019 - https://ieeexplore.ieee.org/document/8642397[10] MIMO Channel Estimation with Non-Ideal ADCS: Deep Learning Versus GAMP, 2019 - https://ieeexplore.ieee.org/document/8918799 |
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| Id | ITU-ML5G-PS-013 |
| Title | Improving the capacity of IEEE 802.11 WLANs through Machine Learning |
| Description | The usage of Machine Learning (ML) is foreseen to be a key enabler to address the challenges podes by future wireless networks. In IEEE 802.11 Wireless Local Area Networks (WLANs), the major challenges will be the user’s density and lack of coordination, which, given the current channel allocation mechanisms, lead to sub-optimal performance. One potential solution is the application of Dynamic Channel Bonding (DCB), whereby an Overlapping Basic Service Set (OBSS) adapts the spectrum to be used so that their performance is maximized. Nevertheless, due to the complexity of massively crowded deployments, choosing the appropriate channel width is not trivial. Moreover, increasing the channel width entails a trade-off between the link capacity and the quality of the link (using more bandwidth entails a lower received signal strength and leads to a higher contention). To address the abovementioned challenges, we propose using Deep Learning (DL) to predict the performance that will be obtained in an OBSS by using different channel bonding strategies. |
| Challenge Track | Network-track  |
| Evaluation criteria | Participants should provide a .csv file containing the predicted performance of each BSS (columns) in the different test deployments (rows).The evaluation of the proposed algorithms will be based on the average squared-root error obtained from all the predictions compared to the actual result in each type of deployment. |
| Data source | To be provided |
| Resources | The IEEE 802.11ax-oriented Komondor simulator [3] has been used to generate both training and test datasets. |
| Any controls or restrictions | This problem statement is open to all participants. |
| Specification/Paper reference | [11] Barrachina-Muñoz, S., Wilhelmi, F., & Bellalta, B. (2019). Dynamic channel bonding in spatially distributed high-density WLANs. *IEEE Transactions on Mobile Computing*.[12] Barrachina-Muñoz, S., Wilhelmi, F., & Bellalta, B. (2019). To overlap or not to overlap: Enabling channel bonding in high-density WLANs. *Computer Networks*, *152*, 40-53.[13] Barrachina-Muñoz, S., Wilhelmi, F., Selinis, I., & Bellalta, B. (2019, April). Komondor: a wireless network simulator for next-generation high-density WLANs. In *2019 Wireless Days (WD)* (pp. 1-8). IEEE. |
| Contact | Francesc Wilhelmi, francisco.wilhelmi@upf.edu (+34 93 5422906) |

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| Id | ITU-ML5G-PS-014 |
| Title | Graph Neural Networking Challenge 2020 |
| Description | Network modelling is essential to build optimization tools for networking. For instance, an accurate network model enables to predict the resulting performance (e.g., delay, jitter, loss) and helps to find the configuration that maximizes the network performance according to a target policy (e.g., minimize the average end-to-end delay). Nowadays, network models are either based on packet-level simulators or analytical models (e.g., queuing theory). The former are very costly computationally, while the latter are fast but not accurate. In this context, Machine Learning (ML) arises as a promising solution to build accurate network models able to operate in real time. Recently, Graph Neural Networks (GNN) have shown a strong potential to be integrated into commercial products for network control and management. Early works using GNN have demonstrated an unprecedented capability to learn from different network characteristics that are fundamentally represented as graphs, such as the topology, the routing configuration, or the traffic that flows along a series of nodes in the network. In contrast to previous ML-based solutions, GNN enables to produce accurate predictions even in networks unseen during the training phase. Nowadays, GNN is a hot topic in the ML field and, as such, we are witnessing significant efforts to leverage its potential in many different fields (e.g., chemistry, physics, social networks). In the networking field, the application of GNN is gaining increasing attention and, as it becomes more mature, is expected to have a major impact in the networking industry.**Problem statement:**The goal of this challenge is to create a neural network model that estimates performance metrics given a network snapshot. More in detail, this model must predict the resulting per-source-destination mean per-packet delay given: (*i*) a network topology, (*ii*) a routing configuration, and (*iii*) a source-destination traffic matrix.As a baseline, we provide RouteNet [5], a GNN architecture recently proposed to model network performance. Participants are encouraged to improve RouteNet or design their own neural network architecture. |
| Challenge Track | Network-track (design, train and test a neural network model for a networking use case) |
| Evaluation criteria | Before the end of the challenge, we will provide a test dataset. Participants must label this dataset with their neural network models and send the results in CSV format. For the evaluation, we will use the Mean Absolute Percentage Error (MAPE) score computed over all the source-destination delay predictions produced by the candidate solutions:Solutions with lower MAPE score will be the winners.  |
| Data source | Datasets are generated using a discrete packet-accurate network simulator (OMNet++). The dataset contains samples simulated in several topologies and includes hundreds of routing configurations and traffic matrices. The data is divided in three different sets for training, validation and test. The validation and test datasets contain samples with similar distributions.You can find more details about the datasets at <https://bnn.upc.edu/challenge2020>.https://lh5.googleusercontent.com/yKEcuyII1DL9LKN3YCxQLGgxawig2VDX6AX8Kf1YgrnpYHzcP6Flap22tD9IoRYfOEQN7UPrAGfQSB1-zEzAfIDrfl24Gx36lkCB4vAbZtEoZFT4JxBQ=w572 |
| Resources | - Paper [5], source code and tutorial of RouteNet, a reference GNN model that can be used as a starting point for the challenge- User-oriented Python API to easily read and process the datasets - Mailing list for questions and comments about the challenge [[Challenge-KDN mailing list](https://mail.knowledgedefinednetworking.org/cgi-bin/mailman/listinfo/challenge-kdn)]- Website with a more detailed description of the challenge and the resources provided (<https://bnn.upc.edu/challenge2020>) |
| Any controls or restrictions | This challenge is open to all participants [ITU AI/ML Primer].The following rules must be satisfied to participate in this challenge:* The proposed solution must be fundamentally based on neural network models.
* The proposed solution cannot use network simulation tools.
* Solutions must be trained only with samples included in the training dataset we provide. It is not allowed to use additional data obtained from other datasets or synthetically generated.
* You can participate in teams of up to 4 members (i.e., 1-4 members). All the team members should be announced at the beginning (in the registration process) and will be considered to have an equal contribution.
* The challenge is open to all participants except members of the organizing team and its associated research group “Barcelona Neural Networking Center-UPC”.

