中国电信全光网3.0

技术白皮书

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目录

1. 引言

在全球数字化浪潮中，人工智能（AI）正成为推动各行各业变革的关键力量。新型信息基础设施作为支撑 AI 等新兴技术发展的信息“大动脉”，已成为现代化基础设施体系的重要组成部分。加快新型信息基础设施建设，对于推进新型工业化、构建现代产业体系、培育发展新质生产力，进而助力制造强国、网络强国和数字中国的建设，具有重要的战略意义和支撑作用。

中国电信作为新型信息基础设施的建设者和运营者，正全力打造服务型、科技型、安全型企业，推动科技创新和产业创新深度融合，不断增强网络核心功能，提升核心竞争力，坚持“云改数转智惠”战略，强化“云网融合”目标，深耕细作“全光网”理念，全力支持新型信息基础设施协调发展。

回顾过去，中国电信“全光网 1.0”以“光进铜退”为核心，实现光纤网络的广覆盖和高速率能力提升，“全光网 2.0”以“全光交换”为核心，率先规模采用可重构光分插复用器（ROADM）及波长交换光网络（WSON）技术，推动网络向扁平化、全光化、智慧化演进。面向智能时代，中国电信全光网将持续发展和变革，适时提出“全光网 3.0”，以打造更佳的新型信息基础光网络。

本白皮书将全面阐述中国电信“全光网 3.0”愿景，提出“全光网 3.0”目标架构与网络特征，明确其分阶段演进策略并阐述支撑全光网持续发展的重点技术创新方向，最后展望全光网的未来发展。

2. 全光网 3.0 概述

2.1. 背景

当前，科技革命与产业变革加速推进，AI、云计算等新一代信息技术日益成为推动实体经济与数字经济深度融合的关键力量，持续构筑起数字经济发展的强大引擎，推动实体经济加快向数字化、智能化方向转型。这一切的融合与变革，均依赖光网络作为核心纽带。

国家相继出台相关政策，强化光网络的核心作用。《深入实施“东数西算”工程加快构建全国一体化算力网的实施意见》指出，要“加快推动国家枢纽节点内部、国家枢纽节点之间、国家枢纽节点与非国家枢纽节点间确定性、高通量网络建设，打造高速泛在、安全可靠的算力传输网络”。《关于开展万兆光网试点工作的通知》强调，“在有条件、有基础的城市和地区，聚焦小区、工厂、园区等重点场景，开展万兆光网试点”,“有序引导万兆光网从技术试点迈向部署应用”。

中国电信作为信息通信行业的骨干央企，坚决履行使命责任，坚定投身数字中国建设，为推进中国式现代化贡献电信力量。通过强化网络多维布局，构建国际国内一体化的高品质网络；构筑弹性、超宽、高速、无损的基础承载网，持续增强算力的供给能力；以人工智能赋能网络，提升云网运营自智水平，重塑业务流程，改善用户体验。

随着网络基础设施能力的持续提升，AI、数据、大模型与网络加速融合，万兆接入需求以及智能应用场景大量涌现。当前，云游戏用户已突破 1.8 亿，云手机用户过千万，多省市发布万兆套餐。同时，根据权威机构预测，到 2033 年，AI 相关流量将占全球网络总流量的

62%，AI 正加速成为驱动网络基础设施变革的核心引擎，亟需大带宽、高可靠、低时延、敏捷灵活、智能协同的新型光网络。

在此背景下，全光网作为信息网络的底座，其能力不仅关乎新型信息基础设施的建设质量，也直接影响算力使用效率与业务体验水平。自 2025 年起，光网络开始迈入“全光网 3.0”时代，网络架构与能力体系将实现系统性演进，加速推进我国新型信息基础设施建设。

2.2. 价值和愿景

“全光网 3.0”是推动新型工业化与数字基础设施融合发展的关键支撑。通过能力升级、架构重构、服务模式创新，光网络向数智融合、多维感知与天地协同转型，并具备超大带宽、极低时延、原生智能、弹性敏捷等核心能力。促进区域资源协同共享，支撑算力资源灵活配置、数据要素高效流通，加速智慧工厂、智慧办公等产业数字化升级，推动远程教育、远程医疗等城乡数字鸿沟弥合，带动实体经济与数字经济的可持续发展，全面释放社会新经济动能。

“全光网 3.0”是引领光通信产业未来发展的重要理念。通过技术创新与融合、标准牵引以及产业链升级，引领未来十年的光通信产业变革。在“全光网 2.0”网络架构与技术创新的基础上，进一步引入并融合人工智能、数字孪生、空间通信、多维感知等前沿技术，提升网络对多样化服务场景的适配能力，推动光通信产业从传输媒介、光电器件、设备制造到全网系统集成等上下游环节实现全链条跃升，开启光通信产业高质量发展新阶段。

“全光网 3.0”将以“全光智联”为核心，致力于构建以“光云

智融合、光感业融合、天地海融合”为愿景的全光智能联接体系，夯实未来十年 AI 时代的网络底座。

1）光云智融合：光网络支持海量数据的高效联接，结合智能化升级，实现光网络和云资源的深度融合。依托弹性敏捷、泛在协同、智能感知的光网络，为算力、存力与运力等所有在网资源构建高效集约的全光联接底座。同时融合网络自智技术，覆盖光网络“规划、建设、维护、优化、运营”全生命周期，满足所有用户、终端、节点和数据中心之间的海量数据快速交换与智能调度需求。

2）光感业融合：通过将光通信与光感知深度耦合，实现从“连接通道”向“感知中枢”跃迁，推动光网络从单一传输向融合主动感知与差异化业务的范式转变。光网络不仅承担数据传输功能，还具备对业务品质、物理环境和网络设施状态的实时感知能力，从而支撑更加智能化、精细化的业务实时管理，推动应用向品质分级、多维感知方向演进，进一步拓展行业应用边界，提供如家庭安全、地震预警、周界安防等增值服务。

3）天地海融合：通过多维网络融合技术，实现天基光网（卫星通信）、空基光网（空中平台）、陆地光网与海洋光网的有机协同。推动光网络向空天延伸，突破传统地理边界限制，构建覆盖天地海的全域无缝连接、立体化布局的下一代光网络体系。通过多层次、多形态网络的互补协同，全面实现天地海融合的泛在连接与资源高效协同，支撑全场景、全业务的应用落地。

3. 全光网 3.0 目标架构与网络特征

3.1. 全光网 3.0 总体目标架构

为实现“光云智融合、光感业融合、天地海融合”的愿景，满足“全光智联”这一核心，需要引入一系列新型技术的创新，白皮书认为“全光网 3.0”目标架构应具备如下六大基本特征：

1、泛在协同的全领域光速联（泛在光速联）

光网络正加速向着泛在覆盖与天地海融合演进，以构建覆盖全球、支撑全场景、高可靠、大带宽通信的基础设施。

光网络在覆盖各类数据中心的基础上，进一步向末端延伸，实现对家庭、企业、园区、工业设备的深度覆盖，满足千家万户与千行百业对高速率、低时延、高可靠光通信的普遍诉求。

面向全球打造天地海融合光网络，需要空间光网络、陆地光网络、海洋光网络在资源规划、网络管控、服务等级协议（SLA）保障等方面全面协同，构筑永不失联、业务永在线的网络。资源规划协同是指天地海网络规划时根据业务预测和业务 SLA 要求，做好网络资源协同衔接；网络管控协同是指天地海光网络统一管控、业务一体化发放、网络一体化运营；SLA 保障协同是指业务根据时延、可用率等 SLA 指标选择相应的网络资源及组合，协同传输实现端到端保障。

光网络技术持续发展，速率大幅提升。长距单载波速率提高至 800Gb/s 或 1.6Tb/s，中短距单载波速率提高至 1.6Tb/s 或 3.2Tb/s，接入段单载波速率提高至超 100Gb/s~200Gb/s，室内段光链路单载波速率提升至 25Gb/s~50Gb/s。

2、新型超宽的全类型光媒质（新型光媒质）

光网络在频谱与介质上持续创新，扩展多波段传输能力与引入新型光纤及空间光通信介质，全面提升网络容量、性能与覆盖能力。

在频谱扩展方面，O、E、S、C、L、U 等波段已在光通信系统中有所应用，如 O、E 波段用于前传场景，U 波段则在接入网中发挥作用。随着业务需求不断提升，部分通信技术或场景对频谱的使用正在进一步拓展，例如长距传输有望从传统的 C+L 波段延伸至 S+C+L 波段，而接入段也存在扩展至 C 波段的可能。

在光纤光缆方面，涌现出空芯光纤、空分复用光纤、基于单模光纤的大芯数光纤光缆等新方案。空芯光纤能降时延、提升传输性能；空分复用光纤和大芯数光纤光缆能显著提升网络容量。

空气/真空是“全光网 3.0”的新介质，利用其实现空间光通信，主要包括卫星间基于真空的激光通信、卫星和地面信关站间以及空中平台间基于空气的激光通信等。

3、弹性敏捷的全场景光链接（动态光链接）

通过弹性连接、弹性带宽、弹性频谱与弹性算力等技术，光网络实现按需建链、速率自适、频谱灵活的智能调度能力，支撑任务式业务高效发放与网络资源最优利用。

针对任务式应用、业务快速发放和网络效率提升等目标，通过弹性连接、弹性带宽、弹性频谱与弹性算力等技术根据可达路径实现敏捷动态链接。

弹性连接：针对传输类专线，通过波长与光业务单元（OSU）分

钟级拆建、快速提供链路资源，满足任务式按需调度和时分复用的需求。针对基于无源光网络（PON）技术的专线，以用户侧网关为锚点，提供应用级的实时识别和标记、跨层多域端到端的快速建拆链路能力。

