International Photonics & Electronics Committee

# Technical Requirements of Intelligent Maintenance for Optical Network

IPEC-IM-O&M-IA V1.0

IPEC Network Requirement WG
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# Technical Requirements of Intelligent Maintenance for Optical Network

**Version 1.0**

**Date Approved**

**Nov. 15, 2024**

**Implementation Agreement created and approved**

**IPEC**

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# Technical Requirements of Intelligent Maintenance for Optical Network

## Summary

This project addresses the benefit of introducing AI technology in optical network maintenance. It will specify basic functional requirements, interface requirements, reference architecture and requirements of intelligent maintenance for optical network, which is an important step as a start for standardizing intelligent maintenance in the scope of optical network.

## Keywords

AI, optical network, intelligent maintenance

**Working Group:** **Network Requirement**

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**TITLE:** **Technical Requirements of Intelligent Maintenance for Optical Network**

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**SOURCE:** **TECHNICAL EDITOR**

Name: Yi DING

Company Name: China Telecom

Email: dingy12@chinatelecom.cn

**SOURCE:** **TECHNICAL EDITOR**

Name: Qian HU

Company Name: China Telecom

Email: huqian@chinatelecom.cn

**SOURCE: TECHNICAL EDITOR**

Name: Ming WEI

Company Name: FiberHome

Email: mwei@fiberhome.com

**SOURCE: TECHNICAL EDITOR**

Name: Zhiyong HU

Company Name: FiberHome

Email: huzy@fiberhome.com

**WORKING GROUP CHAIR**

Name: Hao LIU

Company Name: China Telecom

Email: liuhao3@chinatelecom.cn

## List of Members

The following companies were members of this project at the release of this specification:

| Company | |
|---|---|
| Accelink Technologies Co., Ltd. | China Academy of Information and Communications Technology |
| China Telecommunications Corporation | FiberHome Telecommunication Technologies Co., Ltd |
| Huawei Technologies Co., Ltd. | ZTE Corporation |

## Document Revision History

| Rev | Date | Description |
|---|---|---|

| | | |
|---|---|---|
| D0.1 | 2022-9-16 | The initial baseline of this IA. |
| D0.2 | 2023-3-10 | Add Intelligent traffic prediction |
| D0.3 | 2023-7-6 | Add OSNR prediction and SRLG optimization<br>Update the baseline. |
| D0.4 | 2023-9-22 | Add service intelligent configuration and intelligent cutover scheduling |
| D0.5 | 2024-7-23 | Update Section 8.2 intelligent prediction of optical component failure, Section 8.7 intelligent power saving of equipment, Section 8.8 intelligent Pre-warning for cable breakage-proof, and editorial changes and editorial correction. |
| D1.0 | 2024-10-20 | Final Draft D1.0. |
| V1.0 | 2024-11-15 | Publication of this IA. |

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# 1 Introduction

This specification will specify standards by introduce AI technology in Maintenance of Optical Network.

## 1.1 Scope

Application of AI technology to Optical Network maintenance is still at the beginning stage, though it has been applied in many industries field. By introducing AI to Optical Network maintenance， Data collection from massive data and correlation analysis can be proceed intelligently, which will assist to solve the problem of low efficient by manual maintenance of Optical Network and reducing maintenance cost for network operators. This document will specify the general architecture, functional requirements, and interface requirements for intelligent maintenance of optical network.

## 1.2 Problem Statement

Optical network indicates a communication network that carries information with optical light, including general resources of optical cable and pipeline, Optical transmission network based on WDM technology, and packet transmission network combining IP with optical, such as MPLS-TP/MTN, etc. With the development of communication networks, in order to meet the increasing service requirements, network scale expansion, technical complexity and flexibility customer requirements became critical. All these have brought higher complexity and critical time limitation in maintenance. Operator maintenance of optical network are facing new difficulties and challenges.

Traditional optical network maintenance relies heavily on the knowledge and experience of the engineer. After engineers analysis the network alarm and the performance, the solution that may solve the problems is given, and then the solution will be performed manually. The procedure requires manual identification and analysis of large amount of seemingly irrelevant data, which depend highly on the knowledge and experience of engineer. There are many disadvantages: low efficiency, slow response, passive procedure, and cannot meet the requirement of users' experience. AI technology is urgently required to be introduced to the maintenance of optical network. Currently, the challenges and new requirements are as below:

1) Low efficiency in fault diagnosis: The traditional maintenance requires manual analysis of large amount of information, depend highly on engineer's knowledge and experience, replied too much on the experimental judgment. It has slow diagnosis and time consuming. Higher quality service carrier requirements need more efficient, end-to-end, and intelligent fault diagnosis.

2) Difficulty of performance prediction: including equipment performance, power consumption, network traffic and other indicators that affect network operation. Current maintenance methods cannot make accurate predictions and interventions in advance, and cannot process until performance degradation exceeds the limit or traffic is congested, which will affect the customer's service experience.

3) Complexity of service configuration: The traditional maintenance requires manually configuring service, which with complicated steps, low efficiency, slow response to customer service requirements, unable to provide a good

experience on demand and improve service competitiveness.

4) Difficulty of resource management: resource management of optical network is one of the key points, especially passive resource management. For example, manual management of optical cable resources, which is manually recorded, passive response, inaccurate information and low maintenance efficiency.

## 1.3 Project scope and Objectives

This document clarifies the functional requirements and data requirements to support AI applications by introduce AI for optical network maintenance. The scope of the project is the AI applications for optical network maintenance. The objective of the project is to establish functional and interface requirements specification of AI applications for the optical network maintenance, so that AI can empower maintenance, improve maintenance quality and efficiency. Including but not limited to:

1) Requirements for intelligent faults localization: Based on AI correlation analysis of multi-dimensional data, intelligently analyze the root cause, find the fault location, and provide self-processing solutions or maintenance suggestions based on expert knowledge.

2) Requirements for intelligent performance analysis: Based on AI learning of historical performance data of optical networks, performance trends can be scientifically predicted, warning of future performance degradation can be report automatically. To avoid performance degradation which affecting services, expert advice will be provided in advance and guide users to intervene

3) Requirements for intelligent service configuration: Based on the comprehensive analysis of network resources, network operation status and service requirements, routing strategies are selected for end-to-end services, optimal routes are automatically designed, business parameters are automatically configured, service configuration efficiency will be improved greatly.

4) Requirements for intelligent resources management: during this paper, resources refer to optical cable and its accessories resources, integrating various technologies, such as sensing, big data, GIS, etc., to realize intelligent management and rapid diagnosis of transmission resources.

5) Requirements for intelligence traffic prediction: based on the analysis of historical performance, correlation model between events and traffic variation can be established, so it is possible to predict future network traffic trends, report preventive warning of possible traffic congestion, and provide traffic balancing solutions or maintenance suggestions. It can instruct users to pre-intervene in advance.

6) Requirements for intelligent identification of SRLG: Based on the collection and analysis of common features of SRLG, intelligently identify and label SRLG. Operators can plan service routing reasonably, and avoid the risk of shared links.

The artificial intelligence applications in this document are only intended to illustrate some of the possible applications of AI in optical network maintenance. The list of applications is not exhaustive or final; there are many other possible applications and may be more research in the future.

The applications addressed in this document include:

Intelligent faults localization, Intelligent prediction of optical component failure, OSNR prediction, Intelligent traffic prediction, Intelligent detection and optimization of SRLG, Service intelligent configuration, Intelligent power saving of equipment, Pre-warning of cable breakage-proof.

## 1.4 Relationship to Other Industry SDOs

The project relates to SDN, ML and Transport technologies, therefore the following SDOs will be consulted in our work:

——ITU-T SG13, ITU-T FG-AN, ETSI, TMForum, OIF

| | | |
|---|---|---|
| ITU-T | Y.3170-series | • Define machine learning in future networks.<br>• Include architectural framework, use cases, data handling, evaluation methods of intelligence levels. |
| ITU-T | AN-O-013-R1 | • use cases for autonomous networks<br>• provides use case descriptions and indicates the basic set of possible requirements for each use case. |
| ETSI | ISG ZSM | • Define E2E automation network and service management.<br>• Include architectural, functional, operational requirements, architectural framework, solutions and management interfaces. |
| TMForum | AN (Autonomous Network Project) | • Define automated zero wait, zero touch, zero trouble network/ICT services.<br>• Include the definition of user stories, business architecture, technical architecture, and the definition of different levels of autonomous network. |
| OIF | Application of Artificial Intelligence to Enhanced Network Operations | • The whitepaper illustrates some of the possible applications of artificial intelligence to enhanced network operations.<br>• It identifies the functions, interfaces and associated data required to enable AI implementation. |

# 2 ARCHITECTURE

## 2.1 General architecture

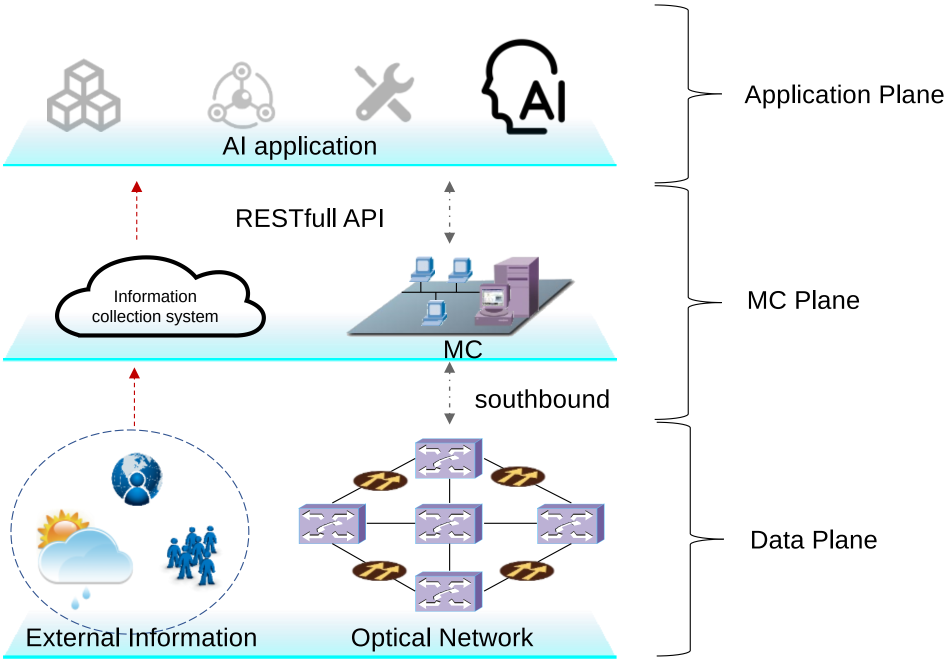


**Figure 1 Architecture of AI application in optical network maintenance**

This project defines the AI application architecture in optical network maintenance, as shown in Figure 1. The system consists of three planes: Data Plane, MC Plane, and Application Plane. Data Plane provides raw data, MC Plane collects data from Data Plane and sends the instructions received from AI Application Plane to Data Plane; Application Plane conducts AI analysis and training based on the data from MC Plane, and reports maintenance decisions or expert advice in diagnosis, prediction, planning and optimization to MC Plane or users.