After the score-based evaluation, winners (top 5) must send the code of the neural network solution proposed, the neural network model already trained, and a brief document describing the proposed solution and how to reproduce it (1-2 pages).Important notice: In the challenge, you may use any existing neural network architecture (e.g., the RouteNet implementation we provide). However, it has to be trained from scratch and it must be clearly cited in the solution description. In the case of RouteNet, it should be cited as it is in [5]. |
| Specification/Paper reference | [5] Rusek, K., Suárez-Varela, J., Mestres, A., Barlet-Ros, P., & Cabellos-Aparicio, A, “Unveiling the potential of Graph Neural Networks for network modeling and optimization in SDN,” In Proceedings of ACM SOSR, pp. 140-151, 2019. |
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| Id | ITU-ML5G-PS-015 |
| Title | DL-based RCA (Root Cause Analysis) |
| Description | **Background*** It is important for carriers to operate their complex network stably.
* The stable operation includes locating and identifying the root cause by looking at symptoms when some faults occur on their networks.
* Vendors provide a variety of indicators (logical syslogs, or physical LED indicators) to indicate the status of the equipment when they release their equipment.
* When constructing a network with a small number of equipment, it is easy to find the root cause and reasoning the core problems.
* By making this reasoning process into a rule set, it is possible to automate the whole inference logic, only under the condition that the size of the network is moderately large
* However, in a very large and complex environment of the network, the rule-based inference method shows the very limited performance.
* Especially in the 5G network, stability and speed are emphasized to provide the new 5G services. Various brand-new 5G equipment, which is physical and also virtual, is deployed, resulting in the number of management points increased exponentially.
* In this situation, the introduction of DL can be of great help to the operators, because it is almost impossible to set up the rules to pin-point the root causes in such a complex environment.

**Motivation*** For the introduction of DL technology, it is essential to collect the training data
* However, it is almost impossible to acquire the fault situation data much enough for training, because the fault situations do not occur frequently in nature
* A promising alternative is to build a test-bed that simulates 5G network to simulate various fault situations and collect data
* Using this collected data, a DL model for RCA can be developed
* This DL model is developed in the form of a pre-trained model through learning the characteristics of network equipment on a test-bed
* In actual application, the characteristics of operator's network can be fine-tuned to quickly increase accuracy and be applied to the site

**Objectives*** By implementing the following two items, the DL-based RCA system can be implemented for complex 5G network
* 1) Implement a Test-bed simulating 5G network (ML5G test-bed)
	+ Composed of communication equipment common to telecommunications operators providing 5G services
	+ Interworking with DB by adding data collection function at the major management points in the simulated network
	+ Configured to enable the fault scenario settings and labeled data collection according to research needs
* 2) Development of DL model optimized for RCA
	+ General DL model for RCA should be pre-trained on this test-bed
	+ The pre-trained DL model will be fine-tuned to be applied to the commercial environment
	+ Once constructed, the simulation test-bed can be used for various purposes other than RCA
 |
| Challenge Track | Network-track  |
| Evaluation criteria |  |
| Data source | TBD |
| Resources |  |
| Any controls or restrictions | This is problem statement is open to anyone[[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)]. |
| Specification/Paper reference |  |
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| Id | ITU-ML5G-PS-016 |
| Title | Radio network traffic prediction |
| Description | **Background:** In the 5G era, multiple new services are emerging, and various Internet applications are constantly being enriched, which has doubled Internet traffic. The rapid growth of traffic has brought a lot of pressure to network bandwidth, computing, and storage. DPI data records and presents key traffic information (data statistics start, end time, and upstream and downstream traffic) in the application dimension. The analysis of current network traffic models and traffic service development trends through DPI data is the basis for solving network congestion, improving user experience, and rationally allocating and utilizing network resources to improve network bandwidth utilization.**Problem:** Based on the DPI traffic data collected by the big data platform and the distance between base stations, artificial intelligence technology can be used to analyse and predict base station traffic, in order to provide guidance to subsequent network planning, operation and maintenance. In this problem, we will provide a unified data set for the participating teams. Each participating team can split the data set into a training set, a test set, and a verification set, and use it for training and testing of the AI ​​algorithm model. The purpose of the algorithm is to predict the traffic trend of base station in the future through the historical DPI traffic data in the target area and the traffic information in the surrounding area.**Submitting:**Competitors need to submit two parts in the preliminary competition: one is to submit the algorithm model and analysis results (submitted in .csv format); the other is the annotated complete code and explanatory documents (separately attached files, submitted in .pdf file format). Finally, all the files are packaged and compressed into a zip file for submission. |
| Challenge Track | Network-track |
| Evaluation criteria | Evaluation criteria： （Mean Absolute Percentage Error, MAPE）， |
|
| Data source | TBD: DPI traffic data collected from the current network and desensitized.  |
| Resources | No |
| Any controls or restrictions | **This is problem statement is restricted** [[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)].Data is under export control |
| Specification/Paper reference | No |
| Contact | xudan6@chinatelecom.cn |

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| Id | ITU-ML5G-PS-017 |
| Title | User-Specific Demand Prediction |
| Description | **Background:**In recent years, more and more research has pointed out that by proactively caching content items, for which users may request, to the edge of the network, the wireless network can reduce the download time when users request the data. However, the benefits of this approach relay heavily on the accuracy of user’s demand prediction. The more accurate the user's demand prediction, the greater the benefits of this approach.**Problem:**This topic focuses on user-specific mobile traffic demand prediction. Competitors need to build mathematical models or design algorithms to predict the time-varying requesting probability of each user requesting each content item in the next 24 hours. The time-varying requesting probability can be modelled by probability density function for continuous random variables and probability mass function for discrete random variables. This problem covers four sub-problems as follows.1. Competitors need to collect datasets by themselves to solve the problem. They can collect any dataset according to their needs, e.g., the time spent by each user on TikTok.
2. Competitors need to predict the time-varying requesting probability of each user requesting each APP (e.g., Youtube, Bilibili, Baidu, Taobao, TikTok) in the next 10minutes, 1hour, and 24 hours. As an example, the time-varying requesting probability of each APP can be recorded as follows.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| APP | 00:00~01:00 | 01:00~02:00 | … | 23:00~24:00 |
| APP 1 |  |  | *…* |  |
| APP 2 |  |  | *…* |  |
| … | … | … | … | … |

1. Competitors need to predict the time-varying requesting probability of each user requesting each content item in the next 10minutes, 1hour, and 24 hours. Here the content item is defined as a concrete file, such as a concrete video from the Youtube platform or article from the Baidu platform. As an example, the time-varying requesting probability can be recorded as follows.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Content Item | 00:00~01:00 | 01:00~02:00 | … | 23:00~24:00 |
| Content Item 1 |  |  | … |  |
| Content Item 2 |  |  | … |  |
| … | … | … | … | … |

1. Competitors need to decide the caching policy for each user. Each user is assumed to be equipped a caching device, which can cache 1GB data. Competitors need to design a caching policy to determine the caching content items for next 10 minutes, 1hour, and 24hours. As an example, the caching policy can be recorded as follows.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Content Item | 00:00~01:00 | 01:00~02:00 | … | 23:00~24:00 |
| Content Item 1 | Caching size  | Caching size  | … | Caching size  |
| Content Item 2 | Caching size  | Caching size  | … | Caching size  |
| … | … | … | … | … |

**Submitting:**Competitors need to solve the problem based on the data collected by themselves. The final submission should cover the following aspects:1. The dataset. In order to facilitate the verification and repeat of the experiment results, if the competitors solve the problem based on a public dataset, they need to indicate the source and download link for the public dataset; if the competitors solve the problem based on the dataset collected by themselves, they need to upload their dataset and a detailed report to explain how they collect the data. (If the dataset is too large, a download link for the dataset is acceptable.)
2. An annotated source code. In order to facilitate the verification and repeat of the experiment results, competitors need to submit all source code and corresponding explanatory documents.
3. A detailed report. Competitors need to submit a detailed report to explain how they process the data, build models, design algorithms, and verify algorithm performance.