弹性带宽：一方面提供线路级速率的弹性可调整，如一块光转换单元（OTU）板卡实现 400Gb/s~1.2Tb/s 不同线路速率可调；另一方面基于 OSU 带宽弹性扩展、双层动态带宽分配机制（DBA）带宽伸缩、应用级接入网切片等能力，提供不同类型用户的应用级带宽弹性适配能力。

弹性频谱：波长间隔灵活调整，可匹配不同速率的高效传输，在同一光层实现多速率波道混合传输。

弹性算力：基于光线路终端（OLT）、智能政企网关、光纤到房间（FTTR）等边端算力，满足 AI 智能体及应用对于本地存算资源的弹性部署及调度编排要求。

4、多层原生的全流程光智能（原生光智能）

原生光智能基于原生在网络各层次中的 AI 技术，构建“三层原生智能”网络架构，全面赋能光网络“规、建、维、优、营”全流程。

在新一代云网运营系统框架下，光网络以原生光智能为根基，深度融合通感一体、数字孪生和人工智能等新技术，为千行百业提供“自配置、自修复、自优化和自服务”的全光网智能服务，使网络规划更精准地预测业务需求、网络建设更高效地安装调测、网络维护更快速地处理故障、网络优化更及时地发现隐患和调优、网络运营更敏捷地满足多样性业务诉求，从而实现 AI 时代的智能光网络。

基于AI构建的光网络原生智能包括网络层、运营层和业务层智能，其中网络层智能包括多参量精确感知、快速采集、基于小模型的网元数字孪生（实现“入网即孪生”）和健康度分析等，运营层智能包括基于智能体的光网络运维大模型、开放管控、故障溯源、性能评估和基于时延/性能裕量等多因子的最优选路等，业务层智能包括业务敏捷发放、SLA风险预判、用户质量监控、资源分析调度、智能决策和差异化保障等。

5、内识外探的全维度光感知（多维光感知）

光网络通过感知能力的全面提升，支撑高可靠、高品质网络和业务保障（内识），并探索面向社会治理提供服务的能力（外探）。

针对内识，在网络感知层面，包括面向光缆网络的同沟同缆监测、光缆闪断监测、光缆地理信息系统（GIS）还原、数字化光配线网络（ODN）、面向设备、链路和网络的数据采集、全参量感知和故障感知等，以提高业务的质量、安全性与快速开通能力；在业务感知层面，实现业务应用类型、应用特征等识别，以及应用级SLA智能感知和业务质量感知等。

针对外探，利用泛在互联的光缆网作为传感介质，结合AI技术，构建实时准确的光纤传感能力，形成具备环境感知等功能的产品，实现哑资源可视化管理，同步支撑地震预测、施工预警、周界安防、智慧交通、桥梁道路塌陷检测等服务。

6、高质体验的分等级光承载（分级光承载）

构建多等级SLA的高品质确定性承载体系，支撑多样化业务的

网络即服务（NaaS）能力与差异化体验保障。

利用光网络低时延、确定性、灵活调度、高可靠、无损等优势，结合互联网协议（IP）网络和第五代移动通信（5G）网络，为包含入算和算间互联在内的多样化业务提供端到端链路的高品质多等级 SLA 确定性承载能力（如保障带宽、有界时延、可承诺丢包率等），实现 NaaS。

多等级 SLA 包含带宽、时延、网络可用率、业务开通时间、安全等多维度网络关键绩效指标（KPI）以及差异化的分级指标，可针对面向企业（2B）和面向家庭（2H）等不同类型的用户和业务，分别形成诸如低时延精品专线、分级 SLA 订阅式网络增值服务等为代表的产品，提供相应分级 SLA 能力，保障分级体验。

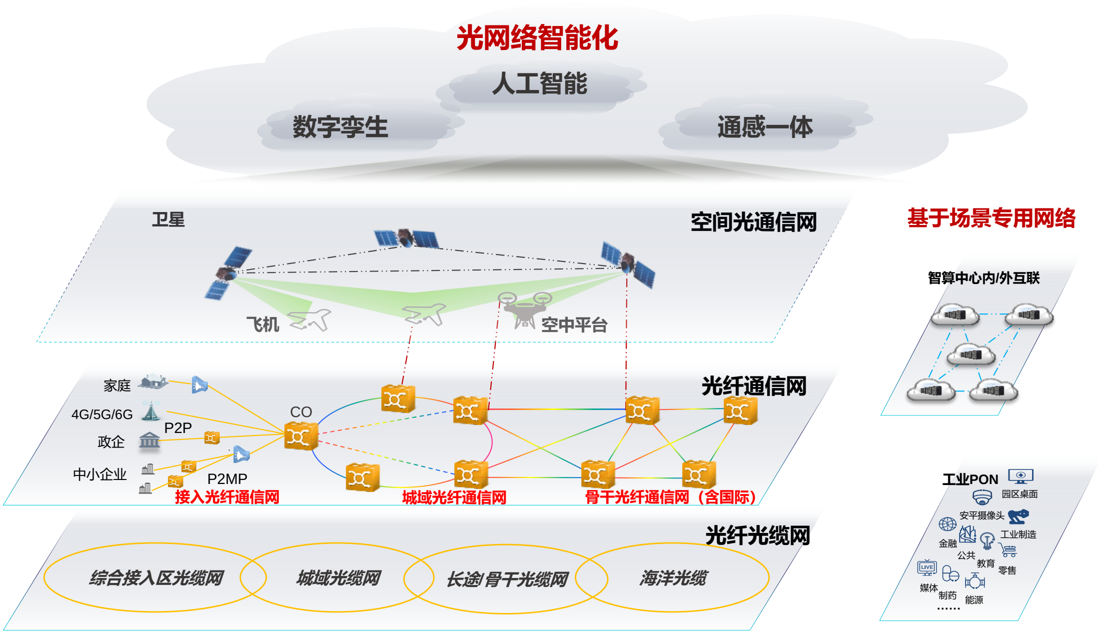

图 1 “全光网 3.0”目标网络架构图

图 1 为“全光网 3.0”的目标网络架构，涵盖光纤光缆网、光纤通信网与空间光通信网，以及基于场景专用网络与光网络智能化体系。

光纤通信网按层级划分为骨干、城域和接入网络；基于场景化构筑智算中心网络和工业 PON；引入光网络智能化能力，形成以人工智能、数字孪生、通感一体为代表的全生命周期智能化体系。

3.2. 光纤光缆网目标架构

光纤光缆网的目标是**广覆盖、低时延、多路由、强感知**，在不同光纤光缆网络层级进行合理规划、部署和建设，适时适度引入新型技术方案。

中国电信光缆网将以服务国家战略和企业发展为目标，扩展全球海陆缆网络布局，构建一个高效、稳定、安全的境内外一体化承载底座，实现全球主要国家和地区的网络通达，增强网络韧性和服务能力。

国际光缆网通过海陆并重、建采结合的方式构建路由多样均衡的国际传输承载网底座。海洋光缆网通过多区域和多路由建设布局，根据需求采用“开放海缆（Open Cable）”架构，融合智能监测技术，强化海洋风险评估，完善主动预警综合保障体系，构建安全可靠的国际通信。同时，积极探索并获取中东、中亚、南亚及东南亚大湄公河区域等方向陆缆穿境资源，拓宽陆地光缆通道，推动多个陆海光缆联运通道建设，为海洋光缆网提供强有力的业务分担与安全备份。

国内骨干光缆网围绕国家算力枢纽节点，构建高效直达（低时延）和战略底座（广覆盖）协同的立体化布局，高效连接超大型/大型数据中心，覆盖枢纽、核心机楼，衔接亚美欧的国际通信出入口局和海缆登陆站。构建干线光缆城区终接新型结构，优化局房基础设施布局，减少进城绕转，优化时延并提升网络安全性。全面部署 G.654.E 光缆，

满足单载波速率400Gb/s及更高的传输系统部署要求。

城域光缆网打破行政区域组网限制，相邻地市间实现跨县镇就近光缆互通，城域多层结构逐渐加密网格，以满足城域网扁平化和边缘下沉的需求。

针对新型光纤光缆，对低时延要求高的线路按需引入空芯光纤；共建共享、管道资源稀缺等场景下，逐步推进大芯数光纤光缆应用；在数据中心内部互联和海洋光缆传输等特殊应用场景，关注空分复用光纤技术发展。

光纤光缆网应具备光纤自身状态和环境情况感知能力，支撑光纤通信系统、城市建设健康监测与地震预警等应用。

光纤光缆网目标架构的实现，在技术方面主要依托新型光纤光缆及配套技术的发展和感知技术的成熟。

3.3. 光纤通信网目标架构

3.3.1.骨干光纤通信网目标架构

骨干光纤通信网的目标是构建以云/数据中心（DC）为中心、**国内多层次网络融合、国际国内一体化、地面网络与卫星空间网络协同**的综合传输承载精品网络，提供**超大带宽、超高可靠、极低时延、弹性敏捷、多维感知、智能运营**的网络能力。

国内网络多层次融合组网：按照一二干融合组网，打造全光覆盖基础干线层和立体高效调度层网络架构，实现多速率、多类型业务高效融合承载、快速敏捷拆建。

国际国内一体化组网：加强国内和国际网络（含陆缆系统与海缆

系统）一体化规划、一体化建设和一体化管控，打造高速大带宽、时延极优、开通快速、调度灵活、安全高效、运营统一的全球一体化专线承载网，实现跨国跨区域业务的端到端快速开通和统一管控，在符合各国对网络合规性要求的前提下，满足公众客户和专线客户高效数据传送服务需求。