## 2.2 Introduction of functional requirements in the architecture

### 2.2.1 Data Plan

- Transport resource:
  It's a collection of optical network resource, including network equipment, optical fiber and cable that form optical network. Transport resource provides basic data of the optical network, including topology, network elements, services, alarms, and performance.

- External information:
  It refers to external information (physical bureau geographic information, climate information, and user event information (such as meetings, social event, etc.)) that may affect the performance of optical network, as well as other external information provided to AI Application for intelligent analysis (such as experts knowledge and experience, instrumentation and other working parameters, etc.). Ex-information provides external data analyzed by AI, such as maintenance cases, geographic coordinates, weather forecasts, events, and other measurement data detected by external devices. It should be noted that external information is not required for

every application scenario, and only when the intelligent maintenance scenario requires external data as the reference for data analysis.

### 2.2.2 MC Plane

- Optical network Management & Control system

  The network management and control system of the optical network communicates with the transport network through the southbound interface, and collects static and dynamic parameters on the network, including topology, network elements, services, alarms, and performance. At the same time, the application plane sends the instruction, to the optical network to complete procedure.

- Information collection system

  There are various sources of external information, information collection system needs to collect various data for AI analysis from external systems, such as the geographic location of sites, activity and events of the optical network that affect network traffic.

### 2.2.3 Application Plan

The AI application plane analyzes and processes data from the MC Plane and decisions, solutions or expert suggestion. The AI application plane establishes various analysis models, such as performance prediction models, fault diagnosis models, etc., through clustering and correlation analysis of the input data, and continuously updates the rules through machine learning and intelligent decision-making to export instructions, Optimization plan or other suggestions to the optical network.

## 2.3 Interface requirements

### 2.3.1 Interface between MC Plane and Data Plane

Southbound interface can be adopted, the protocol or format to data can be OpenFlow, XML, SNCP, PECP. The interface should support the following data collection and delivery as below.

**Table 1 Data requirements for interface between MC Plane and Data Plane**

| Data | Description |
|---|---|
| Topology | NE logical connection |
| NE | NE site, slot, board, and port information |
| Service | Service routing, QoS, port, usage |
| Alarm | Alarm location, time, type |
| Traffic | TX traffic, RX traffic, average traffic, peak traffic |
| Performance | Voltage, IOP, OOP, bias current, temperature |
| Configuration instruction | Service and NE parameters export by MC system which can be identified |
| Other information | Other network data for AI analysis |

### 2.3.2 Interface between external event system and Information collection system

REST full API can support the diversity of external systems and collect necessary data. Generally, external events can also be input through XML data table. Information collection interface should satisfy the requirements as below:

**Table 2 Data requiremets for interface between External event system and Information collection system**

| Data | Description |
|---|---|
| Events | Events time, location GIS, event type |
| Weather forecasts | Occurrence time, location (GIS), type, etc. of abnormal climate |
| Measurement data | Graphics, values, and other data detected by external instruments |
| Processing data | Values from experience, or data from experiments for AI analysis |

### 2.3.3 Interface between AI Application and MC system

With REST full API interface, AI Applications collect data from MC system, report decision to MC system after AI analysis. The output data includes operation commands that can be recognized by the MC system and provide maintenance proposal or expert advises to users.

**Table 3 Data requirements for Interface between AI application and MC system**

| Data | Description |
|---|---|
| Configuration Command | network service parameters, configuration parameters, operation time which can be identified by MC system |
| Identification information | Identification of analysis conclusions, such as fault location information |
| Expert advice | Maintenance proposal or expert advice |

# 3 Requirements of Intelligent Maintenance in optical network

## 3.1 Requirements for intelligent faults localization

### 3.1.1 Overview

Fault diagnose is one of the most important operations for optical network maintenance. When a service failure occurs in optical network, for traditional manual maintenance, engineer cannot analyze, diagnose root causes and offer self-solving solution or expert advice as soon as possible by taking large-scale data such as alarms, performance, and status into consideration. Relying on manual determination, it is impossible to locate the root cause alarm from the massive alarms, and determine the root fault quickly and accurately. The diagnose accuracy is low and the duration is long.

Based on the rich experience accumulated by experts, AI is applied to optical network fault localization, and AI is used to analyze the correlation between alarms and find out the logic between network conditions and the root cause of the fault. The intelligent faults localization provides a method to realize intelligent fault localization, which can be used to locate the root alarm, find the fault location, and provide maintenance suggestions automatically, thereby improving the efficiency of operation and maintenance.

This application can support the following function: quick fault localization, fault simulation analysis.

### 3.1.2 Architecture

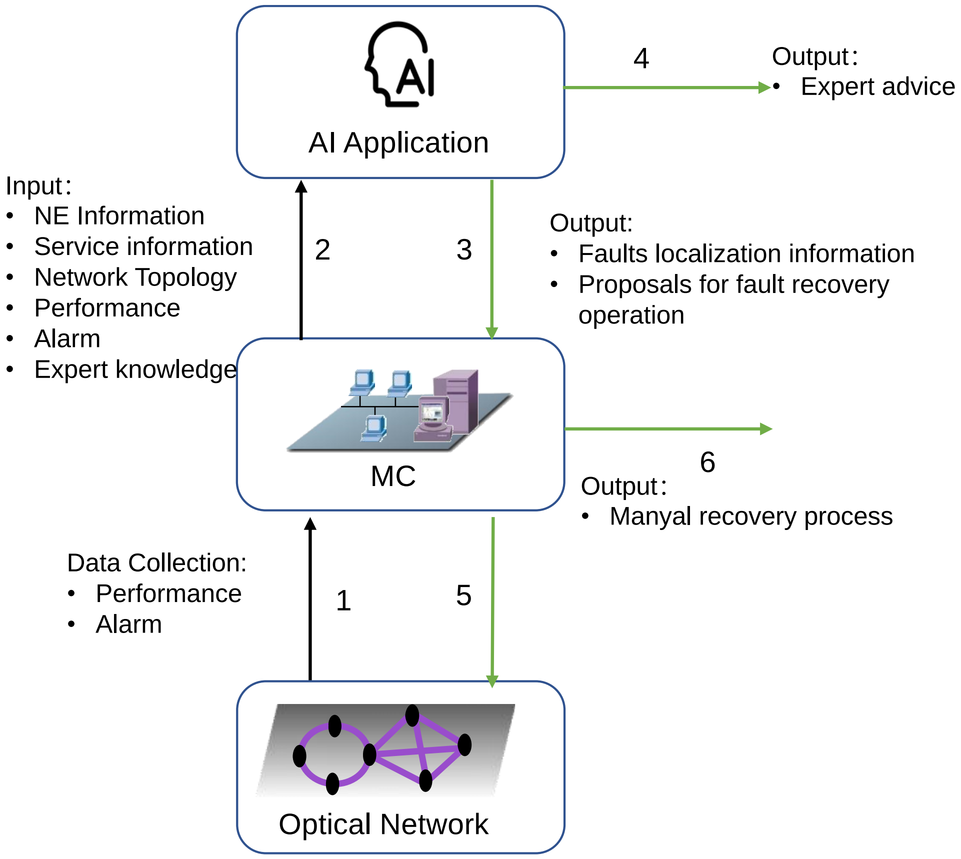


**Figure 2 Architecture of Intelligent faults localization**

Traditional optical network maintenance engineer analyzes the alarm and performance collected by the MC system with personal knowledge and experience, then make fault diagnosis conclusions. For this application, manual analysis will be replaced by AI analysis, which will realize dynamic and real-time quick analysis, combine many technologies of AI, such as knowledge graph learning, neural network, etc., AI can report relatively high-accuracy diagnosis conclusions and proposals.

The AI application in this application integrates the Data cleaning, classification, association and correlation analysis of the input data, also including other AI technologies, such as knowledge graph learning, etc. The decision-making function based on the above analysis. The decision-making of AI application makes decisions based on the analysis results, report fault localization and recovery instruction proposal to the MC system, or provides expert suggestions to maintenance staff.

### 3.1.3 Steps

Step 1 Data collection: MC system collects the performance and alarm data of the optical network through the southbound interface and stores it in the MC database.

Step 2 Analysis and decision：AI Application needs to contain data analysis function and fault handling and decision function. AI Application collects NE Information, Service Information, Network Topology, PM Date, Alarm Date and other data from the MC, by intelligently analysis and decision, AI application locate the problems of the failure, and offer solutions. The process in detail are as below:

1) Based on correlation of alarms and performance in time and location, AI Application clarify and associate fault alarms and performance, and filter invalid and duplicate data by multiple rounds data cleaning. Then AI application perform correlation analysis on the cleaned alarms and performance, learn and establish association rules between root alarms and derived alarms, and use various AI methods, such as knowledge graph learning, neural networks, etc., to locate root cause alarms.

2) AI Application provides fault recovery instructions or solutions by learning from the expert knowledge base, and decides to output operation instructions or maintenance suggestions: based on the analysis conclusion (the probability can be pre-set manually based on experience, and input as an external processing parameter) and AI Application can propose operation instructions (such as switching to redundant protection boards, restarting boards, etc.), then go to Step 3, output fault location information and operation instruction to MC; if the analysis conclusion is uncertain, or the AI Application cannot give a recovery instruction, then go to Step 4, propose a solution, or provide instruction for further analysis.