(All the files are packaged and compressed into a zip file for submission.) |
| Challenge Track | Network-track |
| Evaluation criteria | 1. Competitors need upload a detailed report in PDF format to explain how they process the data, build models, design algorithms, and verify algorithm performance. The report will be rated based on the innovation of solutions, the completeness of implementation, the accuracy of results, and the writing quality.
2. Competitors need upload a detailed file in CSV format to record the prediction results and the caching policy.
3. Competitors can use the hit ratio, i.e., the amount of data the user reads from the cache, to evaluate their caching policy.
 |
| Data source | TBD: Competitors need to collect the data by themselves. |
| Resources | None. |
| Any controls or restrictions | This is problem statement is open to anyone[[ITU AI/ML Primer​](https://www.itu.int/en/ITU-T/AI/challenge/2020/Documents/ITU%20ML5G%20Global%20Challenge_proposal_v23a.docx)]. |
| Specification/Paper reference | [1] M. Lee, A. F. Molisch, N. Sastry and A. Raman, "Individual Preference Probability Modeling and Parameterization for Video Content in Wireless Caching Networks," in IEEE/ACM Transactions on Networking, vol. 27, no. 2, pp. 676-690, April 2019.[2] B. Wu, W. Cheng, Y. Zhang, Q. Huang, J. Li, and T. Mei, “Sequential prediction of social media popularity with deep temporal context networks,” in Proceedings of the 26th International Joint Conference on Artificial Intelligence (IJCAI’17). AAAI Press, 3062–3068, 2017.[3] S. D. Roy, T. Mei, W. Zeng and S. Li, "Towards Cross-Domain Learning for Social Video Popularity Prediction," in IEEE Transactions on Multimedia, vol. 15, no. 6, pp. 1255-1267, Oct. 2013. |
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| Id | ITU-ML5G-PS-018 |
| Title | Compression of Deep Learning models |
| Description | **Background:**While Deep learning has achieved great success in many areas like audio recognition, computer vision and natural language processing, how to use DL models in environment with restrict resource constraints remains a problem due to their huge computing cost and memory footprints. Some technologies have been introduced to address these challenges, among which model compression technology is one of the most effective. Examples of DL model compression methods are model tailoring, kernel sparseness, quantization, low rank decomposition, transfer learning, etc.**Problem:**This problem statement focuses on the construction of general model compression technology. Participants are required to design a general model compression algorithm to achieve model acceleration. The target models are as follows:* BERT
* MobileNet-V3

Participants can choose any model version and dataset as they need, and then design their own model compression solutions, which can either be a single algorithm or a system with multiple algorithms intergrated.**Submitting:**1. A description document. The contents of the document include but are not limited to: insight, opinion and analysis of model compression; selected target model and reason; solution, algorithm used; description and comparison of compression results, etc.
2. Source code.
 |
| Challenge Track | Enabler Track |
| Evaluation criteria | 1. Effect of model compression (50%): The selected model type, loss of accuracy, compression rate of model parameters and computing power.
2. Solution advantage (30%): Whether the solution is reasonable and whether the solution has enough practicability, innovation and universality.
3. Problem analysis (10%): Whether there is a deep and original insight into the problem, and whether the analysis of the key elements of the problem is accurate and reasonable.
4. Completeness (10%): Whether the requirements of the competition are fulfilled according to the proposed scheme and design.
 |
| Data source | No data source needed. |
| Resources | BERT：<https://github.com/google-research/bert>MobileNet-V3：<https://arxiv.org/abs/1905.02244>；<https://github.com/topics/mobilenet-v3> |
| Any controls or restrictions | No restrictions. |
| Specification/Paper reference | . |
| Contact | Liya Yuan ZTE, yuan.liya@zte.com.cn |

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| Id | ITU-ML5G-PS-019 |
| Title | 5G+AI (Smart Transportation) |
| Description | **Background:** Smart Transportation involve an amalgamation of sensor technology, control systems, navigation and safe driving algorithms, and other automated applications related to intelligent transportation technology. Control applications may include automated collections on tolls, traffic congestion control/fleet control and on-board multimedia device assisted systems. Safety analysis includes autonomous vehicle’s speed control, automated lane changing and curvature ahead, impending collision warning, blind spot alerts and dynamic route allocations. Automobile industry has been heavily driven by driver-less vehicles particularly with the advent of companies like TESLA. They are now looking at high end support L3/L4 support in advanced ADAS.The Smart transportation is focused on the research and development of automobiles, which particularly employ vehicle-to-vehicle communication, vehicle-to-environment communication, in-vehicle and out-vehicle analysis in real-time and real-time recommendation required for system assisted driving. The research encompasses the following focus areas:* V2V and V2I Communication
* Underwater UAVs / Aerial UAVs
* IoT / Sensor Technology for Advanced ADAS
* Co-operative Autonomous Systems
* AI/ML for ADAS
* Embedded Deep Learning

Such applications will have a significant impact on the automobile industries, heavy vehicle electronic manufacturers, MoRTH, Ministry of Urban Development and National Highway Authority of India.**Indian Scenario:**Due to the heterogeneous nature of traffic and unstructured road conditions leads to chaotic driving scenarios. The unstructured road conditions are due to rugged terrain and potholes. Further to add on, the chaotic conditions prevalent is owing to the unmarked, or incomplete or disoriented road signs, varying traffic densities, different environmental conditions includes foggy or rainy or bad weather conditions, unpredictable behavior of traffic agents (pedestrians, cyclists, vehicles, etc.), high intra-class variability in vehicle types.Nowadays intelligent driver assistance systems consist of LiDARs, on-board diagnostic sensors, RADARs, proximity sensors etc., but these are not alone sufficient to avoid impending collisions in chaotic driving scenarios like in India. Thus, an ideal solution would be to have communication between vehicles to supplement data from these on-board sensors and alert the drivers about any anomalous driving conditions. **Problems:** * P1: Intelligent Vehicles for unstructured environments: To develop an autonomous or semi-autonomous vehicle with ADAS capabilities. It is built on the on-board vehicular sensors capable of performing i) Road scene understanding in unstructured environments, ii) Semantic labelling, object detection and recognition in complex road scenes and iii) Driver Activity Monitoring in chaotic environments.
* P2: Design and development of robust and real-time systems for IV and ITS in unstructured driving conditions: It is able to use emerging sensors (e.g., multi-spectral, RGB-D, LIDAR and LADAR) and sensor fusion for IV and ITS in unstructured environments and generate real time warnings or recommendations/decision making using edge analytics. It is able to broadcast the messages about the road conditions or accidents ahead to close proximity vehicles.