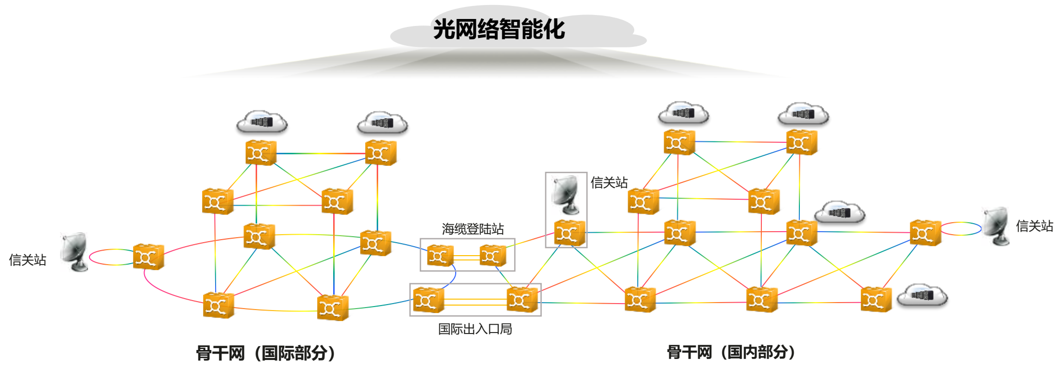

图 2 骨干光纤通信网目标架构

地面与空间光网络协同：通过对地面信关站实施精准覆盖，引入统一管控系统，打造与卫星空间光网络设备层高效互联、控制层智能协同的地面骨干光纤通信网。

骨干光纤通信网目标架构的实现，在技术上主要依托高速大容量全光传输和全光交换技术、管控一体化技术等。

3.3.2.城域光纤通信网目标架构

城域光纤通信网的目标是以云/DC 为中心，逐步实现从“**核心-汇聚-接入**”三层网络向“**核心汇聚-接入**”二层网络的扁平化演进，通过与空间光通信深度协同，达成空地融合发展，提供**灵活敏捷、安全可靠、分级 SLA** 差异化服务能力。

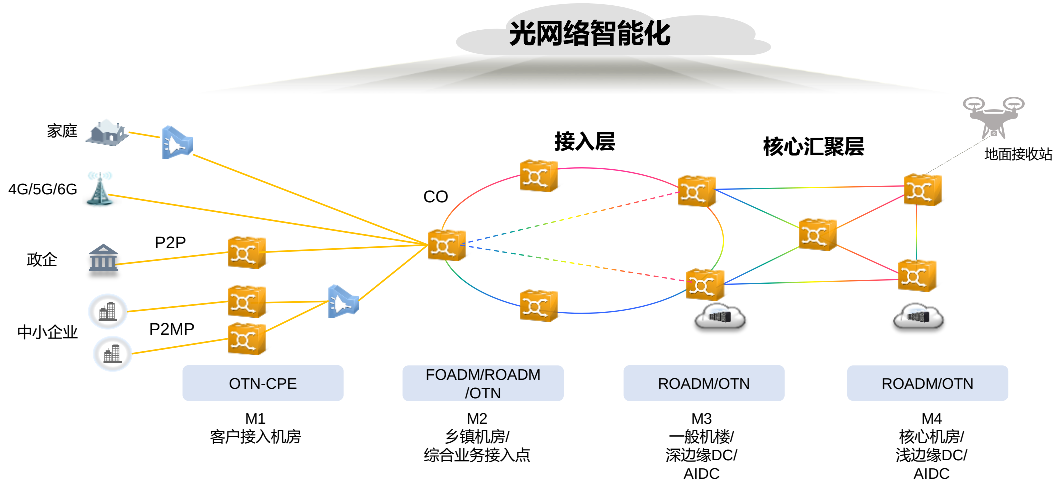

图 3 城域光纤通信网目标架构

网络结构：核心层和汇聚层融合网格化组网，提供波长级大带宽直达连接能力，单站点线路方向保持 3 个以上，通过组建 ROADM 全光网络，保障城域网络的业务弹性配置与灵活调度，减少电层转接和中继，降低网络时延和成本。接入层以环形组网为主，综合业务节点支持多业务泛在接入，部分大型本地网按需逐步向网格化演进。

空地一体：结合低空无人机系统，城域网络覆盖地面接收站，构建地面接收站—低空无人机—卫星的多层次通信链路，对于偏远地区进行补充覆盖，同时增强密集区域的网络接入能力。这些新增链路可作为应急通信出口，提升城域网络的可靠性。

业务体验：针对城市算网需求，提供 1ms 快速入算/算间互联服务。通过业务流特征识别应用，提供多种量纲（如带宽、时延、网络可用率、加密安全等）的分级 SLA 差异化服务，为客户提供定制化、高质量的网络服务体验。

城域光纤通信网目标架构的实现，在技术上主要依托低成本波分复用技术、全光组网技术、城域光传送网（M-OTN）/OSU 技术，以

及应用识别 SLA 分级技术。

3.3.3.接入光纤通信网目标架构

接入光纤通信网的目标是构建以**“万兆光宽-FTTR”**为核心的网络架构，在家庭场景保障智慧生活新体验，**工业行业场景**支持**智能制造**升级，园区场景支撑数字化加速转型，前传场景按需升级前传波分网络速率和容量以**满足未来第六代移动通信（6G）对于前传承载网的需求**。

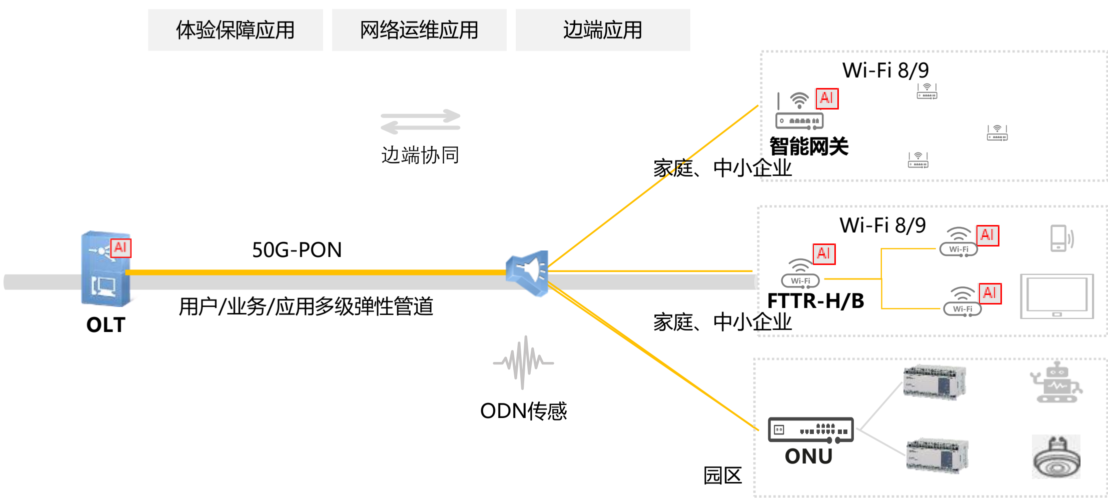

图 4 接入光纤通信网目标架构

在室外方面，针对重点区域/场景/业务，千兆光网按需向万兆光网升级，形成万兆接入管道能力；在 OLT 和系列终端的边端算力基础上，结合 AI 构建分布式智能体并支持协同交互，支持弹性智联和应用级业务保障能力，提升接入效率和服务体验；以 ODN 光纤为介质，探索通信和传感一体化能力。

在室内方面，基于 FTTR（-H/-B）主从节点、路由器等端侧系列化智能设备，构建以光纤为物理层链路、中间件为软件底座、应用智能体为中枢控制、新一代 Wi-Fi 为末端延伸的新一代室内光网，协同

千兆/万兆接入光网，着力发挥运营商在云网和业务领域的优势。

接入光纤通信网目标架构的实现，在技术上主要依托 50G-PON、FTTR-H/B、Wi-Fi、AI/智能体、ODN 传感、与 50G/100G 前传波分等技术。

3.4. 空间光通信网目标架构

空间光通信网的目标是构建一张以**“星-空-地”多平台协同**为核心，**光为基础的层次化协同、动态可控**的空天地融合通信网络。同时，与地面光网络形成互补互联的统一架构，为未来全球范围内的光网络资源互联、感知信息汇聚和任务数据回传提供泛在、高效、可靠、安全、全天候在线的广覆盖光通信能力支撑。

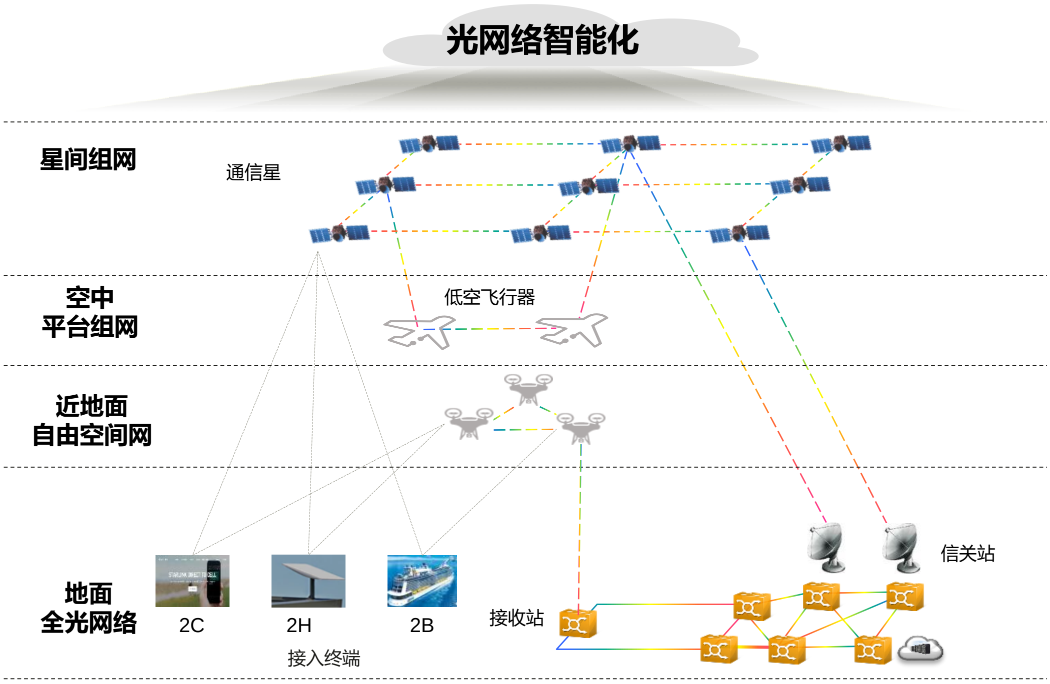

图 5 空间光通信网目标架构

星地与星间光通信组网：依托现有低轨卫星之间的高速激光互联，采用频谱或管道租赁的方式，构建大容量、低时延的空天骨干网络，结合卫星与地面站的高速星地链路，形成立体化的天地数据传输通道。