Step 3 Export fault recovery instruction: Based on the analysis results of Step 2, if the cause and location of the failure are certain, and the AI Application can output a recovery instruction, the failure cause and location information will be exported to the MC, then the operation instruction for failure recovery will be exported, and the MC operate engineer will receive the recovery instruction. The engineer will decide whether to execute it. If yes, then go to Step 5. Otherwise, the procedure will enter manual recovery process according the suggestion given by AI Application and go to Step 6.

Step 4 Export fault recovery proposal: Based on the results of Step 2, If the cause and location of the failure are not clear, nor AI application can offer recovery instruction, maintenance engineer will participate and offer fault recovery suggestions or further operation suggestions to recover failure.

Step 5 Execute automatic recovery operation: MC received failure recovery instruction from AI application, only when manually confirmed it works and it is safe, then the instruction will be forward to optical network equipment and executed.

Step 6 Execute recovery operation manually: If maintenance staff does not accept the recovery operation instruction exported in Step 3, then MC won't forward the instruction to optical network equipment, and the procedure will enter manual recovery process.

### 3.1.4 Functional requirements

R1-01: The interface between AI Application and MC should be authenticated and encrypted in two-way communication to ensure network security.

R1-02: AI Application should support labeling of input data (such as classifying alarms for association analysis), as supervisor of AI learning, improve the efficiency of establishing alarm rules.

R1-03: The network alarm and performance data output from MC to AI Application should include key elements such as time (occurrence, end, duration) and network resource location information (such as alarm location information, including NE ID, slot ID, and port ID). The AI Application should have the ability to capture alarms and performance data dynamically and automatically in a dynamic time window to support intelligent analyze the network status. The alarms and performance that need to be collected should support customize manual editing.

R1-04: The AI Application must support querying NE and adjacent port connections, which will help to dynamic generation and updates of the topology. At the same time, the AI Application must support the dynamic acquisition of service information from MC, including service routing, connection, and QoS parameters, service paths and key parameters calculated (such as service labels, QoS parameters, etc.).

R1-05: The AI application must support continuous rule learning on root alarm and derived alarm, support data cleaning on alarms, and identify key alarm sets which are helpful for fault diagnosis (that is, the remaining alarms after the filter of derivative alarms).

R1-06: AI Application must have the capacity of correlation analysis between alarms, performances, alarms and performances, alarm performances and services, alarm performance and topology. With other AI technologies (such as knowledge graph, neural network, etc.) logic between problems (fault alarm, performance, etc.) and results (fault cause, location, solution, etc.) can be identified, so it is for the root cause alarm and fault location.

R1-07: In order to provide cause analysis and get solutions for root alarms or failure, AI Application should have the ability to learn and update the expert knowledge base continuously.

R1-08: The AI Application needs to have the capability of decisions making based on the probability of fault location, the safety and operability of the operation to recover fault, that is, decide whether to provide MC with fault recovery instructions. AI should provide definite fault location information (including NE, slot, port, and alarm cause) and detail information of operation instruction (such as switchover and restart).

R1-09: When AI Application cannot provide operation instructions to recover the failure, it should provide suggestions to the maintenance staff, such as further analysis ideas, possible reasons, recommended experimental proposal, or other similar cases.

R1-10: For network security, the fault recovery instructions provided by the AI Application should not be forwarded directly to network and executed by MC, the maintenance staff should judge whether to execute the recovery instructions.

R1-11: AI applications should support automatic analysis which can be triggered by fault alarm events or manually by maintenance staff.

R1-12: The input and output of AI Application, clients of AI Application must support security access or interface security services, including service creation, deletion, and service status update.

## 3.2 Requirements for intelligent prediction of optical component failure

### 3.2.1 Overview

The performance of Optical components and optical modules, will gradually degrade over time until the components fail. How to effectively predict the failure trend of optical components using AI can guide maintenance staff to intervene in advance and improve network security. For traditional optical network operation and maintenance, it is not yet possible to accurately predict the life cycle and performance of optical components due to natural aging, working temperature and humidity, power supply current and other related factors.

Usually the corresponding resolution can be identified unless passively waiting for optical components failures.The degradation or failure of optical components performance is mainly due to the influence of internal components and external working environment. The life cycle trend of the optical component itself is mainly affected by bias current, operating temperature and humidity, dust pollution at the optical port, and electrostatic damage.

When introducing AI to predict the failure trend of optical components, it can establish a failure model based on multiple factors. Through self-learning and self-correction of actual operation data, more accurate predictions can be made for prediction.

AI application can support degradation and failure prediction of optical component performance, and simulation of optical component failure.

### 3.2.2 Architecture

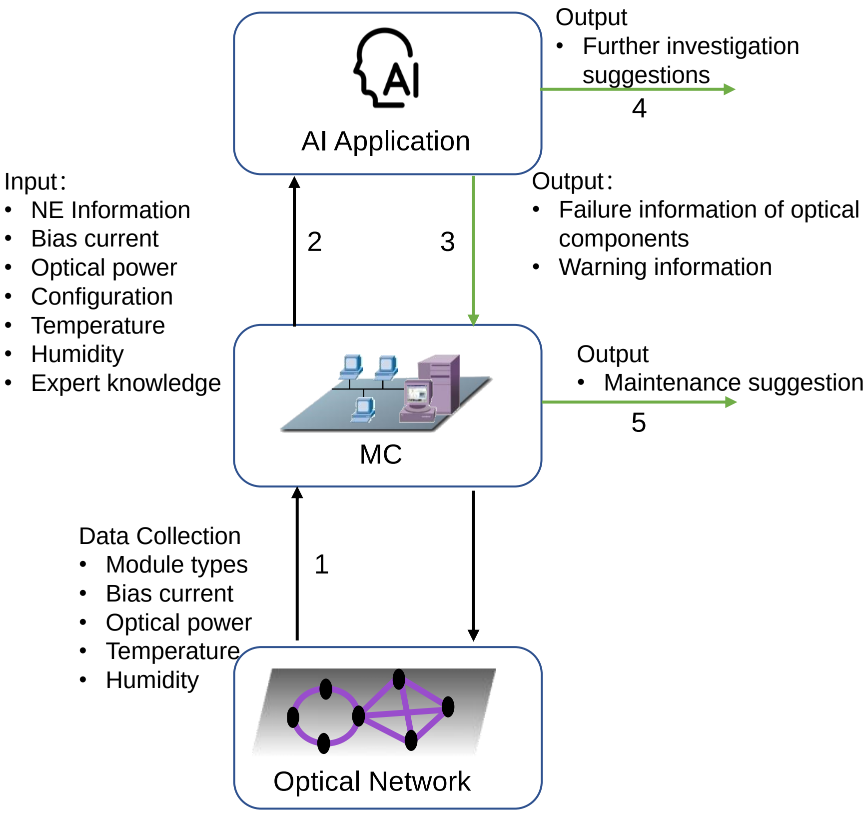

**Figure 3 Architecture of Intelligent prediction of optical component failure**

As shown in Figure 3, MC collects performance parameters of optical components, such as bias current, temperature, working duration, input optical power, output optical power, humidity. AI application will establish a degradation and failure model for optical components based on the above parameters, and continuously correct the model through detection of optical power and sensitivity. AI application will predict and warn the degradation trend of optical modules based on the AI model, and provide operation and maintenance suggestions. It can also simulate failure of optical components under some specific environment.

### 3.2.3 Steps

Step 1 Data collection ： MC collects performance parameters of optical components, such as module types, bias current, temperature, working duration, input optical power, output optical power, humidity.

Step 2 Analysis and decision: AI application can support data analysis and prediction. AI application get performance data from MC.

1) AI application can setup the performance degradation trend model and failure prediction model based on the performance parameters. It can provide early warning for potential performance degradation and failure events of detailed failure or component information that may affect network operation, such as NE location, slot, port, failure time.

2) Some maintenance suggestion can be provided to maintenance staff when AI application can analysis performance degradation trend.

If the analysis conclusion is within the allowable range of steady-state prediction deviation, AI application cat find the degraded or failed components that may affect the operation of the network, then it enters Step 3, and output specific component information and degradation threshold or failure time to MC; If the analysis conclusion deviates significantly from the steady-state prediction, such as being affected by external interference (such as external force damage), it goes to Step 4 and output further investigation suggestions.

Step 3 Output failure information of optical components: Based on the analysis results of Step 2, for situations which component degradation or failure prediction will affect network operation, specific warning information of the components (such as location, degradation, prediction time of failure, etc.) are output to MC.

After receiving the warning information, the maintenance staff will make decision of further operation and maintenance measures; For the impact of component degradation or failure, combined with expert experience, provide operation and maintenance suggestions, and go to Step 5.

Step 4 Output expert troubleshooting suggestions: Based on the results of Step 2, if there is a significant deviation between the predicting data and real-time data, and the component may be affected by external factor, output expert suggestions to update the model and guide maintenance staff for further troubleshooting.

Step 5 Output operation and maintenance suggestions: The maintenance staff enters the manual maintenance process for the operation and maintenance suggestions provided by the AI Application in Step 3.

#### 3.2.4 Functional requirements

R2-01: The interface between AI Application and MCS should be authenticated and encrypted, supporting tamper resistant bidirectional communication to ensure security.

R2-02: AI Application should support labeling of input data (such as types of optical components, rate, batch) for clustering analysis. Based on AI supervised learning, it can improve the alarm rules.

R2-03: AI application should support autonomous learning. The initial prediction model supports manual experience input. It should support intelligent classification of optical components based on the model as the main characteristic parameter and learn to update prediction models.

R2-04: The optical performance should have collection time stamp and location of optical component. For the environmental information, the time stamp and location are necessary. AI application should dynamically define collection time window of optical performance and environment performance. AI Application should also support getting parameters for analysis from external, such as testing instrument.

R2-05：AI application should setup the model to show the degradation of optical components based on the relation of multiple input and output parameters. The model can show the relation function of the degraded parameters like the life span, output power and receiving sensitivity affected by temperature, usage duration and current bias. AI application should support autonomous learning and updating the model according to the real-time optical performance for more accurate prediction.

R2-06: AI Application should support learning and updating knowledge base to provide maintenance suggestion to predict the risk of optical components.

R2-07: AI Application should support pre-warning of the failure of optical components based on alarming rules of aging data and threshold.

R2-08: If there are significant variant of performance data between prediction and collection data, AI Application should provide some suggestion to maintenance staff.