**Submitting:**Submission of works Our competition schedule is divided into two stages: Phase I and Phase II. The two stages need to submit different competition works. |
| Challenge Track | 1 |
| Evaluation criteria | **Phase I：**

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| --- | --- |
| Project ( full mark: 50) | Evaluation Standard |
| Description of the project(10 marks) | 1. Clarity of problem Statement
2. Usability/Motivation
3. Challenges
4. Milestones to be achieved
5. How 5G and AI is being used in solution.
6. End User Details
 |
| Requirements analysis and methodology(15 marks) | 1. Clarity in goals to be achieved
2. Use case diagram/Flow chart
3. Architecture Diagram
4. Clarity in Methodology outline
5. System Design
6. Datasets Used
 |
| Evaluation Setup & Timeline(10 marks) | 1. Clarity in Metrics to be used

(Quantitative and Qualitative)1. Pert Chart
2. What kind of solution is developed? Web app/Mobile App/Algorithm
 |
| Team Dynamics (5 marks) | 1. Clear outline on work division
2. What are the key strengths of team members
 |
| Relevance with Indian automotive industry(10 marks) | How the solution can benefit in a large scale automotive Industry? |
| Total | 50 marks |

**Phase II：**

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| Project ( full mark: 50) | Evaluation Standard |
| Report+PPT(10 marks) | Detailed report giving: i) Problem Statement, ii) Motivation, iii) Challenges, iv) Milestones achieved, v) Methodology: System Design, Flow Chart, vi) Results and Discussion vii) Conclusion |
| DEMO completion (40 marks) | Demonstratable solution: Component of 5G is must. Points to take care: Feasibility, scalability and usability (ease of use), Could be a web app/mobile app meeting industry requirements and an integrable solution. |
| Total | 50 marks |

 |
| Data source | A participant may be required to take permission to use this data-set (in case permission is required) and give due credits to the community hosting it. For train and test split use the standard split given in respective data sources else keep it as 7:3.<https://insaan.iiit.ac.in/datasets/><http://www.cvlibs.net/datasets/kitti/><https://bdd-data.berkeley.edu/><https://www.kaggle.com/c/state-farm-distracted-driver-detection> |
| Resources | Use Collab or Google Credit Points or any other available free cloud resources. |
| Any controls or restrictions | This problem statement is open to all participants. |
| Specification/Paper reference (in Indian context) | [1] [Girish Varma](https://geevi.github.io/), [Anbumani Subramanian](https://insaan.iiit.ac.in/publications/), [Anoop Namboodiri](https://insaan.iiit.ac.in/publications/), [Manmohan Chandraker](https://insaan.iiit.ac.in/publications/) & [C V Jawahar](https://insaan.iiit.ac.in/publications/) - *IDD: A Dataset for Exploring Problems of Autonomous Navigation in Unconstrained Environments* - IEEE Winter Conf. on Applications of Computer Vision (WACV 2019)[2] [Sudhir Kumar Reddy](https://insaan.iiit.ac.in/publications/), [Girish Varma](https://geevi.github.io/) & [C V Jawahar](https://insaan.iiit.ac.in/publications/) - *Cityscale Road Audit System using Deep Learning* - International Conference on Intelligent Robots (IROS’18)[3] Wen, L., Zhu, P., Du, D., Bian, X., Ling, H., Hu, Q., ... & Bo, L. (2019). VisDrone-MOT2019: The Vision Meets Drone Multiple Object Tracking Challenge Results. In Proceedings of the IEEE International Conference on Computer Vision Workshops (pp. 0-0).[4] Garg, N., Janveja, I., Malhotra, D., Chawla, C., Gupta, P., Bansal, H., ... & Lall, B. (2017, October). Poster: DRIZY: Collaborative Driver Assistance Over Wireless Networks. In Proceedings of the 23rd Annual International Conference on Mobile Computing and Networking (pp. 546-548).And many other papers in IEEE ITSS, IVS, CVPR, ICCV, ECCV, Ubicomp, Mobicom, Mobihoc etc. |
| Contact | **Email**preranam.jnu@gmail.com |

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| --- | --- |
| Id | ITU-ML5G-PS-020 |
| Title | Improving experience and enhancing impressiveness of Video conferencing and collaboration  |
| Description | Future communication networks are expected to support novel communication technologies such as multiple modalities based conferencing (an enhancement of video conferencing which is currently 3 modalities – speech, video and digital screen information). Multiple communication programs will co-exist with varying level of compression and representations. AI technologies are crucial to maintaining effectiveness of communication technologies involving multiple modalities and compression technologies over 5G networks. This challenge calls for methods and algorithms to improve perceptual effectiveness of enhanced communication techniques such as future video conferencing methods. Some possible communication approaches to assume are 3D holographic communication, real-time immersive communication (one to one and many to many video conferencing – e.g. attendees attending conferences virtually in an immersive environment). The high level definition of the problems are as follows.To improve perceptual impressiveness, algorithms need to be designed to communicate a person's peripheral characteristics and interaction with the surroundings to communicate important information related to the event. An example is in a teaching scenario, the interaction of the teacher with the whiteboard is captured.The challenge is to capture and represent people's visual appearance and interaction to communicate and present the information in its entirety.There are two specific challenges:1. In a(n) (informal) video conferencing scenario, the video we see is in animated format, however there can a tool on the speaker side to find out local context (dressing style, facial grooming, ambientlighting etc). and incorporate it in the rendering at the other end.2. In a teaching platform, again where we have animated rendering of the teacher and the board. here, the tool should mine the relative position (white board and teacher) and gestures (for emphasis e.g.) etc. and incorporate in the bit stream and render faithfully on the other side. |
| Challenge Track | Vertical – The submissions to this challenge have the potential to contribute to the important vertical of Immersive conferencing and collaboration. |
| Evaluation criteria |

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| **Criteria** |  **Evaluation** |
| **Description**(20 marks) | * Clarity of problem statement and comprehensiveness
* How well is the use of ML/AI brought out?
 |
| **Architectures and Methodology**(30 Marks) | * Completeness of requirement spec
* Clarity of architectures
* Innovation and Technical Strength of the methodology
 |
| **Implementation and performance evaluation**(35 marks) | * Creativity
* Quality of implementation
* Performances against specs criterion
 |
| **Value Adds**(15 marks) | * Any achievement beyond the scope
* Ability to interact within the team and outside
* Technical papers/ patents/ white papers: Potential of this work
 |
| **Total** | 100 marks |