空中平台组网：基于飞机、无人机等高空/中空平台构建空中光通信节点，通过激光链路实现跨区域的快速数据中转。同时，实现与地面站等节点的统一调度、灵活部署能力，适配数据传输需求。

近地面自由空间光通信组网：面向海岛接入、跨江传输、跨楼宇通信等环境，部署点对点短距离高速激光链路，以低成本的方式构建光纤难以到达区域的高带宽接入补盲网络，有效拓展光网络的边界覆盖能力。

空间光通信网目标架构的实现，在技术上主要依托大气湍流补偿技术、多普勒频移补偿技术，以及捕获、跟踪、瞄准（ATP）等技术。

3.5. 基于场景专用网络目标架构

3.5.1.智算中心光网络目标架构

智算中心光网络的目标是构建一张**贯穿智算中心之间和内部的全光高速网络**，涵盖跨智算中心互联、智算中心内部互联以及中心间与中心内的网络融合，实现算力和网络资源共享。基于算网协同实现本地及远端资源的灵活互联，动态构建多地互联的分布式集群，满足推理和训练等各类业务的超宽带传输、无损低时延通信和算力资源灵活调度等关键需求。

跨地域智算中心之间互联：基于城域网或骨干网，依托400G/800G ROADM 逻辑平面，实现跨地域智算中心之间超大带宽、超高可靠的光联接。在业务密集的城域短距离智算中心间，可根据需求部署轻量化光传输设备实现互联。为确保网络连接的高可靠性以实现无损化传输，可探索 50ms 波长重路由恢复技术。

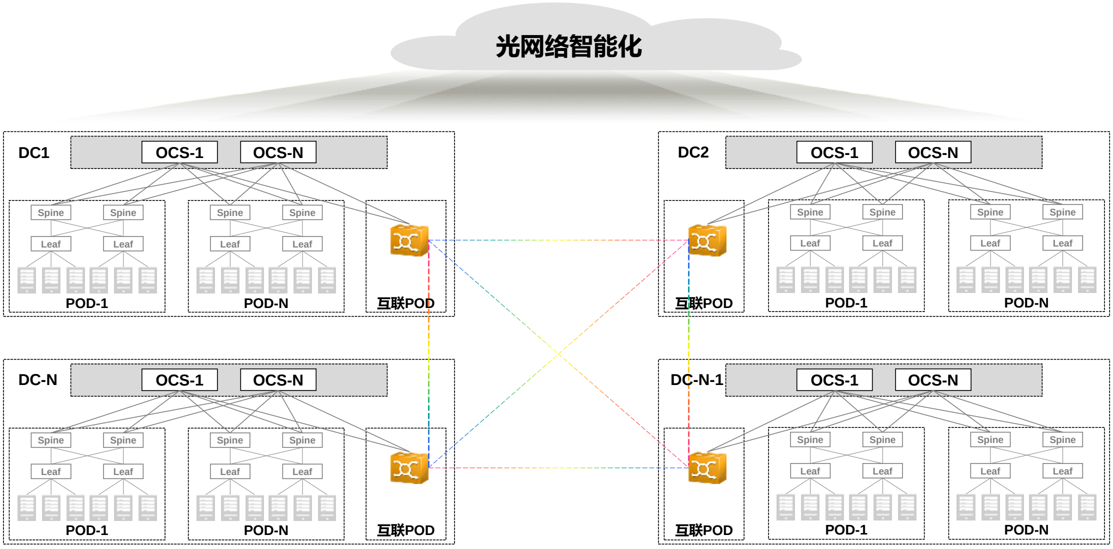

图 6 智算中心光网络目标架构

智算中心内部大规模算力互联：全光交换机（OCS）在部分超大规模数据中心内替代传统电架构的核心层交换机，未来甚至进一步下沉部署于超节点内，实现智算中心内各算力节点间的大容量无阻塞互联。未来引入芯片出光与光电合封技术，如共封装光学（CPO），进一步降低卡间互联功耗与延迟，提升卡间互联带宽密度，实现智算中心内部更强算力、更大规模的高效互联。

智算中心内外网络融合：在管控层和设备层需要具备协同的能力，光传送网（OTN）设备需感知远程直接内存访问（RDMA）协议，实现各智算中心之间的数据无损传输。融合网络基于跨域算力调度能力，依托算网协同的运营平台实现算力资源的状态感知与统一调度，灵活供给互联带宽。结合波长动态拆建能力，网络可根据任务类型和业务负载精准配置光层资源，提升智算光网络资源调配效率与服务弹性。构建“芯片—机柜—集群”全光化链路，全面释放智算网络的性能潜力。

智算中心网络目标架构的实现，在技术上主要依托超高可靠的弹性带宽技术、50ms 波长重路由恢复技术、OCS 技术，以及先进的光电封装技术。

3.5.2.工业 PON 光网络目标架构

工业 PON 光网络的目标是构建以**算网控制一体化**光底座为核心，具备**泛在互联、确定性承载、高度智能化**能力的通信基础设施，实现企业信息网、工业控制网、设备连接网多子网的一网承载。

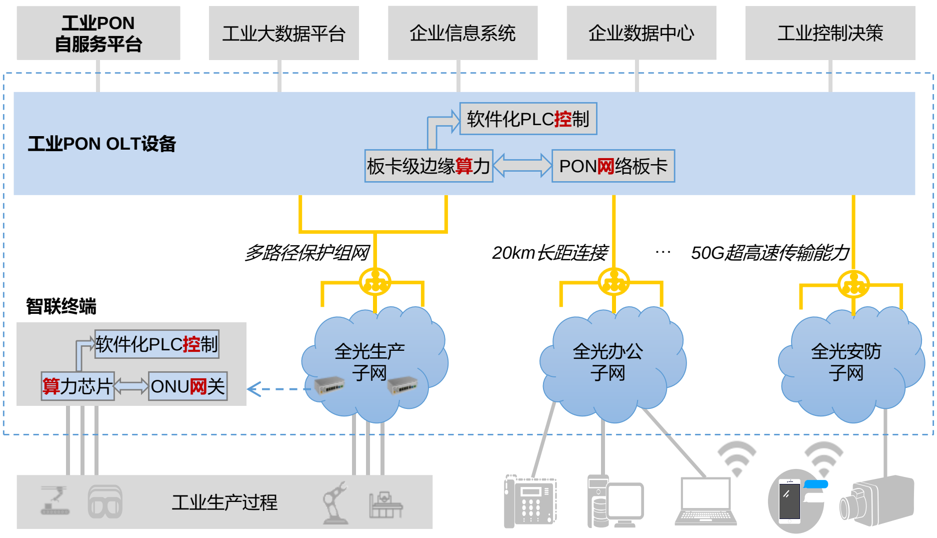

图 7 工业 PON 光网络目标架构

设备形态： 具备算力和边缘工业应用的新型 OLT 和光网络单元（ONU）设备，支持边缘算力、网络终端、软件化可编程逻辑控制器（PLC）一体化集成，实现单节点集约赋能。

网络通信： 面向智能制造中多源异构大数据的确定性传输需求，基于多级协同的确定性技术，构建差异化业务确定性保障能力。

光网/工控融合： 在时间同步、实时网络控制联动等层面优化，为工业应用提供更高效的融合解决方案。

管控模式： 构建全光工业组态，基于 PON 网络层次化开放接口，

打造工业业务极简定制能力，以此简化工业 PON 落地应用。

工业 PON 网络目标技术架构的实现，在技术上依托多级协同的确定性技术、算网控一体化集成技术以及工业组态技术，推进 PON 网络和工业应用的深度融合。

3.6. 光网络智能化目标架构

光网络智能化的目标是以“弹性敏捷，智赋网慧，内识外探，分级体验”为核心，**原生光智能为根基，开放管控为基础**，实现跨厂商跨域的数据实时采集、数据统一共享和管控协同；深度融合数字孪生、通感一体和人工智能等新技术，形成**“三层原生智能”架构**。