R2-09: AI Application should support automatic analysis of performance degrade and failure. It also should support proactively initiated predictive analysis through manual means at any time.

R2-10: AI Application should support secure web or API interface services for other client service for service creating, deleting and service updating.

### 3.3 Requirements for OSNR prediction

#### 3.3.1 Overview

For traditional optical network operation and maintenance, the OSNR cannot be predicted and can cause passively maintenance. On one hand, when the maintenance operations occurred to change the optical cable link (such as repairment of the optical cable breakage), the verification of OSNR and affection of services caused by the relevant operations cannot be automatically discovered; on the other hand, the verification of OSNR caused by aging of optical cable and components cannot be predicted in advance, so it is impossible to guide the maintenance engineers to take preventive measures.

When introducing AI into the OSNR prediction in optical network, it helps to eliminate network vulnerabilities in advance and reduce network risk to improve network availability based on configuration parameters and environment changes. Therefore, the intelligent OSNR prediction of optical network can predict the OSNR based on historical performance data and network configuration parameters. The prediction and decision results can be used to effectively eliminate network risks or evaluate the availability of system expansion.

### 3.3.2 Architecture

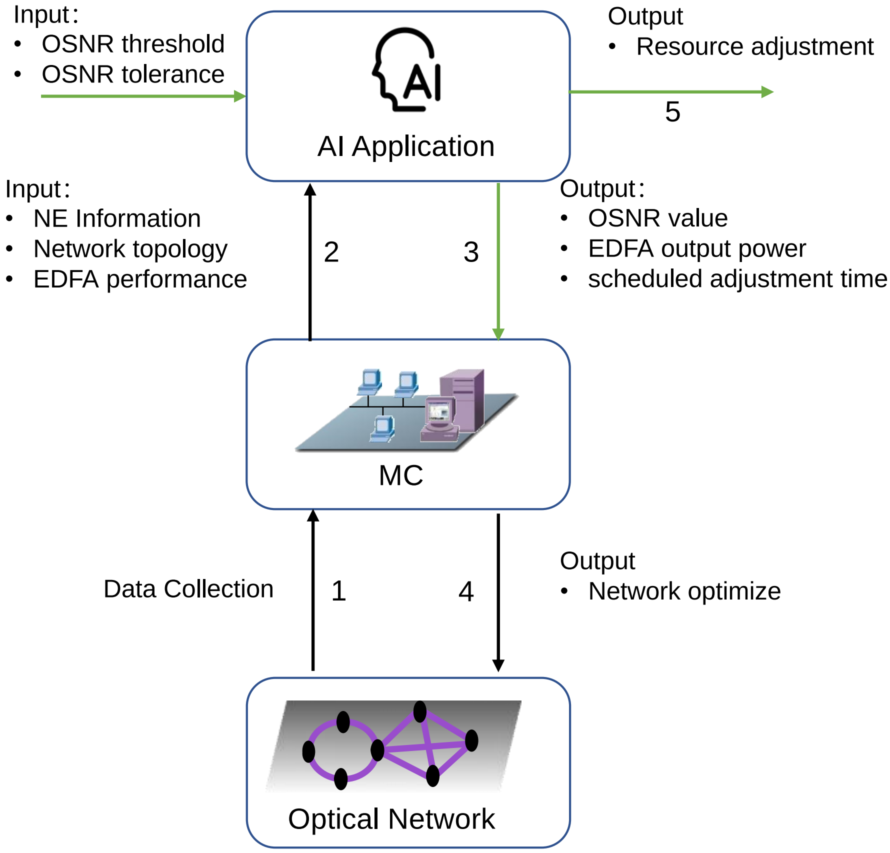


**Figure 4 Architecture of Intelligent OSNR Prediction**

Traditional optical network maintenance engineers analyze the performance data collected by MCS with personal knowledge and experience. When introducing AI to replace manual maintenance, the rapid and real-time result helps to predict and optimize the optical network. The AI application can send network optimize instruction to the optical network or provide optimize suggestion to maintenance engineers.

### 3.3.3 Steps

Step 1 Data collection: MC collects performance data of the optical network through the southbound interface and stores it in MCS.

Step 2 Analysis and decision making: MCS provides some data (such as topology information, NE information, EDFA performance) as input to the AI Application. At the same time, the processing parameters (such as the tolerable FEC error rate, combined with OSNR tolerance and OSNR threshold) are input into the AI application.

The AI application can predict future OSNR based on the intelligent analysis of the input historical performance and network configuration parameters.

The maintenance staff can get the OSNR prediction value to judge whether the VOA margin of EDFA can meet the requirements. The AI application can output optical power adjustment and resource adjustment suggestion (replacing cable, replacing amplifier, install new repeater, etc.). If the optical network can meet the adjustment requirement, then it goes to step 4. Otherwise, it goes to step 5.

Step 3 Output optimize suggestion: AI application outputs the adjustment period and target bandwidth for MCS, which can take some adjustment actions to optimize the optical network as shown in step 4.

Step 4 Network optimize action: The Management & Control system sends some optimize instruction to the optical network for adjustment action.

Step 5 Additional resource requirements: If there is new resource requirement for the optical network, the AI application outputs additional resource requirements in order to get expansions for the optical network.

### 3.3.4 Functional requirements

R3-01: The interface between AI Application and MCS should be authenticated and encrypted, supporting tamper resistant bidirectional communication to ensure security.

R3-02: The output from MCS to AI Application includes: network element information, topology, EDFA performance and parameters, FEC error rate, and other data.

R3-03: The network performance data output from MC to AI Application should have time stamp (occurrence, end, duration) and network resource location information (NE identification, slot identification, board identification, port identification). AI application should have dynamic and automatic configuration of time window for alarms and performance data to support AI analysis. EDFA parameters should include gain, gain range, noise figure, saturated output optical power, input optical power, output optical power, and other parameters.

R3-04: AI application must support querying NE and network port adjacency relationships from MCS to support dynamic generation and updates of network topology. AI can get service information dynamically from MCS.

R3-05: AI application can calculate OSNR degradation limitation and predict OSNR based on OSNR tolerance, tolerable FEC bit error rate.

R3-06: In order to get OSNR degradation limitation and network optimize solution, AI application can support the ability to continuously learning and updating expert knowledge base.

R3-07: Based on history performance, resource availability and operability, AI application can provide optimize suggestion and instruction. If the network resource can meet adjust requirements, MCS send optimization instructions to optical network, including NE, slot, port, adjust value, OSNR object value, EDFA objective power, adjustment time and other detail information.

R3-08: If the optical network cannot meet the resource adjustment requirement, AI application can provide suggestion to maintenance engineers (such as additional resource requirements, recommended experimental plan or recommended solution),

R3-09: Considering the network security, the optimize instruction provided by AI application cannot send to MCS and optical network directly. It should be evaluated by maintenance engineers.

## 3.4 Requirements for intelligent traffic prediction

### 3.4.1 Overview

With the accelerated development of digital transformation, network traffic has shown characteristics of explosive growth, high complexity and high burst. Therefore, accurate traffic prediction in intelligent optical networks is essential for network operators to realize dynamic resource allocation, predict traffic abnormal conditions, and improve the quality. The traditional operation & maintenance methods cannot detect traffic variant influenced by date, geography site, service type and social event. It's difficult to predict and optimize the bandwidth to avoid traffic congestion. Manual traffic control is time consuming and not real-time traffic balance.

Intelligent network traffic prediction can provide a way to predict Ethernet network traffic in Ethernet layer over OTN in the future just based on historical traffic data and related topology information, network element information and service bandwidth. Prediction and decision results can be used to expand and adjust bandwidth of optical network equipment. At present, there is extensive research on traffic prediction algorithms in the industry. But there is still a lack of general flow for traffic prediction and application in the intelligent process of optical networks.

### 3.4.2 Architecture

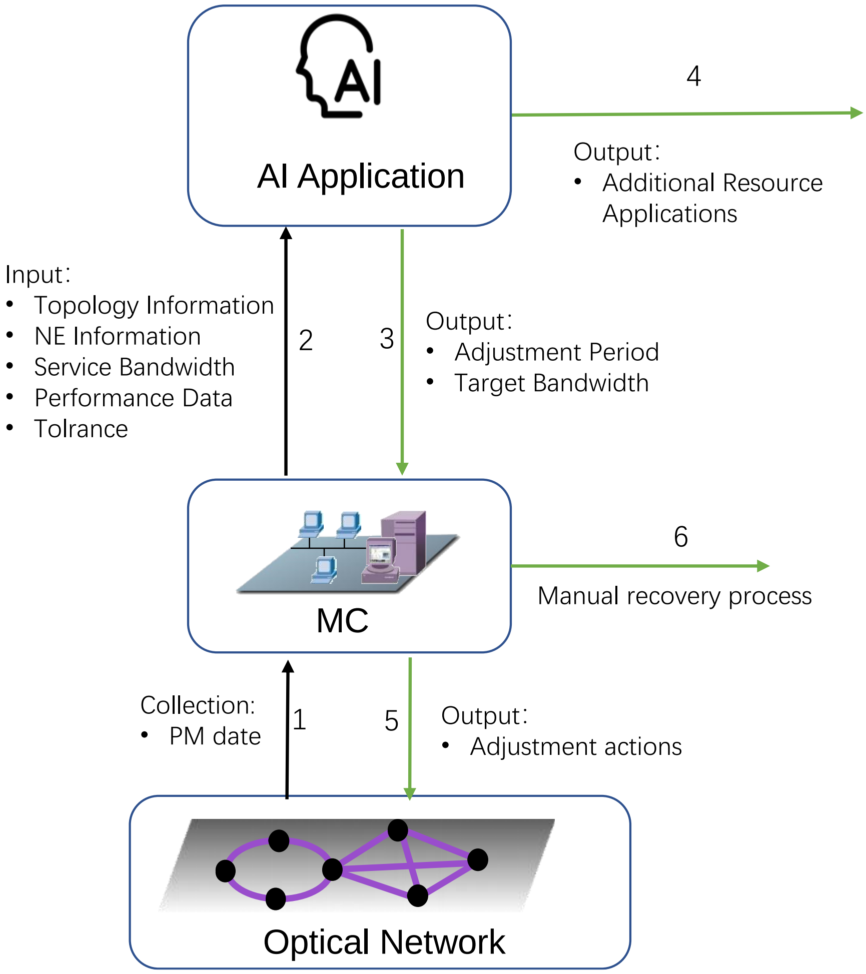


**Figure 5 Architecture of Intelligent Traffic Prediction**

Traditional optical network maintenance engineers perform the expansion or adjustment actions when the traffic has exceeded the service bandwidth. It will result in poor user experience. For this application, manual analysis will be replaced by artificial intelligent (AI) prediction, which will realize automatic and real-time traffic prediction. It will combine many technologies of AI, such as reinforcement learning, neural network, etc., AI can report relatively high-accuracy traffic prediction.