Option-1: Predicting the QoE score. Evaluation based on accuracy of prediction.Option-2: Predicting the QoS parameters (network and buffer conditions). Evaluation based on accuracy of prediction.Option-3: Predicting the parameters of the client-based adaptation.  |
| Data source | Open data sources, e.g. <http://live.ece.utexas.edu/research/LIVE_NFLX_II/live_nflx_plus.html>(The participants can portion the entire data set into testing and training for evaluation. We will generate our own data to ensure fairness which would not be shared with participants.) |
| Resources |  |
| Any controls or restrictions | Open to all with no restrictions. |
| Specification/Paper reference | C. G. Bampis, Z.Li, I. Katsavounidis, TY Huang, C. Ekanadham and A. C. Bovik, “Towards Perceptually Optimized End-to-end Adaptive Video Streaming,” submitted to IEEE Transactions on Image Processing. |
| Contact | fauziyafarheen@gmail.com  |

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| ID | ITU-ML5G-PS-021 |
| Title | 5G+ML/AI (Dynamic Spectrum Access) |
| Description | **Background:**  Today, the motivation for dynamic spectrum access allocation is for spectrum sharing between LTE and 5G to make 5G roll out faster and less costly. Use of Generalised Frequency division Multiplexing (GFDM) for opportunistic cognitive waveform as brought out in [1] for such a scenario has been discussed often. It has been proposed in [2] that network slicing and QoS techniques can be used for mission critical radio access in 5G. However, it is expected that 5G systems would be capable of employing explosively scalable bandwidths for varying applications. Even though spectrum efficient schemes have been proposed to be deployed for 5G, the only way forward is to share the spectrum dynamically amongst users using cognitive approach. It has been shown in [3] that various strategies for spectrum and network resource sharing can be employed to get significant reduction in per user requirement. In [4] has been proposed to incorporate some degree of intelligence into the spectrum management process using a ‘Smart Spectrum Model’. The concept is to use historical as well as real time inputs to take decisions for utilizing spectrum spaces by utilizing a three layered viz “data”, “information” and “knowledge” model. The paper has carried out limited demonstrations to show improved performance at the physical layer for sensing spectrum utilization and taking a decision to either utilize an available free slot or to back off. It has been discussed in [5] that Machine Learning can be theoretically applied to most functions for 5G or Beyond 5G communications, however real world implementation of this would be costly, time consuming and complex and therefore it would take many more years to mature such approaches. **Concept:**   5G has been envisaged to incorporate varied applications for Mission critical, Machine to Machine and Device to Machine Applications. User patterns for usage are difficult to predict, however there can be certain relevant information which may be gainfully utilized to take decisions. Utilizing available windows of opportunity / white spaces in spectrum under these variable conditions would be a dynamic and a complex problem for spectrum allocation and sharing. It would require a homogenised approach where the UEs as well as the Networks cooperate with each other and follow certain common protocols.Example: The UE and the network learn the user behaviour and cumulatively and derive intelligent inputs such as * expected spectrum / resource demand
* available slack for immediate allocation
* spaces for free access advertised to UEs
* low latency and mission critical bands
* previous performance in these bands
* quality of spectrum spaces depending upon climatic conditions / locations
* special conditions during disaster management for mission critical requirements

These inputs are utilised to take decisions for dynamic spectrum access and performance is evaluated concurrently. Accordingly a UE can be classified as ‘light’, ‘medium’, ‘heavy’ and network state can be classified as ‘available’, ‘limited’, ‘restricted’ for each band. Bands can be dynamically subdivided into ‘desirable’, ‘average’ and ‘not-desirable’. Decisions by the UE and the network to utilise spectrum can be based on such classifications which depend upon the data. **Problem:****Identification of Key variables for Dynamic Spectrum Access**: It is proposed to identify key variables for spectrum management in 5G / Beyond 5G under complex and dynamic conditions.**Propose a Framework using Key Variables:** and work out a demonstratable framework for spectrum utilization for 5G usage by using known machine learning approaches. The framework should preferably comply with existing 3GPP architecture (Release 15-17) while at the same time look at beyond 5G.* Data models (with comparison to O-RAN E2 messages, ONAP VES events)
* APIs in accordance with [ITU-T Y.3174]
 |
| Challenge Track | The problem could form a part of either the **Network Track** and **Enablers Track**.  |
| Evaluation criteria |

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| --- | --- |
| Criteria | Evaluation Standard |
| Description of the project(20 marks) | · Clarity of problem Statement· Usability/Motivation· Challenges for spectrum access· How ML/AI is being used in solution.· Proposed use cases |
| Requirements analysis and methodology(30 marks) | · Clarity in goals to be achieved· Use case diagram/Flow chart· Architecture Diagram· Clarity in Methodology outline· System Design· Datasets Used / Defined  |
| Evaluation Setup & Timeline(25 marks) | · Simulation Design· Results demonstrated· Clarity in deviation of results from expected theoretical framework. |
| Team Dynamics(10 marks) | · Clear outline on work division· What are the key strengths of team members |
| Relevance with(15 marks) | · How can the solution can benefit future 5G implementation?· Future work |
| **Total** | **100 marks** |

  |
| Data source | Participants would be required to extract datafrom a simulated 5G environment and use it to demonstrate performance objectives defined by them. |
| Resources | <https://www.3gpp.org/release-17><https://www.3gpp.org/DynaReport/38-series.htm><https://5g-lena.cttc.es/><https://github.com/nyuwireless-unipd/ns3-mmwave><https://github.com/shkrwnd/Deep-Reinforcement-Learning-for-Dynamic-Spectrum-Access> |
| Any controls or restrictions | This problem statement is open to all participants. |
| References | [1] R. D. F. Martin Danneberg, "Experimental Testbed for Dynamic Spectrum Access and Sensing of 5G GFDM Waveforms," IEEE, September 2014. [2] M. Höyhtyä et al., "Critical Communications Over Mobile Operators’ Networks: 5G Use Cases Enabled by Licensed Spectrum Sharing, Network Slicing and QoS Control," in IEEE Access, vol. 6, pp. 73572-73582, 2018. [3] M. W. L.Shang, "A survey of advanced techniques for spectrum sharing in 5G networks," IEEE wireless communications, vol. 24, pp. 44-51, Oct 2017. [4] Y. C. L. W. Jianzhao Zhang, "Spectrum Knowledge and Real-Time Observing Enabled smart spectrum Management," IEEE Access, vol. 8, 2020. [5] W. L. ME Morocho-Cayamcela, "Machine Learning for 5G/B5G Mobile and wireless Communications : Potential , Limitations, and Future Directions," IEEE Access, vol. 7, Sep 2019.  |
| Contact | **email**amit.oberoi@alumni.iitd.ac.in  |