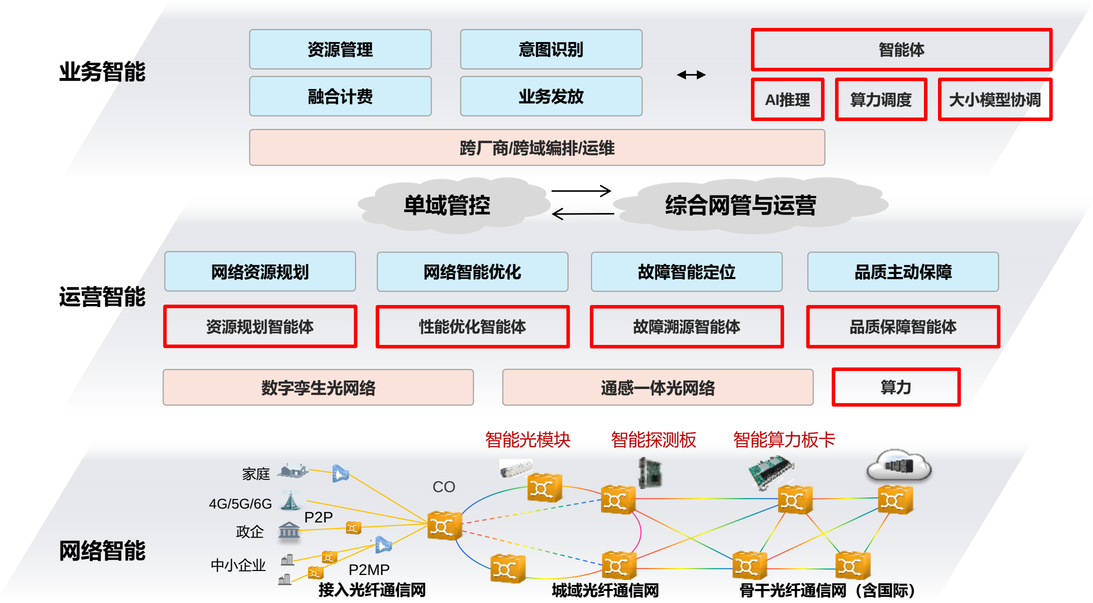

图 8 光网络智能化目标架构

网络智能层：通过分布式传感、数字信号处理（DSP）等技术及嵌入式原生算力与 AI 实时推理能力，实现对光纤链路及设备的多维度物理参量的精确感知、快速采集，推动网元从“被动响应”向“主动感知-决策-优化”、管理控制从“静态规则和策略”向“基于动态

模型和智能体驱动”的智能化跃迁，提升网络传输效率和资源利用率。

运营智能层：通过数字孪生、AI与大模型技术深度融合，构建覆盖全域的智能化管控体系，实现联接智能调度、网络健康度评估、故障溯源的端到端协同管理。基于开放架构整合多厂商设备能力，支持灵活策略生成与自动化运维闭环，推动光网络从“人工干预”向“意图驱动、自治闭环”转型。

业务智能层：实现体验保障/边端应用智能体，完成目标定义、任务链规划、用户意图和环境事件感知，按需与云侧通用智能体和数字人应用协作；通过智能化能力与业务场景深度融合，基于动态感知与智能决策体系，支撑业务敏捷发放、SLA风险预判及资源弹性调度，构建“需求-策略-执行”的智能闭环，驱动光网络从“应答式服务”向“主动服务”转型，提供高可靠、自适应的智能化业务体验。

3.6.1.光网络通感一体目标技术要求

光网络通感一体在传统光网络的基础上，强化光网络状态与外部环境监测，形成**“网络感知-业务感知-环境监测”三大关键能力**，以提升光网络韧性及智能化能力。

网络感知：以分布式光纤传感、DSP光信号监测等技术为核心实现光纤质量、光纤路由、系统性能等多维感知增强。升级已有光时域反射仪（OTDR）和DSP分析能力，实现光纤链路闪断异常的高敏度捕捉；引入分布式声学/振动传感（DAS/DVS）技术，感知光纤外部振动特征，实现光纤同路由风险预警；基于节点性能和配置数据，主动感知系统性能，建立ODN数字化视图，结合物理拓扑，实现光路

主动排障和稽核。

业务感知：通过毫秒级监测和业务特征识别技术，实现业务质量感知增强，对业务中关键应用的质差进行监控和优化，支撑应用级SLA保障；毫秒级流量监测支撑业务带宽扩容，并实现业务流量突发导致的丢包、误码等问题感知和定位。

环境感知：基于分布式光纤传感技术检测如振动、温度等环境异常，增强光纤周边环境感知能力，可及时发现陆缆光纤被施工挖断、海缆光纤被抛锚影响等故障风险；可开放感知能力，拓展环境监测潜力，支撑园区周界入侵、城市交通态势感知、桥梁健康监测及海底地震预警等应用。

3.6.2.光网络数字孪生目标技术要求

光网络数字孪生系统作为增强管控技术，可与当前管控系统一体或分离部署，以**"虚实映射、智能闭环、全域协同"**为核心，涵盖数据层、模型层、服务层、交互层四大层级，推动分层解耦、跨域融合，支撑光网络全生命周期智能化管理。

数据层：精准感知与高效治理。光网络数字孪生体采集光网络物理空间器件、设备、拓扑、网络、业务等要素的数据信息建立孪生模型。网元侧通过嵌入式智能引擎对原始数据进行预处理，网络侧和业务侧整合多域数据，构建全域资源统一视图，提供高质量数据底座。

模型层：高保真虚拟模型构建。通过基础模型、功能模型及知识库，建立光网络物理实体与数字空间的精准映射，实时同步网络运行状态的高保真仿真，支持跨厂商、跨域与多层级协同建模。

服务层：智能决策与闭环控制。依托仿真推演、分析评估与优化决策能力，提供网络规划、故障预判、资源调度等服务。例如，通过因果推理引擎实现故障根因秒级溯源，结合强化学习生成动态优化策略，驱动网络自愈与 SLA 主动保障。

交互层：单域互通与跨域协同。数字孪生网络内部通过标准化接口实现光网络单域数据互通与功能协同，北向接口实现意图翻译和能力调用，南向接口实现高速数据采集和控制下发，内部接口实现模型交互；另外，数字孪生架构支持跨领域智能化架构和与其它领域的交互协同，通过开放的标准化接口，实现跨领域应用。同时，数字孪生系统可实现人机交互，显著提升复杂系统透明化管控与敏捷响应能力。

3.6.3.光网络人工智能目标技术要求

为应对 AI 时代新型业务对网络的高要求，光网络需构建**“资源智能协同、隐患主动防控、运维自智闭环”的关键能力**，在自动化管控的基础上引入大小模型协同的多智能体体系，实现光网络“规、建、维、优、营”全生命周期自智能力。

网络规建：构建高可靠、低时延、敏捷的网络。基于业务需求和资源预测规划，保障业务敏捷提供。通过时延评估规划，实现算网低时延圈的精准覆盖。基于数字孪生规划，强化高可靠拓扑结构、设备选型、站点位置选择等规划，保障网络无单点失效，提供高可用率等级业务。

网络维护：提升故障处理效率。通过毫秒级感知实现闪断精准定位，利用智能化光模块检测故障原因。基于 AI 算法实现根因告警识

别，并通过大语言模型实现交互式运维助手和精准故障定位。基于通感一体，对光缆及周围环境振动情况进行监测和分析。

网络优化：实现网络隐患的自动识别和主动优化。在纤缆层自动识别光纤同沟/同缆，主动优化路由。在网络层评估光链路性能，并主动调优；主动预警时延绕路等风险开展拓扑优化。业务层主动识别应用质差，自动提供高优先级连接，保障业务 SLA。

网络运营：实现业务敏捷与用户满意度双提升。进行基于意图识别的多因子路由规划，构建波长自动发放能力，实现分钟级业务拆建。基于数字孪生技术，模拟业务配置和路由等调整，支撑业务快速发放和智能调度。基于弹性算力，通过光缆质量感知、分布式智能体灵活部署、算网智能管控协同调度技术，实现差异化 SLA 应用级体验保障能力。基于 AI 驱动的本地服务类智能体，实现在自然语言交互、知识问答、智能客服等业务服务。

4. 全光网 3.0 分阶段演进策略

4.1. 2030 目标和演进策略

1）光纤光缆网

国际光缆网加强主要方向的海缆建设，在亚太、亚欧、亚（南）美、亚非方向新增采用“Open Cable”模式的新海缆系统，并采用穿境陆缆+海缆登陆站+国际海缆的海陆联运模式拓展出口方向及通道，增强国际网络韧性；提升国际延伸段与跨境段光缆层级，将国际通信出入口局、信关站的接入段全部纳入一干光缆直接接入，增加国际网络质量与安全性。骨干光缆网基本完成高效直达光缆网建设，完成干线光缆城区外终接的新型结构优化调整，加快 G.654.E 光纤光缆建设，基本完成 2000 年以前建成的一干光缆焕新工程，保证光缆网络质量。在大型数据中心园区内互联、跨越大江大河、共建共享等特殊区域开展芯数≥288 芯的基于单模光纤的大芯数光纤光缆试点；在金融交易所之间与算力需求旺盛的数据中心互联区域进行空芯光纤光缆试点；跟踪空分复用光纤光缆应用，适时推进其在数据中心内部与海缆传输中的应用。

城域网持续加密光缆网格，核心/汇聚层光缆多路由、接入层光缆至少双路由，满足 ROADM 与波分复用（WDM）/OTN 在城域网中的演进需求，进一步提升城域光缆网的质量。同时，在部分城域光缆网开展路由的可视化管理及故障定位能力试点。

2）光纤通信网络

骨干光纤通信网：坚持一二干融合架构。400Gb/s ROADM 网基本实现扩展 C+L 波段一体化，依托 400Gb/s ROADM 网光层，在网络业务流量集中的方向和区域开通 800Gb/s 波长，实现多速率混合 ROADM 全光交换组网。

100Gb/s ROADM 网络借助冗余 OTU 端口提供辅助检测光源，400Gb/s 及以上速率 ROADM 网络借助填充光提供辅助检测光源，通过软件调度进行恢复路由性能检测和故障定位，增强网络可靠性，持续提升波道恢复成功率，在网络资源具备的情况下，单点光缆故障的业务平均恢复成功率实现 98%。