### 3.4.3 Steps

Step 1 Performance data collection: MCS collects the performance data of the optical network through the southbound interface and stores it in the MCS database.

Step 2 Input data collection: Data including performance data, configuration information (topology information, network element information, service bandwidth) and tolerance is input into AI application.

Step 3 Traffic Prediction: The AI application module provides the prediction results, including the predicted traffic data. The conclusion of bandwidth adjustment or additional resource application is drawn based on the predicted traffic data. The predicted target network bandwidth is calculated by predicted traffic data and tolerance. If the available network resource is unable to meet the requirements of predicted target network bandwidth, go to step 4. Otherwise, go to step 5 or Step 6.

Step 4 Additional Resource Applications: AI application outputs additional resource applications in order to get expansions for the transport network.

Step 5 Adjustment actions: AI application outputs the predicted target network bandwidth and adjustment period of the MC system. The MC system can take some adjustment actions to optimize the transmission network.

Step 6 Manually Adjustment: If maintenance staff does not accept the adjustment operation in Step 5, the procedure will enter manual adjustment process.

### 3.4.4 Functional requirements

R4-01: The interface between AI Application and MC system should be authenticated and encrypted in two-way communication to ensure network security.

R4-02: By adopting different bandwidth adjustment actions for optical network equipment of different protocol types, the operation and maintenance management process of optical network equipment does not depend on specific optical network bearer technology.

R4-03: The predicted target network bandwidth is proportional to the predicted traffic data and tolerance. Predicted target network bandwidth = (1+ tolerance) * predicted traffic data. The range of tolerance is between 0 and 1.

R4-04: The AI Application requires data which is labeled according to the application, protocol type, and location.

R4-05: Previous traffic data is collected for each port at second/minute/hour/day level. The MC system is required continuous collection of traffic data at port level.

R4-06: Require tagging timing and location information of the collected data.

R4-07: The MC system is required to store the collected traffic consumption data for a sufficiently long duration up to 60 months.

R4-08: AI Application must have the capacity of traffic prediction based on the previous traffic data.

R4-09: The AI Application needs to have the capability of decisions making based on the predicted traffic data and service bandwidth.

R4-10: When AI Application cannot provide operation instructions to optimize the network, it should request manual adjustment to the maintenance staff.

R4-11: The AI Application can be divided into prediction module and decision module. The prediction module can predict traffic data. The decision module can make the decision of network optimization.

R4-12: When AI Application cannot provide operation instructions to optimize the network, it should request manual adjustment to the maintenance staff.

R4-13: The input and output of AI Application, clients of AI Application must support security access or interface security services, including service creation, deletion, and service status update.

## 3.5 Requirements for intelligent detection and optimization of SRLG

### 3.5.1 Overview

In the daily operation and maintenance of optical network, when different optical fibers are deployed in the same physical optical cable, these physical fiber connections belong to the shared risk link group (SRLG). When deploying working and protection paths in single SRLG, any interruption of the optical cable may cause both the working and protection paths of the connected services to fail, leading to network failures. However, in the operation and maintenance of the optical network, there is a lack of intelligent method for finding SRLG, and a large amount of human resource needs to be invested in step-by-step troubleshooting, or human analysis is used to identify SRLG issues.

Introducing artificial intelligence into the detection and optimization of optical network SRLG can help to detect and optimize optical networks in advance, reduce human operation and maintenance costs, reduce network risks, and improve network stability. SRLG detection can intelligently analyze SRLG links by combining basic data such as network topology, network element information, service data, and historical alarms and performance of optical networks. SRLG optimization can intelligently evade co-routed working paths and protection paths, improving customer service security.

### 3.5.2 Architecture

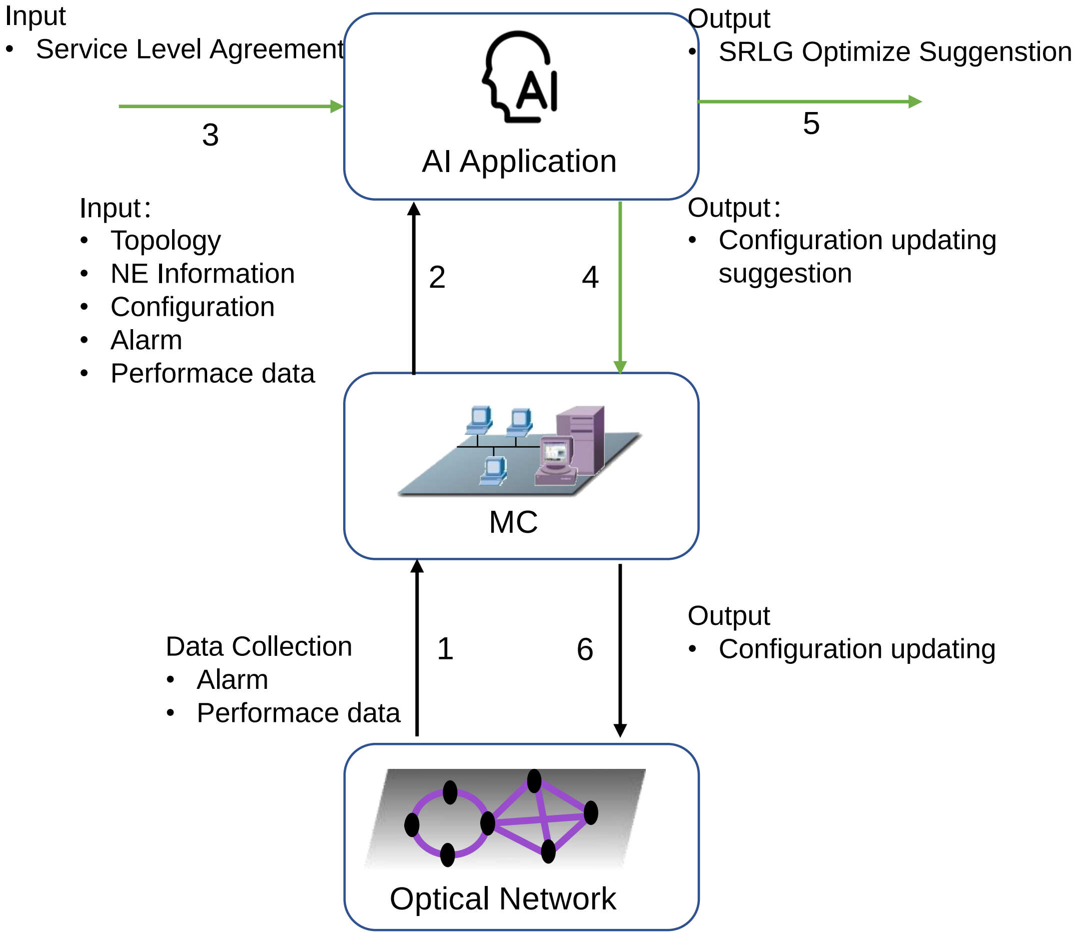


**Figure 6 Architecture of detection and optimization of SRLG**

The traditional discovery of SRLG link is done by manually identifying optical fibers and cable data. In this new kind of application, manual label is replaced by AI analysis. By combining information such as network topology and service data, and analyzing historical alarms and performance, high accuracy SLRG links can be output.

AI application can integrate the clustering of input data, analysis data association, and other AI technologies such as alarm analysis learning model to make decision. AI application can send configuration updating to MCS or output SRLG optimization suggestions to the engineers.

### 3.5.3 Steps

Step 1 Data collection: MCS collects alarm and performance data from the optical network.

Step 2 Data input: The management and control system provide data (such as topology information, NE information, alarm, performance, service configuration) as input to the AI Application.

Step 3 External input: AI application has external input of Service Level Agreement.

Step 4 Output and decision: AI application can SRLG optimization suggestion with clustering and association of alarm model and performance model. Considering the topology, SRLG, service optimization and SLA requirements, it optimizes the customer service. If SLA constrains should be applied to the customer service, it can output the SRLG optimization suggestion.

Step 5 Output maintenance suggestion: If the network resource cannot meet the optimization requirements, it can output SRLG optimization suggestions to the engineers.

Step 6 Update configuration: If the network resource can meet the optimization requirements, the MCS update service configuration.

### 3.5.4 Functional requirements

R5-01: The interface between AI Application and MCS should be authenticated and encrypted, supporting tamper resistant bidirectional communication to ensure security.

R5-02: The output from MCS to AI Application includes: network element information, topology, service, alarm and performance data.

R5-03: The network performance data output from MC to AI Application should have time stamp (occurrence, end, duration) and network resource location information (NE identification, slot identification, board identification, port identification). AI application should have dynamic and automatic configuration of time window for alarms and performance data to support AI analysis. Network alarm information should also have key elements such as time (occurrence, end, duration) and network resource location (such as alarm location information, including NE ID, slot ID, board ID, port ID).

R5-04: AI Application can get adjacent between NE ports to update topology dynamically. AI Application can get service configuration from MC system dynamically.

R5-05: To get SRLG optimization solution, AI Application should have ability to continuously learn and update performance model and alarm model to enhance the accuracy of analysis.

R5-06: AI Application should make decision to optimize SRLG. AI Application can get SRLG optimization with network topology, NE, service and history performance model and history alarm model. To intelligently avoid SRLG for working and protection path, the reliability of service is improved.

R5-07: AI Application can evaluate the resource availability. If there are no enough resource available, it should provide some suggestion to network operator, such as adjust fiber cable.

R5-08: AI Application can provide optimize instruction to MCS. Considering the network security, MCS cannot instruct the optical network directly. The optimize instruction should be evaluated by operators.