|  |  |
| --- | --- |
| Id | ITU-ML5G-PS-022 |
| Title | Privacy Preserving AI/ML in 5G networks for healthcare applications |
| Description | **Background**: AI applied to healthcare looks very promising in future. Increase in smartphone penetration and high-speed networks such as 5G when combined with AI –based medical diagnostic techniques can help in mitigating the problems in the healthcare sector in developing countries. There are many rural and remote areas which lack medical diagnostic facilities. With 5G networks coming up, these areas are expected to get high-speed data connectivity. 5G-based enhanced mobile broadband can be useful for transmitting large medical data records (such as CT scans, MRI files) over the network. AI-based data modelling has already been used for a preliminary diagnosis of diseases such as tuberculosis (based on chest X-Ray scans), diabetic retinopathy (based on retina scans). There is a scope to use AI techniques to do a preliminary diagnosis in many other diseases as well. However, training AI-based models requires huge numbers of labelled patient data records. Further, for diseases prevalent in developing countries like India, adequate healthcare data in many cases is not available. To add to these problems, privacy of patient related healthcare data collected by medical practitioners is not only of utmost importance but has also become a regulatory compliance requirement in many countries. There has been some work done in anonymization of patient data records before the data records are used for AI-based data modelling. However, anonymization is not fool-proof as there is a possibility of re-creating anonymized data using correlated data. Another solution to this problem is to use Privacy-preserving AI/ML Techniques. The objective of such techniques is to use data for training the data model without compromising the privacy of the data.Following are some examples of Privacy-Preserving AI techniques:* Homomorphic Encryption
* Differential Privacy
* Secure Multi-party computation
* Federated Learning
* A combination of above

However, all these techniques have some limitations. Therefore, there is a lot of scope for innovation and improvisation in Privacy-Preserving AI techniques.**Problem Statement**:1. Design & Implement a suitable Privacy-Preserving AI Technique to share Patient Data Records available in multiple Distributed Patient Data Repositories and use the shared data to train a data model for medical diagnosis. This must be done without compromising the privacy of patient data records.
2. Host the trained data model on a web-server ensuring patient privacy is not compromised and implement REST APIs on the server for the purpose of inference from the trained data model
3. Implement an easy-to-use UI-based tool on a smartphone to do medical diagnostic inference for a patient by calling the REST APIs on the web-server

**Assumption**: Multiple Distributed repositories of labelled patient healthcare data are available. If a single repository is available then the participant can split the same into multiple repositories. Participants can choose any medical diagnostic problem for which the data is available in open-access. Some references are being provided below. Participants can use simulated data as well.**Significance of this problem solution to IMT-2020 networks and ITU:**With IMT-2020 networks, a solution to this problem shall help in designing better healthcare diagnostic systems using AI techniques without compromising on privacy of patient data records. This problem solution shall contribute towards UN’s SDG #3 related to Ensuring Health Lives and ITU’s objective to use ICT to impact the well-being of the society.**Submissions:**Participants need to submit:1. Design document showing the reasons for the choice of privacy-preserving technique and the network architectural components.
2. Source code for the implementation of the privacy-preserving design across various architectural components.
3. Tested code and Test Report for all implementations- Implementations of Privacy-Preserving AI Technique, Trained Data Model, UI on smartphone.
4. A Video of the demonstration of Proof-of-Concept.
 |
| Challenge Track | Social-Good-track because the problem solution shall contribute towards United Nation’s Sustainable Development Goal #3 related to “Ensuring Health Lives and promote well-being for all at all ages” |
| Evaluation criteria | Justification of selection of a particular privacy-preserving AI technique and how it ensures privacy protection: 20 marksInnovation in improvisation of an existing privacy-preserving AI technique: 20 marksEase of use of smartphone-based inference tool: 20 marksDemonstration of scalability of the solution: 20 marksDegree of Privacy-Protection & Security offered to patient data records and data models: 20 marks |
|
| Data source | These data sources are just for example. It is not mandatory to use these in the Problem Solution. A participant may be required to take permission to use this data-set (in case permission is required) and give due credits to the community hosting it.<https://www.kaggle.com/raddar/chest-xrays-tuberculosis-from-india><https://www.kaggle.com/raddar/tuberculosis-chest-xrays-shenzhen><https://www.kaggle.com/raddar/tuberculosis-chest-xrays-montgomery><https://ieee-dataport.org/documents/automation-and-analysis-chest-x-ray-and-microscopy-images-tuberculosis-detection-0><https://www.kaggle.com/tanlikesmath/diabetic-retinopathy-resized><https://www.tensorflow.org/datasets/catalog/diabetic_retinopathy_detection>[https://ieee-dataport.org/open-access/indian-diabetic-retinopathy-image-dataset-idrid](https://ieee-dataport.org/open-access/indian-diabetic-retinopathy-image-dataset-idrid#_blank) |
| Resources | These resources are just for example. It is not mandatory to use these in the Problem Solution. A participant may require to take permission to use these resources (in case permission is required) and give due credits to the community hosting it. Participants are encouraged to make use of any open source resources.[https://wiki.lfai.foundation/display/EDL/EDL+Home](https://wiki.lfai.foundation/display/EDL/EDL%2BHome)<https://github.com/Microsoft/SEAL><https://palisade-crypto.org/> |
| Any controls or restrictions | * This problem statement is open to all participants.
* The source code offered in the solution to this problem should be available as open source with license to use, enhance and distribute further.
 |
| Specification/Paper reference | These references are just for example. It is not mandatory to use these in the Problem Solution. A participant using these references should give due credits to the community hosting it.<https://github.com/bargavj/distributedMachineLearning><https://towardsdatascience.com/perfectly-privacy-preserving-ai-c14698f322f5><https://www.microsoft.com/en-us/ai/ai-lab-he> |
| Contact | E-mail: prashantchugh1234@gmail.com  |

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| Id | ITU-ML5G-PS-023 |
| Title | Shared Experience Using 5G+AI (3D Augmented + Virtual Reality) |
| Description | **Background:** VR can help realize the utopian environment where distance disappears and we interact as richly with friends, family, and colleagues around the world as we do with those around us.This could also allow us to have natural interactions with those who cannot travel to meet physically. In order to create such rich experiences, there are certain challenges we need to overcome. The alienation that many of us already observe in connection with smartphones and the social fabric is only made more acute by a technological experience that fully absorbs our senses and that significantly reduces our ability to communicate directly with those near to us. Working out the obstacles to a truly shared experience is perhaps the most important challenge confronting virtual technologies and their broader cultural acceptance.**Problem Statement :**1. Design a 3D Augmented + Virtual Reality based Immersive shared experience between friends for themes including but not limited to:
* Birthday Party
* Watching Cricket / Games
* Tourist site visit
	+ Monument visit: Taj Mahal
	+ Hill station visit: Rohtang Pass
	+ Activity such as paragliding

**Target:*** Shared experience creation with interactivity
* Content curation: personalized and dynamic

**Data Provided to the Contestants*** Animate Model such as UMA-2 in Unity
* Videos (360 degrees) of the experience / tourist site

**Deliverables specification :*** Participants need to submit the documents showing flow charts and high level model/pipelines architecture.
* Source Code of the implementation containing VR/3D based models to create shared experiences.
* Tested code and test report of all implementations - Containing source code, Software tools, AI models.
* Videos of demonstration for Proof of Concept.