融合海陆缆资源，提供国际跨区域三路由能力，并协同卫星光网，延伸覆盖地面信关站，通过跨域跨厂家的统一管控系统实现面向政企专线业务的综合承载和端到端开通。

提升网络敏捷灵活性并匹配智算网络演进发展趋势，网络由静态联接向动态按需拆建能力演进，为入算、联算业务提供分钟级动态拆建能力。

进一步提升网络运营效率，在网络资源具备的情况下，光信道发放时间由天级向小时级、分钟级演进，同时针对多速率、多频宽承载的场景提供资源预测和调优能力。

按需部署光系统检测点，例如光性能监测（OPM）、DAS、OTDR 等，升级网络数字化能力，提供确定性的业务体验。

进一步简化光网络，完成链状波分系统退网，公众业务全部由 ROADM 网络承载。

城域光纤通信网：大型、特大型城市基本实现核心汇聚层扁平化融合，网格状组网；接入层逐步具备快速入算能力，大中型城市的核心区域实现 1ms 快速入算/算间互联。DC 间引入单载波 800Gb/s 或 1.6Tb/s 实现大带宽互联。基于 M-OTN/OSU 的动态灵活小颗粒业务承载技术逐步替代基于同步数字体系（SDH）的以太网业务承载（EoS）技术，实现端到端业务开通调度和带宽调整。网络支持通过业务流的特征来识别应用的类型，提供分级 SLA 差异化服务。探索 IP+光协同、O 波段波分等技术在城域光纤通信网的应用。

接入光纤通信网：具备 50G-PON 万兆光网方案的规模部署能力（支持三代共存、50G-PON 通道上行双速率接收等特性），重点区域和场景实现万兆光宽升级和覆盖；探索下一代超高速 PON（VHSP）（暂定 200G-PON）关键技术和领先应用。面向家庭和中小企业具备 10G 速率 FTTR 部署能力，支持集约化 Wi-Fi 管控能力、网络质差标签体系，以及闭环调优能力，实现多元化应用互联互控能力；为 AI 应用提供了高速、稳定、灵活的数据接入和无损传输能力。探索 50G/100G 等面向未来 6G 业务需求的前传光模块试点。

3）空间光通信网

完成实验室星间/星地激光链路技术验证。在应急通信场景中，引入近地面的自由空间光（FSO）通信技术，实现自然灾害条件下的分钟级通信恢复，以及海岛、海上社区的数据互联。

4）场景专用网络

智算中心光网络：实现多个区域内算力中心高速互联。部分城域

网引入基于快速波长切换激光器的 50ms 电信级 WSON 恢复能力，以及无损的传输能力，确保网络连接的高可靠性。部分数据中心内试点部署 OCS。智算中心内外融合网络初步具备跨域算力调度能力，开展算网协同运营平台试点，实现算力资源状态感知、按需编排、统一调度。探索为政企客户提供“网络+算力”的新型服务模式。

工业 PON 光网络：面向垂直行业，突破高速实时全光现场网络关键技术，推进通信技术（CT）/运营技术（OT）的深度融合；构建 PON 网络层次化开放能力，研制全光工业组态软件，推进工业 PON 的落地应用。

5）光网络智能化

基于内识全域感知，全面支持光缆质量、传输性能和业务 SLA 的管理。实现光网络单域孪生，具备仿真建模、拓扑映射、动态同步、状态预测和故障推演的能力。探索大模型和智能体技术融入光网络全生命周期，自主完成感知、分析、决策与执行任务，支撑资源规划、网络各层级性能及故障实时感知、业务动态拆建、分时复用和差异化品质保障等应用，实现故障溯源、动态调优、自动扩容等闭环自智场景，并逐步开放为客户提供简洁的智慧化服务。基于光网络智能化技术，实现毫秒级感知、分钟级故障溯源以及分钟级业务发放，推动光网络达到高度自智等级。

4.2. 2035 目标和演进策略

1）光纤光缆网

国际海缆网持续增加亚太、亚欧、亚（南）美、亚非方向的海缆

投产，增加出口方向及通道。国内骨干光缆网不区分省际一干和省内二干光缆网，主要采用 G.654.E 光纤完成高效直达（低时延）干线光缆网、基本完成战略底座（广覆盖）干线光缆网的建设，覆盖全国所有省会、地市核心枢纽楼及 DC、国际通信出入口局、海缆登陆站和信关站。完成 2010 年前建设的干线光缆焕新工程。时延需求热点区域按需部署空芯光纤，开展 500 芯以上的基于单模光纤的大芯数光纤光缆试点。

城域光缆网普遍具备多路由的光缆能力，基本完成 2010 年前建设的城域光缆的焕新，大幅度提升城域光缆的质量、安全和容灾能力。同时，实现光缆路由的可视化，并在部分城域光缆网开展风险智能化预警及环境监测能力试点。

2）光纤通信网络

骨干光纤通信网：以 400Gb/s 和 1.6Tb/s 为演进代际，实现 400Gb/s 广覆盖，800Gb/s 区域提效后，逐步部署 1.6Tb/s，同步进行 C+L+S 波段创新和逐步商用，在 1.6Tb/s 代际实现单纤容量翻倍的目标。网络基本实现国内国际一体化，基本完成地面信关站覆盖，设备实现按需对接，逐步实现天地海协同的一体化管控，提供路由端到端可视可管可控、协同规划、协同保护等能力，同时实现专有加密专线/专网、永久在线的贵宾（VIP）高价值专线等新商业场景。

城域光纤通信网：完成大型、特大型城市核心汇聚层扁平化融合，网格状组网；大型城域网的核心层光层频谱扩展到 C+L 波段，探索单载波 3.2Tb/s 技术的应用。接入层向网格状网络演进，核心汇聚层

与接入层光层打通，提供波长直达能力。通过对业务的准确识别，结合 AI 技术对不同业务提供精细化区分的差异化管道，助力用户体验提升。

接入光纤通信网：深度覆盖万兆网络基础设施，基于 50G-PON 技术开展万兆光网规模建设。AI 智能体技术规模应用，结合 10G 速率 FTTR 技术、高速 Wi-Fi 将万兆能力、智能化运营服务能力延伸到用户/应用端。探索基于 200G-PON 的下一代 VHSP 的新业务试点和网络设备试商用。研究高集成度、低功耗前传光模块技术。

3）空间光通信网

基于频谱或管道租赁的方式，构建“星-空-地”融合的空间光通信网络，作为地面网络的补盲能力，并在条件允许的情况下，与地面光缆链路统一调度、灵活部署，支持应急通信、远洋航运、边远接入、跨境数据等多场景。并适时开展 Tb/s 级星间、星地传输能力的大容量激光链路试验。

4）场景专用网络

智算中心光网络：全面建成算网一体的区域内高质量智算中心互联网络，具备算力泛在互联、灵活编排、智能调度能力。基于芯片出光技术，在部分智算节点打通“芯片-机柜-集群”的全光化链路。根据不同场景按需部署差异化能力的波分系统，在集群间部署支持长距的 800Gb/s 密集波分复用（DWDM）系统，在城市间部署 1.6Tb/s DWDM 系统，在城域短距 DC 间部署 3.2Tb/s DWDM 系统。OCS 与智能调度系统全面融合，支撑各种算力互联的任务。构建电信级算网

运营平台，提供算力租用、算力入云、异地协同等标准化服务，支撑高价值业务连续运行。

工业 PON 光网络：面向垂直行业，针对多行业定制化需求开展基于新型全光工业网络的场景化应用创新，推进规模化应用。

5）光网络智能化

突破全生命周期数据贯通与策略联动技术，实现零人工干预的自智；深化大小模型与开放管控协同，构建“光-感-业”融合的服务，扩展空天地海智能化场景；开放网络自智接口赋能千行百业，保障技术可持续发展。光网络全面提升自智能力，网络具备跨域孪生与自我进化能力，可动态适应未知业务场景与外探环境变化。

5. 全光网 3.0 重点技术创新方向

5.1. 新型光纤光缆技术

当前，新型光纤光缆主要包括空分复用光纤、基于单模光纤的大芯数光纤光缆与空芯光纤。空分复用光纤中弱耦合多芯光纤最具实际应用潜力，可实现单根预制棒的千公里拉丝，串扰可实现 C 波段下-45dB/100km，对近千公里传输系统影响较小。然而，弱耦合多芯光纤存在熔接时间长、芯间损耗差异大、系统复杂等问题，且当前还未解决能够降低系统复杂度的放大问题，未来预期适用于数据中心、海缆等空间受限场景。基于单模光纤的大芯数光缆依靠光纤小型化与光单元紧凑化，单根光缆可容纳数千根纤芯，降低管道受限场景下的建设成本，技术上基本不存在瓶颈，需进一步解决接续时间长和损耗大问题。空芯光纤已实现最低衰减＜0.1dB/km，但当前存在常用波段的吸收峰、结构标准不一、成本高、OTDR 与大输出功率放大器等配套设备发展不成熟等问题，同时需要进行施工维护方案探索，未来可优先应用于时延敏感业务。

5.2. 高速大容量全光传输技术

单载波超高速、超宽带与超长距离传输是突破光通信容量与性能瓶颈的关键技术。在单载波超高速传输方面，目前业界已推出基于约 200GBaud 的单载波 1.6Tb/s 商用产品，并向着更高速率持续演进。在超宽带传输方面，扩展 C+L 波段已在运营商网络中开始规模部署，S+C+L 波段有望成为下一代波段扩展的方向，全波段（O/E/S/C/L/U）

的传输方案在实验室已有初步的验证。在超长距离传输方面，单载波400Gb/s 系统已覆盖 2000km，800Gb/s 有望超 1500km，持续支撑陆地骨干网与全场景光网络发展；对于海底光缆系统，单载波 200Gb/s 无电中继距离将超 15000 公里。在技术上，单载波速率的提升依赖于大带宽器件，以及高端制程的 DSP 芯片技术；超宽带传输则依赖各波段光电器件的成熟、功率管理机制与损伤补偿技术；超长距传输则依赖新型光纤的突破，如超低损大有效面积光纤（G.654.E 光纤），DSP 补偿算法的创新，以及低噪声光放大器的优化等。