## 3.6 Requirements for service intelligent configuration

### 3.6.1 Overview

For complex optical network topology such as mesh networks, various services have different requirements for optical network. The most matched service link should be configured to match customer service requirements based on the SLA and QoS. The traditional manual deployment of service parameters is inefficient and unable to meet rapid response business needs. By introducing AI functionality, it is expected that service deployment can automatically select routes based on network status to achieve intelligent configuration of service parameters, achieving the goal of end-to-end service intelligent configuration.

### 3.6.2 Architecture

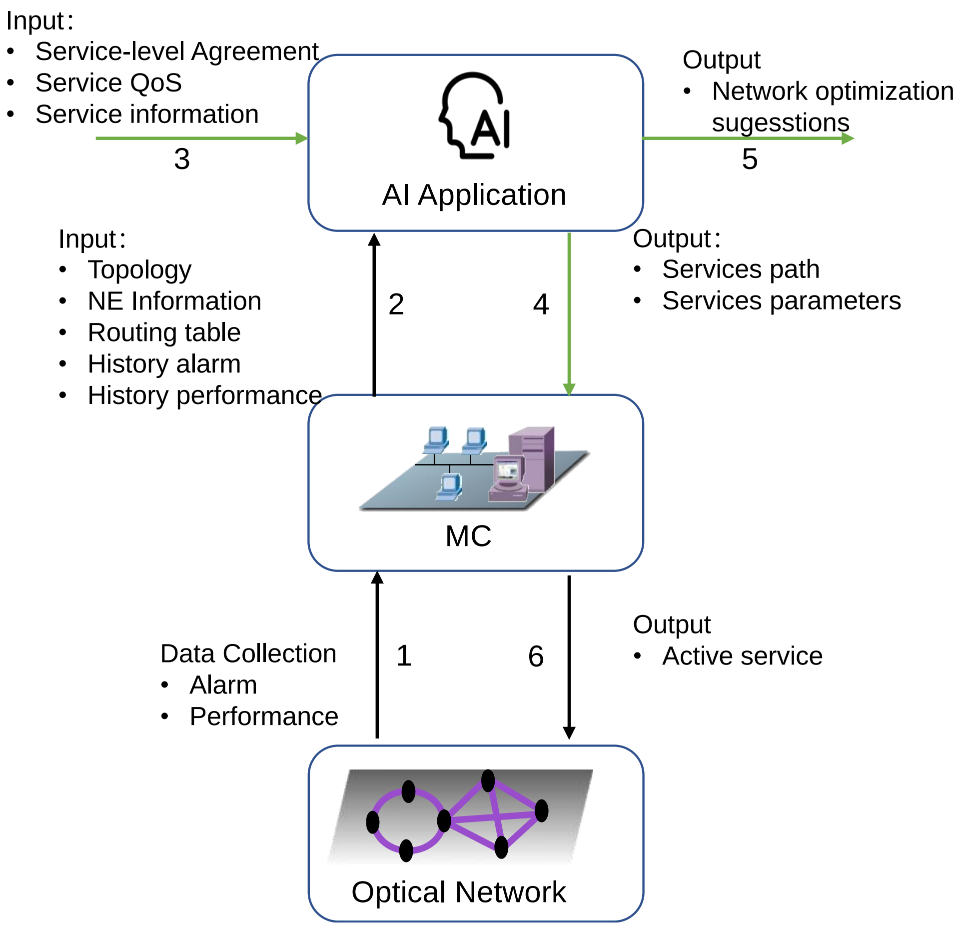


**Figure 7 Architecture of service intelligent configuration**

When inputting network element information, historical network alarms, and historical performance, the service path with the best cost, shortest path, lowest link failure rate, least packet loss, minimum latency, and lowest bandwidth utilization is calculated. Based on customer service SLA and business QoS requirements, automatically or manually adopt one or more routing strategies to calculate a path that is most suitable for the business. For example, if the service is voice service and requires the highest latency, the most suitable service path can be calculated based on the minimum latency strategy and cost optimization to Meet the requirements of different customer service.

### 3.6.3 Steps

Step 1 Data collection: MC system collects alarm and performance data from the optical network.

Step 2 Data input: Data including history alarm, history performance, and configuration information (topology information, network element information, service path, ) are input into AI application.

Step 3 External input: AI application has external input of Service Level Agreement and service Qos.

Step 4 Output and decision:

The service analyzer automatically or manually selects a routing strategy according to the service requirements and the link cost. This strategy can be one of the best costs, the shortest path, the minimum unavailable time, the minimum packet loss, the minimum delay and the maximum bandwidth utilization, or any combination of various strategy. For example, the service is a voice service with the highest delay requirements, Then the most appropriate service path can be calculated based on the combination of minimum delay and cost optimal routing mode, and enter step 5; If the path cannot meet the service requirements, proceed to step 6

Step 5 Decision making: If the calculated service path does not meet the requirements of SLA, output network optimization suggestions.

Step 6 Service configuration: If there are resource can meet the SLA requirements, MC system active optimized service with configuration parameter.

### 3.6.4 Functional requirements

R6-01: The interface between AI Application and MC system should be authenticated and encrypted, supporting tamper resistant bidirectional communication to ensure security.

R6-02: The output data from MC system to AI Application should include NE information, topology, service, service path, history alarm and history performance.

R6-03: The history performance output from MC system to AI Application should have time stamp (occurrence, end, duration) and network resource location information (NE identification, slot identification, board identification, port identification). The performance collecting period should be an interval of 15 minutes and 24 hours. AI application should have dynamic and automatic configuration of time window for alarms and performance data to support AI analysis. AI application should collect packet loss, bit error rate, delay. The alarm data should also have time stamp and network resource location information.

R6-04: AI Application can get adjacent between NE ports to update topology dynamically. AI Application can get service configuration from MC system dynamically.

R6-05: AI Application should support marking the service cost, including planning cost value, average utilization of link traffic, link failure rate, link packet loss rate and link delay.

R6-06: AI Application can decide service path and service configuration parameters based on the SLA and QoS requirements, the path and configuration parameters of the service are determined by combining the marking information of the best cost, shortest path, lowest link failure rate, minimum packet loss, minimum latency, and lowest bandwidth utilization for each link.

R6-07: If there is no resource available to meet the SLA requirements, AI Application should output network optimization suggestions.

## 3.7 Requirements for intelligent power saving of equipment

### 3.7.1 Overview

With the increasing capacity of network equipment, higher transmission speed, more complex functions and higher energy consumption, equipment energy consumption has become one of the major cost expenditures for network operators. How to timely reduce the power consumption of equipment based on the dynamic network load has becomes an urgent and important issue of current network operations.

Introducing AI can analyze the service flow of network equipment based on historical and real-time performance data, including analyzing long-term idle ports, low traffic load equipment, and equipment with drastic traffic fluctuations etc., to find the low traffic equipment, ports, time-based load fluctuation pattern, it can output energy conservation instruction to shut down idle ports, traffic re-schedule, CPU frequency reduction and other suggestion. It can provide instructions or guideline for network optimization of long-term low load equipment and setup energy consumption learning model for short-term load fluctuation equipment.

This AI application can support power consumption analysis of network equipment and intelligent energy-saving of network equipment.

### 3.7.2 Architecture

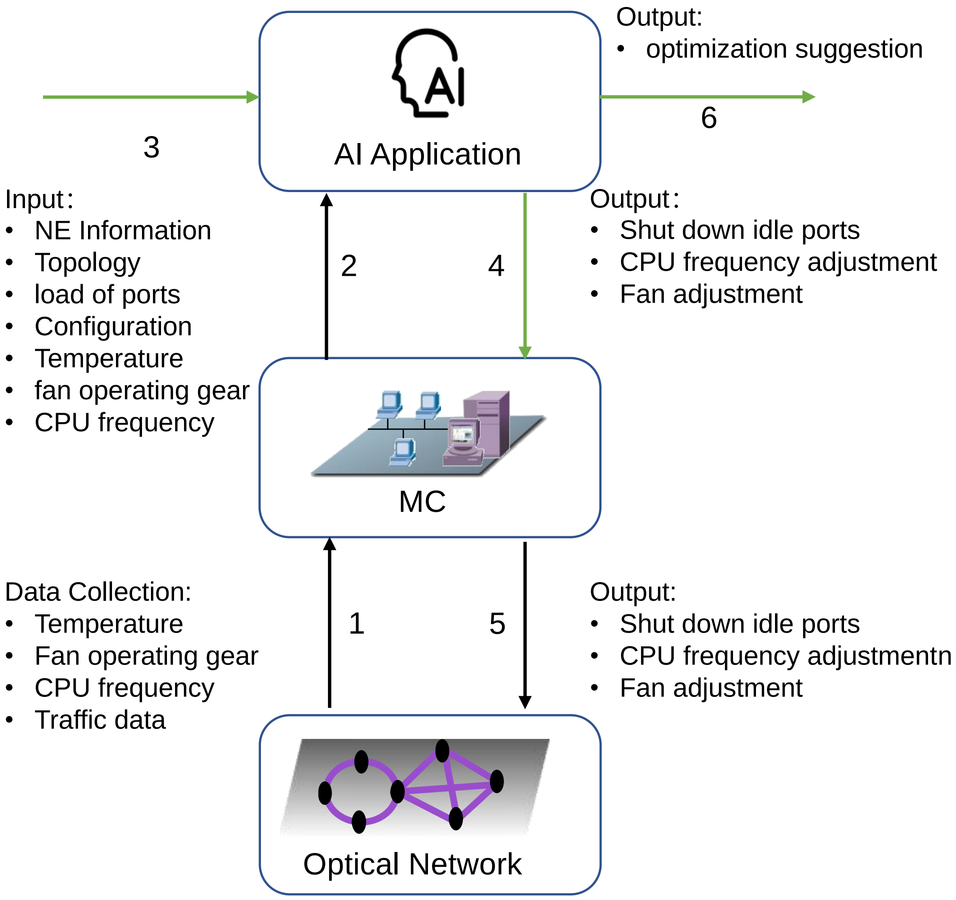

**Figure 8 Intelligent power saving of equipment**

The current network maintenance cannot quickly find long-term idle ports and low load equipment. It is desirable to reduce power consumption automatically based on the actual operation of the network.