**Submitting:**Submission of works Our competition schedule is divided into two stages: Phase I and Phase II. The two stages need to submit different competition works.  |
| Challenge Track | Vertical-track (invite participant to make solutions for AI+5G applications for shared experiences based on 3D + Virtual Reality) |
| Evaluation criteria | **Phase I：**

|  |  |
| --- | --- |
| Project ( full mark: 50) | Evaluation Standard |
| Description of the project(10 marks) | 1. Clarity of problem Statement
2. Usability/Motivation
3. Challenges
4. Milestones to be achieved
5. How 5G and AI is being used in solution.
6. End User Details
 |
| Requirements analysis and methodology(15 marks) | 1. Clarity in goals to be achieved
2. Use case diagram/Flow chart
3. Architecture Diagram
4. Clarity in Methodology outline
5. System Design
6. Datasets Used
 |
| Evaluation Setup & Timeline(10 marks) | 1. Clarity in Metrics to be used

(Quantitative and Qualitative)1. Pert Chart
2. What kind of solution is developed ? Web app/Mobile App/Algorithm
 |
| Team Dynamics (5 marks) | 1. Clear outline on work division
2. What are the key strengths of team members
 |
| Relevance with Indian Market (10 marks) | How the solution can benefit in scaling shared Experiences in indian market? |
| Total | 50 marks |

**Phase II：**

|  |  |
| --- | --- |
| Project ( full mark: 50) | Evaluation Standard |
| Report+PPT(10 marks) | Detailed report giving: i) Problem Statement, ii) Motivation, iii) Challenges, iv) Milestones achieved, v) Methodology: System Design, Flow Chart, vi) Results and Discussion vii) Conclusion |
| DEMO completion (40 marks) | Demoable solution: Component of 5G + AI + AR/VR is must. Points to take care: * Interactivity in shared experience
* Quality of shared experience
* Fidelity of the curated content
 |
| Total | 50 marks |

 |
| Data source | 1. <https://www.airpano.com/360photo/Taj-Mahal-India/>
2. <https://www.youtube.com/playlist?list=PL-KnbPtxpFMwOTINzu45aLJxHl8Fmhoh4>
3. <https://www.youtube.com/watch?v=OR_Y7vj66PU>
4. <https://www.youtube.com/watch?v=7bD6xR8pAO4>
5. <https://3d.bk.tudelft.nl/opendata/>
 |
| Resources | Not needed |
| Any controls or restrictions | This problem statement is open to all participants. |
| Specification/Paper reference (in Indian context) | 1. Deepali Aneja, Daniel McDuff, Shital Shah,A High-Fidelity Open Embodied Avatar with Lip Syncing and Expression Capabilities
2. Misha Sra,Aske Mottelson,Pattie Maes: Your Place and Mine: Designing a Shared VR Experience for Remotely Located Users
3. Liszio, Stefan & Masuch, Maic. (2016). Designing Shared Virtual Reality Gaming Experiences in Local Multi-platform Games. 10.1007/978-3-319-46100-7\_23.
4. CVPR Workshop on Computer Vision for Augmented andVirtual Reality
5. W3C workshop on web and virtual reality.
6. Ran Yi, Zipeng Ye, Juyong Zhang ,, Hujun Bao, Yong-Jin Liu :Audio-driven Talking Face Video Generation with Learning-based Personalized Head Pose
7. Varun Jain, Shivam Aggarwal,Suril Mehta,Ramya Hebbalaguppe: Synthetic Video Generation for Robust Hand Gesture Recognition in Augmented Reality Applications
 |
| Contact | **Email -** neerajku@hike.in, ankur@hike.in |

# 5. Resources

NOTE 1- the structure of the list below is intentionally kept simple for our partners to easily add or change it. The structure is as below:

<<type of resource: 1-line description, link, contact>>

NOTE 2- this list is in no specific order.

[RayMobTime] Data set: Raymobtime is a collection of ray-tracing datasets for wireless communications. <https://www.lasse.ufpa.br/raymobtime/>, aldebaro@ufpa.br

[CUBE-AI] ML marketplace: It is an open source network AI platform developed by China Unicom Network Technology Research Institute, which integrates AI model development, model sharing. <https://github.com/cube-ai/cubeai> , liutf24@chinaunicom.cn

[Adlik] Toolkit: an end-to-end optimizing framework for deep learning models. <https://github.com/Adlik/Adlik> , yuan.liya@zte.com.cn

[KNOW] Challenge platform: a data challenge platform which lists several challenges and competitions. <https://knowledgepit.ml/>

[SE-CAID] Data sets: An open AI research and innovation platform for networks and digital infrastructures for industries, SMEs and academia to share a broad range of telecom data and AI models. <https://se-caid.org/>

[AIIA] Challenge: past competition, led by AIIA in China <https://cloud.tencent.com/developer/contest/AIIA-Unicom>

<http://aiiaorg.cn/AIDC/2019AIDC/index.html>

<https://mp.weixin.qq.com/s?__biz=MzU0MTEwNjg1OA==&mid=2247487451&idx=1&sn=cb4370e9fa9d7f827dc632c79fe41d2d&chksm=fb2fb81ecc583108221592c69fdea3eb226da933859514dbd9fb8c15288c6fcb392c65399ddc&mpshare=1&scene=1&srcid=&sharer_sharetime=1575542631509&sharer_shareid=75fb4d5f665341fa1dafcbc554417e75&key=67a2c7aa29623c33d72ba777f7853d102e6f4db8ac8b23733613e267ce0dae54ca817de36bde651b3cf32c3a0daf055c432e46c3b8f43b088f60edcdef801a54201eea05d0de9051201391ee19fd326f&ascene=1&uin=MjEzNjY3NDQ5Mw%3D%3D&devicetype=Windows+7&version=62070141&lang=en&exportkey=AoB%2BIuWyreUPRCOzxdLg0q0%3D&pass_ticket=fCmC%2FiTFfXlmGxvOLq%2BdVPRElGBj59sZO2eVMyeABxg07Ve7tOfmRWTtKc1rmCRV>