5.3. 全光交换技术

高维度波长选择开关（WSS）、WSON 快速恢复与 OCS 是提升光网络灵活性与可靠性的关键技术。作为 ROADM 的核心器件，WSS 已实现 1×32 维（线路组）与 1×40 维（本地组）的规模商用。面向多路由、高业务量的场景，需推进 N×M 高维度 WSS 应用以降低空间与成本。WSON 基于“集中算路+分布式控制”，结合假光监测与光信噪比（OSNR）建模，实现恢复路由的快速感知；通过协议、WSS 器件、光放大器、光模块等技术的突破实现 50ms 级 WSON 恢复，提升光网络的可靠性，目前正处于样机验证阶段。OCS 通过微机电系统（MEMS）或硅基液晶（LCoS）实现全光透明交换，当前已在数据中心内开展试点工作，未来有望拓展至智能配线应用，支撑 AI 集群与光网络的智能运维。

5.4. 全光接入技术

室外光接入最新技术能力是 50G-PON，采用单纤双向时分复用

（TDM）技术，支持 50Gb/s 下行、25Gb/s 与 50Gb/s 双速率上行，兼容现有 ODN 网络，可规模提供万兆接入能力；面向规模商用部署，需突破高功率预算、波长冲突、互通性等关键技术与工程瓶颈。下一代 VHSP 预期拥有至少 200G 业务接入能力，兼容多代 ODN，存在直调直检（IM/DD）（具备低成本低功耗优势，但技术难度高）和相干（具备灵活接入能力，但成本高）两种技术路线，其国际技术标准预计 2030 年左右初步完成。室内全光组网技术通过点到多点（P2MP）拓扑，将光纤延伸至室内，主从网关之间支持 2.5Gb/s 与 10Gb/s 两种速率，并结合 Wi-Fi 6/7/8，提供大带宽、低时延服务。面向高效运维与体验保障，在光接入和 FTTR 系统层面重点推进智能管控、边端算网协同等技术，以提升网络可管理性与服务质量。

5.5. 工业 PON 技术

当前工业 PON 可提供高性能高可靠的工业连接光底座，满足智能制造多场景多模态工控数据确定性传输需求，并构建基础、实时、等时同步差异化通信等级，增强光网络在工业场景的适配性与可靠性。同时，面向工业场景应用和网络协同配置需求，研制全光工业组态，以图形化、模块化方式标准化设备、控制与数据交互，降低工控系统开发门槛，助力工业数字化转型与规模化落地。

5.6. 通感一体技术

光网络通感一体技术是在光网络的基础上融合多种感知手段，实现对网络的高可靠感知能力。分布式光纤传感结合放大、编码等技术可在百公里级范围实现温度、应力、振动等多参量的空间定位，聚焦

多参量融合、大动态高分辨率感知、通感融合组网、AI智能处理等创新突破，面向海陆缆通信网，提供故障风险定位及预警能力。在设备、链路及系统层面，基于DSP或AI小模型，实时感知性能状态，且感知精度依赖光纤非线性效应；在业务层面，感知依托流量特征与应用标识，支持应用级SLA保障与光性能感知，现需突破算法与高速数据采集两大瓶颈。ODN传感基于无源器件后向散射，实现不中断故障监测与环境感知，提升接入网可靠性与运维效率。

5.7. 光网数字孪生技术

光网络数字孪生当前已基本支持物理网络与数字镜像的映射，其最新技术能力体现在可通过建模实现网络与资源规划、传输质量精准评估与风险分析、业务智能发放等典型应用。但仍面临三大问题：一是光器件物理建模精度不足，影响孪生可靠性；二是跨厂商设备数据以及不同环境下的数据异构性强，模型泛化能力受限；三是现有系统兼容数字孪生能力差，难以实现闭环的"感知-仿真-预测-验证-执行"。未来，突破方向可聚焦以下三方面：一是开发高准确度、高泛化性的模型；二是构建开放式数字孪生架构，实现多厂商设备统一接口；三是探索光网络数字孪生的闭环仿真、分析和验证能力，赋能光网络全生命周期，使规划更精确、建设更高效、维护更快速（分钟级故障溯源）、优化更及时（重路由恢复成功率>95%）、运营更敏捷（分钟级业务发放）等。

5.8. 光网络人工智能技术

人工智能技术正深度赋能光网络管控，实现自主分析与动态优化。

当前，AI 小模型已在光纤同路由检测、精确故障识别及智能 Wi-Fi 调优等特殊任务中展现了显著效果，提升了风险识别与定位能力。大模型结合运维模型、语料治理与微调，初步形成闭环智能体，但其应用并不广泛。自动化管控融合 AI，增强了波长/速率优化、SLA 保障及自动调测能力，推动光网络的高效敏捷运维。当前光网络 AI 技术发展仍面临两大关键挑战：一是 AI 大小模型在复杂场景下的自主决策可靠性、实时性以及可解释性不足；二是自动化平台需突破系统壁垒，实现更深度的跨层跨域协同。面向未来，需发展具备深度认知与复杂推理能力的下一代运维大模型，构建自适应网络知识图谱，攻克闭环决策技术，实现意图驱动且策略可解释的端到端智能化，实现在无人工或极少人工干预下，光网络资源的极致优化、故障的瞬时自愈、服务的按需智能配置。

5.9. 面向全光连接的光电集成新技术

硅基光电混合集成技术通过提高光模块内部芯片的集成度，逐步成为当前 1.6Tb/s 光模块的主流技术路线，并支撑未来单通道 400Gb/s IM/DD 与超 200GBaud 相干光模块发展。因此，需构建更为成熟和完善的国内产业生态环境，摆脱对高端原材料进口的依赖。在高集成低功耗封装方面，采用光电共封的 2.5D CPO 已能提供 3.2Tb/s~6.4Tb/s 总带宽，3D 封装将进一步提升互联密度，但仍需针对热管理、复杂工艺等问题进行攻关。基于小芯片（Chiplet）的光互连技术能够进一步提高 AI 算力集群的能效，为硅光技术提供了新的发展机遇。线性可插拔光模块/线性接收光模块（LPO/LRO）通过去 DSP 处理实现功

耗和时延的降低，但在互操作性上需要标准牵引。简化相干以低复杂度、低功耗等优势有望在 DC 与城域接入等场景中部署，但其规模应用需要软硬件技术的协同创新与突破。最后，多载波技术正成为制程与速率受限下的关键突破路径。

5.10. 空间激光通信技术

空间激光通信作为地面通信的重要补充，需突破大气湍流补偿、多普勒频移补偿与 ATP 等关键技术。目前，星间激光通信速率已达到 400Gb/s，基于相干探测、自适应调制等多项技术也开始进入试验阶段。当前发展趋势体现在以下三个方面：大气湍流补偿通过多入多出（MIMO）算法、自适应光学、孔径平均与分集接收提升链路稳定性与信号质量；多普勒频移补偿利用锁频环/锁相环（FLL/PLL）反馈与高速 DSP 算法，实时修正 GHz 量级频移，保障相干通信同步性与相位稳定；ATP 技术通过粗瞄准、光束捕获与精跟踪实现微弧度级精度指向，确保星间链路稳定。面向未来，空间光通信将实现 Tbps 级组网能力，支持星间、星地、星海的融合通信体系，在全球宽带接入、深空探测、灾难应急等领域发挥核心作用。

6. 全光网的未来展望

在“云改数转智惠”战略与“云网融合”目标下，中国电信将持续推进全光网络建设，面向“全光网 3.0”的三大愿景：“光云智融合、光感业融合、天地海融合”，通过技术创新，打造“泛在光速联、新型光媒质、动态光链接、原生光智能、多维光感知、分级光承载”六大基本特征，分阶段实现2030年能力基本达成、2035年能力完善稳定，构建架构稳定、敏捷智能、行业领先的全光网络。

“全光网 3.0”并非终点，未来将持续演进。面向智能时代，算力、存力、运力深度融合，全光网将进一步提升智能化水平，从底层硬件到顶层服务实现全面跃升，打造自感知、自决策、自演进的智能化网络。

全光网的进一步发展，离不开运营商、产业界、高校和科研机构的协同创新，持续突破高性能全光传输、全光交换、光电集成与感知智能等关键技术。中国电信愿携手产业伙伴，共建自主可控的全光网产业链。

附录 缩略语

中文名	英文缩写	英文全称
面向企业	2B	To Business
面向家庭	2H	To Home
第五代移动通信	5G	Fifth Generation Mobile Communication
第六代移动通信	6G	Sixth Generation Mobile Communication
人工智能	AI	Artificial Intelligence
捕获、跟踪、瞄准	ATP	Acquisition Tracking and Pointing
共封装光学	CPO	Co-Package Optics
通信技术	CT	Communication Technology
分布式声学/振动传感	DAS/DVS	Distributed Acoustic Sensing / Distributed Vibration Sensing
动态带宽分配	DBA	Dynamic Bandwidth Allocation
数据中心	DC	Data Center
数字信号处理	DSP	Digital Signal Processing
密集波分复用	DWDM	Dense Wavelength Division Multiplexing
基于 SDH 的以太网业务承载	EoS	Ethernet over SDH
锁频环	FLL	Frequency-Locked Loop
自由空间光	FSO	Free Space Optical
光纤到房间	FTTR	Fiber to The Room
地理信息系统	GIS	Geographic Information System
直调直检	IM/DD	Intensity Modulation/Direct Detection