The AI application can Integrate data cleaning, clustering, correlation analysis, and other AI technologies for input data. The AI application can make decision to locate the long-term idle objects (including equipment, cards, ports) and optimization suggestion. The AI application can also find load fluctuation objects, setup manual intervention rules (such as fan adjustment threshold) and automatically generate consumption reduction instructions (adjust fan, CPU frequency reduction, card hibernate, shutting down ports). The network equipment can execute these instructions verified by MC.

### 3.7.3 Steps

Step 1 Data collection: MC collects traffic data from the network equipment, including mean traffic flow and peak flow, CPU utilization rate, equipment temperature, fan operating gear, etc.

Step 2 Data input: The management and control system provide data (such as topology information, traffic flow, NE information, fan configuration, service configuration) as input to the AI Application.

Step 3 External input: AI application has external input from experts defined rules, including CPU frequency reduction threshold, fan downshift threshold, etc.

Step 4 Output decision: AI Application can provide traffic flow analysis and optimization suggestion. When AI Application collects history load of equipment, boards and ports, the history data can get data cleansing and clustering. The load model is time related as long-term zero load model, low load model and Fluctuating model.

Combined with the initial threshold parameters given by expert experience, various AI methods can be used to learn the load time-related models and energy-saving models based on history load of equipment, boards and ports.

As shown in Step 6, AI Application can give suggestions to remove, delete or turn-off the ports based on long-term zero load model.

For those fluctuating equipment, boards and ports, AI Application can give suggestions and instructions to save power like start and end times to save power.

During idle period, the instructions could be Automatically reducing the CPU frequency, automatically reducing the fan gear, migrating traffic from one port to a different reachable port.

Step 5 Issue energy-saving instruction: MC can send the instructions to the optical network equipment. AI Application generate specific objects and power saving instructions.

Step 6 Optimization suggestion: AI Application AI Application can give suggestions to maintenance staff to remove equipment, migrate service, turn-off ports.

### 3.7.4 Functional requirements

R7-01: The interface between AI Application and MC should be authenticated and encrypted, supporting tamper proof bidirectional communication to ensure security.

R7-02: AI applications should support annotating input data (such as classifying traffic loads by time, device, board, port for clustering analysis) as AI supervised learning to improve the efficiency of building load models.

R7-03: The network load performance data output by MC to AI Application should have key elements of time and network resource location (such as NE ID, slot ID, port ID). At the same time, this data should support steady-state 24-hour, 15-minute load performance data (such as traffic) for no less than 3 months.

R7-04: AI applications should support the input of expert experience rules from external sources as a basis for decision analysis.

R7-05: AI applications must support global resource analysis of the network, including querying NE and network port adjacency relationships based on interfaces with MC, to support dynamic generation and updating of topology; Obtain dynamic service data from MC, including service routing, connection, bandwidth parameters, network element port utilization, etc., and analyze network dynamic traffic load.

R7-06: AI applications need to support continuous load and rule learning between components, boards, ports, and fans, iteratively optimizing the consumption reduction models (the basic element of this model should be that an object takes a certain energy-saving measure during a certain time period). Various AI algorithms can be used to achieve correlation analysis.

R7-07: AI applications should have decision-making functions. On the one hand, based on long-term load analysis of the idle network resources, it can provide reports and consumption reduction suggestions for long-term no load/low load objects. On the other hand, a load curve and energy-saving and consumption reduction instructions should be provided for the short-term fluctuations resource. It can provide detailed operation instructions (such as CPU shutdown, CPU frequency reduction, fan downshifting, port shutdown, etc.) for energy-saving object information (NE, slot, port, fan). If detailed and specific noise reduction measures cannot be provided, optimization suggestions for energy conservation and consumption reduction should be provided to the operation and maintenance staff.

R7-08: All consumption reduction measures must comply with safety rules, which ensure the normal operation of the load and cannot interfere with the automatic activation (i.e. switching protection) of redundant protection backup units when needed. Moreover, it is necessary to support automatic wake-up of shut down objects or restoration of normal CPU frequency or fan speed when the load exceeds the expected overload (such as increased flow or temperature).

R7-09: The consumption reduction instructions provided by AI Application to MC should not be directly executed and downloaded to the network through MC because of network security considerations. Instead, they should only provide instruction suggestions, and whether to execute them should be manually determined by MC operators. MC should report the execution result of the instruction.

R7-10: AI applications should support automatic triggered pro-active analysis (such as manually defined daily and weekly), as well as on-demand analysis.

R7-11: The secure web or API interface services should be supported for the input and output of AI Application, or other supported clients must support, including service creation, deletion, and service status updates.

## 3.8 Requirements for Pre-warning of cable breakage-proof

### 3.8.1 Overview

It is heavy load of maintenance resulted by fiber cable failures during daily maintenance operation. For traditional maintenance, it is difficult to manage optical fiber cable resource because of the passive characteristics of cable resource. on the one hand it's impossible monitor and pre-warning the fiber cable and facilities (handholes, aerial fiber cable, splitters, fiber distribution cabinets), on the other hand it's difficult to locate the fault rapidly when the fault is caused by the cable resource. Applying EOTDR, GIS, RFID, tag recognition and other IoT technology can help to real-time monitor of fiber cables and resource. AI technology can help to analysis the optical cable loss waveform and correlation alarms to pre-warning the cable resource risk and fault localization.

This AI application can support Pre-warning of cable breakage-proof and fault localization.

### 3.8.2 Architecture

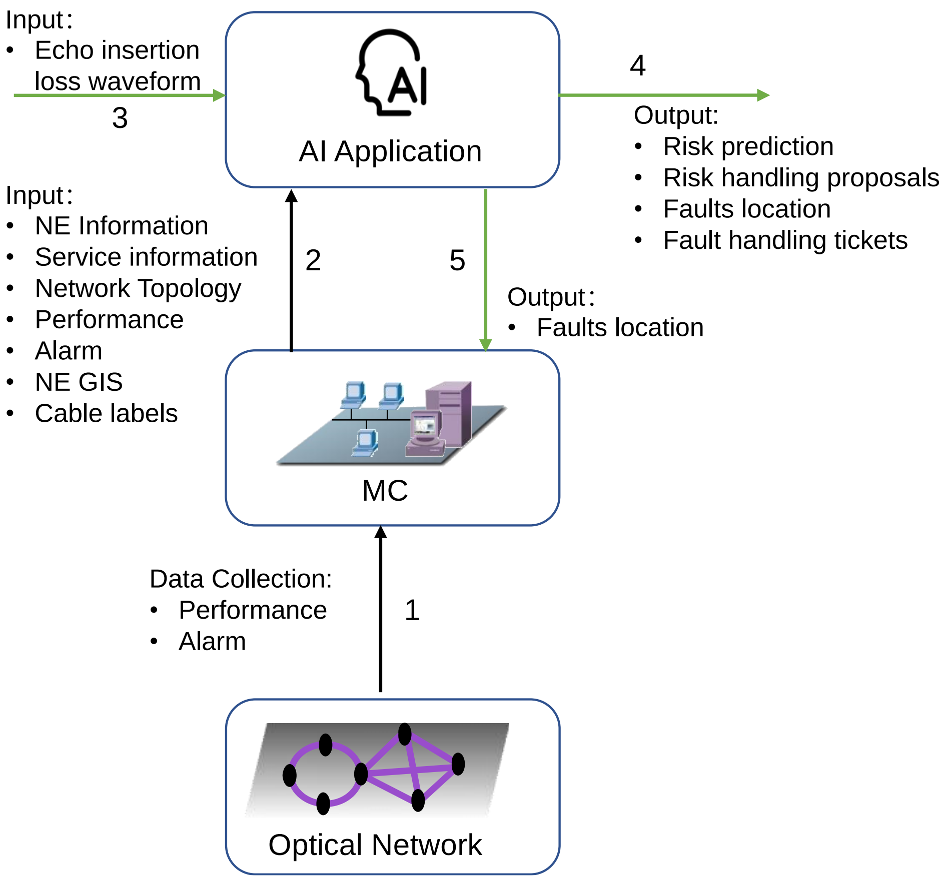


**Figure 9 Architecture of intelligent Pre-warning for cable breakage-proof**

Traditional optical network maintenance cannot identify failures of cable breakage-proof in advance, and can only passively wait for the occurrence of failures. It is desirable to locate the specific geographical coordinates when the failures and performance degradation occurs. Even if the faults such as external force damage are found in the optical cable, it is difficult to accurately locate the specific geographical coordinates. Equipment alarms are used for a rough location judgment, and then manual line patrol is used to troubleshoot each section, which is inefficient. AI technology can predict the risk of external damage by analyzing signals such as fiber optic echo insertion loss, associated equipment alarms, optical performance and other related data. AI can combine fiber optical cable labels, GIS location and echo loss waveform for rapid fault point localization, guiding rapid recovery.

In Figure 9, the architecture shows that the fiber resource and on-line detecting data are external input data.

AI technology can predict and pre-waring the location by cleaning, clustering, and correlation analysis of the input data.

### 3.8.3 Steps

Step1 Data collection: MC collects performance and alarm from optical networks.

Step 2 Data input: AI Application gets fiber resource data (such as NE GIS, pipeline information, fiber cable labels, cable types, cable length etc.),

NE Information, Service Information, Network Topology from MCS.

Step 3 External input: AI Application should obtain real-time monitoring information of optical cables from external online testing instruments, such as Echo insertion loss waveform,

Vibration sensing parameters.

Step 4 Analyzation and decision making: AI Application conducts analyzation and decision making. AI Application can predict the risk of cable damage.

1) AI Application analysis the temporal and spatial correlation between alarm, performance of equipment.

It cluster data and clean invalid and duplicate data based on NE GIS, equipment correlation and Echo insertion loss waveform.

Learning and establishing prediction and localization models can be achieved through various AI methods, such as knowledge graph learning, neural networks, etc.

2) AI Application can dynamically predict the risk of cable damage. Combined with expert experience, it can output maintenance proposals to maintenance staff and trouble tickets.

At the same time, AI Application output the risk prediction to MCS, i.e. risk or fault location and service affected. MCS can select redundant cable routing to avoid fault location and reduce risk.

Step 5 Output proposals for MCS: Based on the analysis results of step 4, it output the proposals and avoidance advice to MCS for prediction and fault localization. The proposals could be potential risk location or fault location and service affected. The avoidance advice could be circuitous cable routing, service restoration advice. Once the maintenance staff get the proposals from MCS, they can make decision.