[DuReader] Challenge: past competition, includes data sets, including the largest Chinese public domain reading comprehension dataset, DuReader <https://www.kesci.com/home/competition/5ad56e667238515d80b53704>

[IUDX] Data and challenge: a research project for an open source data exchange software platform, <https://www.iudx.org.in/>

[PUDX] Past challenge, Datathon  to develop innovative solutions based on India Urban Data Exchange ([IUDX](https://www.iudx.org.in/)), <https://cps.iisc.ac.in/pudx/>

[TI-bigdata] Data: a large dataset of 30+ kinds of data (mobile, weather, energy, etc. from Telcom Italia big data challenge. <http://theodi.fbk.eu/openbigdata/>

[TI-phone] Data: The Mobile phone activity dataset is a part of the Telecom Italia Big Data Challenge 2014. <https://www.kaggle.com/ijfezika/mobile-phone-activity-exploratory-analysis>

[MDC] Data: Mobile Data Challenge (MDC) Dataset,  restricted to non-profit organizations, <https://www.idiap.ch/dataset/mdc> (you need to make a request to get a copy)

[MIRAGE] Data: MIRAGE-2019 is a human-generated dataset for mobile traffic analysis with associated ground-truth, <http://traffic.comics.unina.it/mirage/>

[Urban-Air] Data: An air quality dataset that could be useful for verticals <https://www.microsoft.com/en-us/research/project/urban-air/>

[UCR] Data: UCR STAR is built to serve the geospatial community and facilitate the finding of public geospatial datasets to use in research and development. <http://star.cs.ucr.edu/>

[NYU] Data: NYU Metropolitan Mobile Bandwidth Trace, a.k.a. NYU-METS, is a LTE mobile bandwidth dataset that were measured in New York City metropolitian area; <https://github.com/NYU-METS/Main>

[Omnet] Data: Challenge and dataset from comes from Omnet++ network simulator, contains several topologies and thousands of labeled routings, traffic matrices with the corresponding per-flow performance (delay, jitter and losses). <https://bnn.upc.edu/challenge2020>

[GNN] Data: data sets for Unveiling the potential of GNN for network modeling and optimization in SDN. This data set can be divided in two components: (i) the data sets used to train the delay/jitter RoutNet models and (ii) the delay/jitter RouteNet models already trained <https://github.com/knowledgedefinednetworking/Unveiling-the-potential-of-GNN-for-network-modeling-and-optimization-in-SDN/tree/master/datasets>

[Unity] <https://github.com/Unity-Technologies/ml-agents/>

[ETSI ARF] ETSI GS ARF 003 V1.1.1 (2020-03) Augmented Reality Framework (ARF); AR framework architecture <https://www.etsi.org/deliver/etsi_gs/ARF/001_099/003/01.01.01_60/gs_ARF003v010101p.pdf>

[TH\_COVID] COVID-19 Live Updates of Tencent Health is developed to track the live updates of COVID-19, including the global pandemic trends, domestic live updates, and overseas live updates. <https://github.com/Tencent/TH_COVID19_International>

[HW\_NAIE] NAIE Learning Service Telecommunication scenario AI training solutions, providing pre-consultation from now on. <https://www.hwtelcloud.com/>

[IBM\_COVID] IBM has resources to share — like supercomputing power, virus tracking and an AI assistant to answer citizens’ questions <https://www.ibm.com/covid19>

[FB-COVID] public data sets from Facebook Data for Good <https://dataforgood.fb.com/>

[GOOG\_COVID] Google Cloud COVID-19 public dataset program: Making data freely accessible for better public outcomes <https://cloud.google.com/blog/products/data-analytics/free-public-datasets-for-covid19>

**Appendix I: Academic papers of interest**

[1] ` "Very Long Term Field of View Prediction for 360-degree Video Streaming", Chenge Li, Weixi Zhang, Yong Liu, and Yao Wang, 2019 IEEE Conference on Multimedia Information Processing and Retrieval.

[2] "A Two-Tier System for On-Demand Streaming of 360 Degree Video Over Dynamic Networks", Liyang Sun, Fanyi Duanmu, Yong Liu, Yao Wang, Hang Shi, Yinghua Ye, and David Dai, IEEE Journal on Emerging and Selected Topics in Circuits and Systems (March 2019 )

[3] “Multi-path Multi-tier 360-degree Video Streaming in 5G Networks”, Liyang Sun, Fanyi Duanmu, Yong Liu, Yao Wang, Hang Shi, Yinghua Ye, and David Dai, in the Proceedings of ACM Multimedia Systems 2018 Conference (MMSys 2018),

[4] “Prioritized Buffer Control in Two-tier 360 Video Streaming”, Fanyi Duanmu, Eymen Kurdoglu, S. Amir Hosseini, Yong Liu and Yao Wang, in the Proceedings of ACM SIGCOMM Workshop on Virtual Reality and Augmented Reality Network, August 2017;

[5] Rusek, K., Suárez-Varela, J., Mestres, A., Barlet-Ros, P., & Cabellos-Aparicio, A, “Unveiling the potential of Graph Neural Networks for network modeling and optimization in SDN,” In Proceedings of ACM SOSR, pp. 140-151, 2019. [[ACM SOSR](https://dl.acm.org/doi/abs/10.1145/3314148.3314357)] [[arXiv](https://arxiv.org/pdf/1901.08113.pdf)]

[6] Source code and tutorial of RouteNet. (URL: <https://github.com/knowledgedefinednetworking/demo-routenet>)

[7] 5G MIMO Data for Machine Learning: Application to Beam-Selection using Deep Learning, 2018 - http://ita.ucsd.edu/workshop/18/files/paper/paper\_3313.pdf

[8] MmWave Vehicular Beam Training with Situational Awareness by Machine Learning, 2018 - https://ieeexplore.ieee.org/document/8644288

[9] LIDAR Data for Deep Learning-Based mmWave Beam-Selection, 2019 - https://ieeexplore.ieee.org/document/8642397

[10] MIMO Channel Estimation with Non-Ideal ADCS: Deep Learning Versus GAMP, 2019 - <https://ieeexplore.ieee.org/document/8918799>

[11] Barrachina-Muñoz, S., Wilhelmi, F., & Bellalta, B. (2019). Dynamic channel bonding in spatially distributed high-density WLANs. *IEEE Transactions on Mobile Computing*.

[12] Barrachina-Muñoz, S., Wilhelmi, F., & Bellalta, B. (2019). To overlap or not to overlap: Enabling channel bonding in high-density WLANs. *Computer Networks*, *152*, 40-53.

[13] Barrachina-Muñoz, S., Wilhelmi, F., Selinis, I., & Bellalta, B. (2019, April). Komondor: a wireless network simulator for next-generation high-density WLANs. In *2019 Wireless Days (WD)* (pp. 1-8). IEEE.

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