### 3.8.4 Functional requirements

R8-01: The interface between AI Application and MC should be authenticated and encrypted, supporting tamper proof bidirectional communication to ensure security.

R8-02: AI Application may support data labeling of input data (such as classify alarms for clustering analysis).

Supervised learning may improve pre-warning and faults localization efficiency.

R8-03: AI Application may get physical fiber optical cable resource information.

It should include but not be limited to cable ID (Handhole well ID, Pipeline ID, central office ID, Closure ID, splitter ID), GIS information of cable (Central office, splitter),

cable type, Number of fiber cores, attenuation and topology (Connector interconnection information, span distance).

R8-04: AI Application may get support alarm and performance from MC. It should support start time, end time, duration of the alarm and performance.

It should have configurable time window to dynamically and automatically capture alarms and performance.

R8-05: AI Application can get external input from optical cable resource management system, including Echo insertion loss waveform, Vibration sensing parameters.

R8-06: AI Application can get cable routing and service routing from optical cable resource management system and MC.

AI Application should dynamically analysis the correlation of cable and service to judge the cable breakage and faults influence.

R8-07: AI Application should dynamically analysis the availability of cable resource. It can propose alternative route to avoid cable failures.

R8-08: AI Application should continuously support Pre-warning of cable breakage-proof and iteration of Fault Location Model.

R8-09: AI Application should support capability of continuous learning and update expert knowledge base to providing risk avoiding proposals.

R8-10: AI Application should dispatch trouble tickets. Once it predicts risk or faults location, it should distribute trouble tickets with maintenance proposals to maintenance staff.

R8-11: AI Application should send MC the pre-warning of cable breakage-proof. Once it predicts risk or faults location, it should locate faults and send risk avoiding proposals.

R8-12: AI Application should support real-time pre-warning of cable breakage-proof and faults localization.

## 3.9 Requirements for intelligent scheduling for optical cutover

### 3.9.1 Overview

With the development of optical networks towards ultra-large scale, immense capacity, ultra-large capacity and intelligence, the number of cutover operations increases significantly. Tens of thousands of transmission cutovers need to be arranged every year. Cutover in optical networks typically refers to planned maintenance operations on network resources such as power, fiber, systems, and equipment due to engineering construction, network construction and optimization, node expansion, among other factors. During cutover operations, service interruptions or adverse impacts on normal network functionality may occur.

The task scheduling of cutover is the most time-consuming aspect of the process, usually taking 1-2 days to complete each schedule. Based on collected cutover information of the optical network, AI is applied for intelligent scheduling for cutover in optical network. The corresponding expert rules and networks topology rules in cutover rules base are called to obtain schedule without conflicts. When there are conflicts in the pre-scheduling plan, it is iteratively optimized. The iteration process stops until the current iteration reaches the maximum number of iterations. The intelligent scheduling methods based on AI can save human resources and improve execution efficiency.

### 3.9.2 Architecture

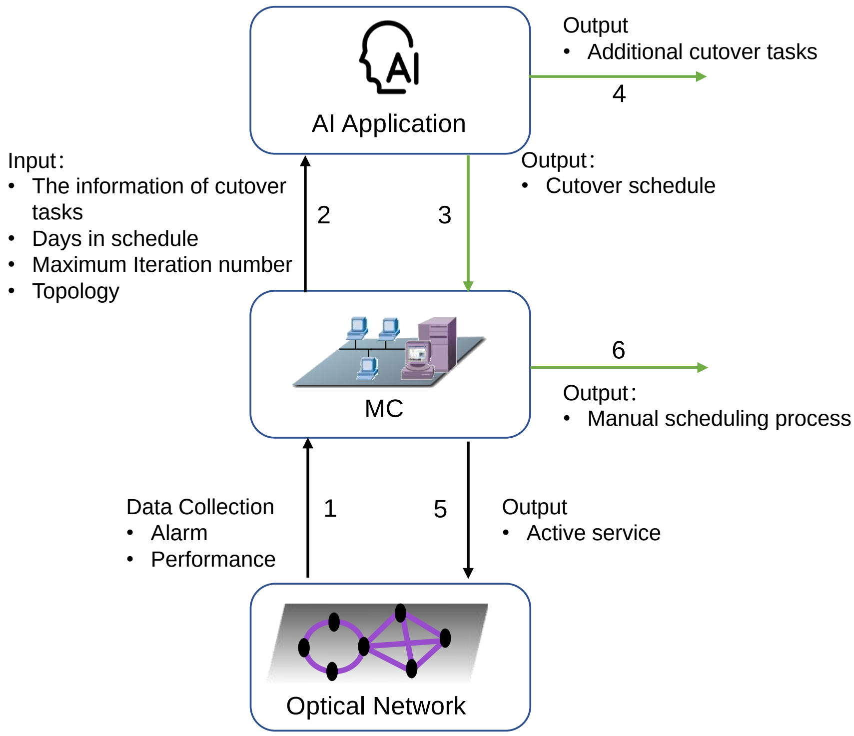


**Figure 10 Architecture of intelligent task scheduling for optical cutover**

Traditional method of cutover scheduling relies on the experience of the cutover administrators who manually schedule tasks and call upon conflict judgment from resource repository to verify the results. The manual cutover scheduling has notable drawbacks, such as wastage of human resources, low efficiency, and slow execution. For this application, manual scheduling will be replaced by AI scheduling, which will realize dynamic and real-time quick scheduling, combine many technologies of AI, such as neural network, reinforcement learning, etc., AI can report relatively high-efficiency scheduling and proposals.

### 3.9.3 Steps

Step 1, Cutover tasks collection: Management and control systems (MCS) configures parameters of cutover tasks based on the information of collected cutover in optical network.

Step 2, Input cutover tasks and configuration parameters collection: Cutover tasks and configuration parameters including cutover type, cutover area, cutover risk level, days and the maximum number of iterations in schedule is input into AI application.

Step 3, Intelligent Scheduling: The cutover rules are called in cutover rules base based on parameters of cutover tasks. The pre-scheduling plan are obtained based on cutover rules in AI application. When there are resource conflicts in resource repository for the pre-scheduling plan, it is iteratively optimized to get target schedule. If there are no conflicts before the current iteration reaches the maximum number of iterations, AI application outputs the schedule operation for MC, which can schedule the cutover tasks automatically to optimize the transport network as shown in step 5. Otherwise, go to step 4.

Step 4, Additional cutover tasks applications: AI application requests more cutover tasks for scheduling.

Step 5, Cutover actions: AI application outputs the schedule to MCS. MCS takes cutover actions based on schedule.

Step 6, Manually scheduling: If maintenance staff does not accept the operation instruction exported in Step 3, execute manual scheduling process.

### 3.9.4 Functional requirements

R9-01: The interface between AI Application and MC should be authenticated and encrypted in two-way communication to ensure network security.

R9-02: The output from MCS to AI Application includes: Input cutover tasks and configuration parameters including cutover type, cutover area, cutover risk level, days and the maximum number of iterations in schedule.

R9-03: The corresponding expert rules and networks topology rules in cutover rules base are called based on the cutover area, cutover risk level, cutover type, days in schedule and the maximum number of iterations. The cutover rules are generated based on the expert rules and the network topology rules.

R9-04: The multi-layer cutover topology graph is generated by networks topology rules and optical cutover tasks. The inter-layer tasks and intra-layer tasks in the multi-layer cutover topology graph are connected based on the expert rules and fully connected conditions.

R9-05: In the graph, cutover tasks are presented as vertices. The two vertices are not connected when the two tasks have conflicts based on rules. The total number of vertices in the first layer is also the total number of days in one schedule. The tasks in the following layer are layered and sorted in graph based on cutover type and risk level.

R9-06: During the scheduling process of cutover task, if the conflict of tasks is detected, the conflict is processed based on task conflict processing rules to obtain the schedule.

R9-07: During the scheduling process of cutover task, routing conflicts and/or regional conflicts are detected, it is determined that there are conflicts in schedule. If there is a conflict between the tasks of different layers, adjust the tasks of lower-layer. If there are conflicts between task of the same layer, tasks with lower risk levels should be adjust priority.

R9-08: The schedule is verified by resource repository. When there is no conflict in the scheduling plan based on the verification results of the current network and current iteration is less than the maximum number of iterations, the scheduling plan will be determined as the target scheduling. When there are conflicts in the scheduling plan, the scheduling plan will be iteratively optimized by rescheduling. If there is still a conflict when the number of iterations optimized for the rescheduled iteration reaches the maximum number of iterations, a manual scheduling process is requested.

R9-09: After completing a schedule, the tasks in the schedule is deleted in the graph.

R9-10: The optimization rules is generated based on the identification and analysis results of scheduling conflicts. Add the optimization rules to the cutover rules base based on a self-learning mechanism.

R9-11: For network security, the schedules provided by the AI Application should not be forwarded directly to network and executed by MC, the maintenance staff should judge whether to execute the recovery instructions.

R9-12: The input and output of AI Application, clients of AI Application must support security access or interface security services, including service creation, deletion, and service status update.

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# 5 Abbreviations and Acronyms

The following abbreviations and acronyms are used:

| | |
|---|---|
| AI | Artificial Intelligence |
| CPU | Central Processing Unit |
| EDFA | Erbium-doped Optical Fiber Amplifier |
| EOTDR | Embedded Optical Time Domain Reflectometer |
| XML | Extensible Markup Language |
| GIS | Geographic Information System |
| IOP | Input Optical Power |
| IP | Internet Protocol |
| MC | Management and Control |
| MCS | Management and Control System |
| ML | Machine Learning |
| MPLS-TP | Multi-Protocol Label Switching Transport Profile |
| MTN | Metro Transport Network |
| NE | Network Element |
| OSNR | Optical Signal to Noise Ratio |
| OOP | Output Optical Power |
| PECP | Path Computation Element Protocol |
| QoS | Quality of Service |
| RFID | Radio Frequency Identification |
| RX | Receive |
| RestFul | Representational State Transfer |
| SDN | Software Defined Network |

| | |
|---|---|
| SRLG | Shared Risk Link Group |
| SNCP | Sub-Network Connection Protection |
| TX | Transmit |
| VOA | Variable Optical Attenuator |
| WDM | Wavelength Division Multiplexing |

Email: info@ipec-std.org
Website: www.ipec-std.org