中文名	英文缩写	英文全称
互联网协议	IP	Internet Protocol
关键绩效指标	KPI	Key Performance Indicator
硅基液晶	LCoS	Liquid Crystal on Silicon
线性可插拔光模块	LPO	Linear Pluggable Optics
线性接收光模块	LRO	Linear Receiver Optics
微机电系统	MEMS	Micro-Electro-Mechanical System
多入多出	MIMO	Multiple-Input Multiple-Output
城域光传送网	M-OTN	Metropolitan Optical Transport Network
网络即服务	NaaS	Network as a Service
全光交换机	OCS	Optical Circuit Switch
光配线网络	ODN	Optical Distribution Network
光线路终端	OLT	Optical Line Terminal
光网络单元	ONU	Optical Network Unit
光性能监测	OPM	Optical Performance Monitor
光信噪比	OSNR	Optical Signal-to-Noise Ratio
光业务单元	OSU	Optical Service Unit
运营技术	OT	Operational Technology
光时域反射仪	OTDR	Optical Time Domain Reflectometry
光传送网	OTN	Optical Transport Network
光转换单元	OTU	Optical Transform Unit
点到多点	P2MP	Point-to-Multipoint
可编程逻辑控制器	PLC	Programmable Logic Controller

中文名	英文缩写	英文全称
锁相环	PLL	Phase-Locked Loop
无源光网络	PON	Passive Optical Network
远程直接内存访问	RDMA	Remote Direct Memory Access
可重构光分插复用器	ROADM	Reconfigurable Optical Add-Drop Multiplexer
同步数字体系	SDH	Synchronous Digital Hierarchy
服务等级协议	SLA	Service Level Agreement
时分复用	TDM	Time Division Multiplexing
超高速无源光网络	VHSP	Very High-Speed Passive Optical Network
贵宾	VIP	Very Important Person
波分复用	WDM	Wavelength Division Multiplexing
波长交换光网络	WSON	Wavelength Switched Optical Network
波长选择开关	WSS	Wavelength Selective Switch

China Telecom All-Optical Network 3.0

Technical White Paper

China Telecom

July 2025

Content

1. Introduction

In the wave of global digitalization, Artificial Intelligence (AI) is becoming a key force driving transformation across various industries. As a crucial “information artery” supporting the development of emerging technologies like AI, new information infrastructure has become an essential component of the modern infrastructure system. Accelerating the construction of new information infrastructure plays a significant, strategic and supportive role in advancing new industrialization, building a modern industrial system, and fostering the development of new types of productive forces, thereby contributing to the construction of a manufacturing power, a cyberspace leader, and a digital China.

China Telecom, as the builder and operator of new information infrastructure, has been committed to constructing a service-oriented, technology-driven, and secure enterprise. It is promoting the deep integration of technological and industrial innovation, continuously enhancing the core functions of its network, and improving its core competitiveness. It adheres to the strategy of “Cloudification and Digital Transformation, and Intelligent Empowerment”, strengthens the goal of “Cloud-Network Convergence”, focuses on the concept of “All-Optical Network (AON)”, and strives to support the coordinated development of new information infrastructure.

Looking back, China Telecom’s “AON 1.0” focused on the core principle of “Fiber In, Copper Out”, achieving wide coverage and enhanced high-speed capabilities for optical networks. “AON 2.0”, with “all-optical switching” as its core, is the first to adopt Reconfigurable Optical Add-Drop Multiplexer (ROADM) and Wavelength Switched Optical Network (WSON) technologies at scale, driving the evolution of the network toward flat, fully optical, and intelligent architecture. Looking ahead to the intelligent era, China Telecom introduces the “AON 3.0” for continuous development and transformation, with an aim to build an optimized new-generation information-based optical network.

This white paper will comprehensively describe the visions of China Telecom’s “AON 3.0”, propose the target architecture and network features of “AON 3.0”, define its phased evolution strategy, elaborate on key technology innovations supporting sustainable AON development, and finally envision the future development of AON.

2. Overview of AON 3.0

2.1. Background

Currently, the technological revolution and industrial transformation are accelerating, with new-generation information technologies such as AI, cloud computing, and big data increasingly becoming key drivers of the deep integration between the real economy and the digital economy. These technologies continue to build a powerful engine for the development of the digital economy, driving the real economy to accelerate its transformation toward digitalization and intelligence. All the convergence and transformation rely on optical networks as the core link.

Chinese government has successively introduced relevant policies to strengthen the core role of optical networks. *The opinions on deepening the implementation of the "East Data, West Computing" project and accelerating the construction of a national integrated computing power network* emphasizes the need to "accelerate the construction of high-throughput, deterministic networks within national hub nodes, between national hub nodes, and between national and non-national hub nodes, and create a high-speed, ubiquitous, secure, and reliable computing transmission network". *The Notice on Conducting Pilot Projects for 10-Gigabit Optical Networks* stresses that, "In cities and regions with the necessary conditions and infrastructure, focus on key scenarios such as residential communities, factories, and industrial parks to carry out pilot projects for 10-gigabit optical networks", and "orderly guide the transition of 10-gigabit optical networks from technical trials to deployment and application".

China Telecom, as a key state-owned enterprise in the information and communications industry, is firmly committed to fulfilling its mission and responsibility, and is dedicated to contributing to the construction of a

Digital China, thus supporting the advancement of Chinese-style modernization. By strengthening its multi-dimensional network layout, China Telecom is building an integrated, high-quality network that serves both international and domestic markets. It is also constructing a resilient, ultra-wide, high-speed, and lossless foundational transmission network, continuously enhancing its computing power supply capacity. With the empowerment of AI, China Telecom is improving network intelligence, enhancing cloud network autonomous operation capabilities, reshaping service processes, and enhancing user experiences.

With the continuous improvement of network infrastructure capabilities, AI, data, large models, and networks are accelerating their integration, leading to a surge in demand for 10-gigabit access and intelligent application scenarios. So far, the number of cloud gaming users has exceeded 180 million, cloud phone users have surpassed 10 million, and many provinces and cities have launched 10-gigabit packages. Meanwhile, according to authoritative predictions, by 2033, AI-related traffic will account for 62% of global network traffic. AI is rapidly becoming the core engine driving the transformation of network infrastructure, creating an urgent need for a new type of optical network that offers high bandwidth, high reliability, low latency, agility, flexibility, and intelligent collaboration.

Against this backdrop, AON, as the foundation of information networks, not only affects the quality of new information infrastructure construction, but also directly affects the efficiency of computing power utilization and the level of service experience. Starting from 2025, optical networks will enter the “AON 3.0” era, where the network architecture and capability system will undergo systematic evolution, accelerating the development of new information infrastructure in China.

2.2. Values and Visions

"AON 3.0" is a key enabler for promoting the integration of new industrialization and digital infrastructure development. Through capacity upgrades, architectural reconstruction, and service model innovation, optical networks will transform towards digital-intelligent integration, multi-dimensional sensing and space-ground collaboration, while possessing core capabilities such as ultra-large bandwidth, ultra-low latency, native intelligence, elasticity and agility. It will promote regional resource collaboration and sharing, support the flexible allocation of computing resources, facilitate the efficient flow of data elements, accelerate the digital upgrading of industries like smart factories and smart offices, bridge the urban-rural digital divide in areas like remote education and telemedicine, and drive the sustainable development of both the real economy and the digital economy, ultimately unleashing new social economic momentum.

"AON 3.0" is an important concept that will lead the future development of the optical communication industry. Through technological innovation and integration, standard guidance, and industrial chain upgrades, it will drive the transformation of the optical communication industry over the next decade. Based on the "AON 2.0" architecture and technological innovations, it will further introduce and integrate cutting-edge technologies such as AI, digital twin, space communication, and multi-dimensional sensing. It will enhance the network adaptability to diverse service scenarios, pushing the optical communication industry to achieve a full-chain leap across upstream and downstream sectors, from transmission media and optoelectronic devices to equipment manufacturing and full-network system integration. This will usher in a new phase of high-quality development for the global optical communication industry.

"AON 3.0" will center around "All-Optical Intelligent Connectivity" and is committed to building an all-optical intelligent connection system with the vision of "Optical-Cloud-Intelligence Convergence, Optical-Sensing-Service Convergence, and Space-Ground-Sea Convergence". This will lay a solid foundation for the network infrastructure in the AI era over the next decade.

1) Optical-Cloud-Intelligence Convergence: Optical networks support the efficient connectivity of massive amounts of data, and enable deep integration with cloud resources through intelligent upgrades. Relying on elasticity, agility, ubiquitous collaboration, and intelligent perception, the optical network builds an efficient, centralized all-optical connectivity foundation for all network resources, including computing power, storage, and bandwidth. And it integrates autonomous network technologies across the entire lifecycle, including "planning, construction, maintenance, optimization, and operation", to meet the needs for rapid data exchange and intelligent scheduling between all users, terminals, nodes, and data centers.

2) Optical-Sensing-Service Convergence: By deeply coupling optical communication with optical sensing, the transition from a "connection channel" to a "perception hub" can be realized, driving the shift of optical networks from a passive transmission model to a paradigm that combines active sensing and differentiated services. Optical networks will not only transmit data but also possess the real-time perception capabilities of service quality, physical environment, and network facility status. This will support more intelligent and refined real-time service management, drive the evolution of applications toward quality differentiation and multi-dimensional sensing, further expand the boundaries of industry applications, and provide value-added services such as home security, earthquake early warning, and perimeter security.

3) Space-Ground-Sea Convergence: Through multi-dimensional network integration technologies, space-based optical networks (satellite communication), airborne optical networks (aerial platforms), ground optical networks, and submarine optical networks can be organically coordinated. The goal is to extend optical networks into space and air, break through traditional geographical boundaries, and construct a next-generation optical network system that offers seamless connectivity and a three-dimensional layout across space, ground, and sea. By leveraging the complementary collaboration of multi-level, multi-form networks, ubiquitous connectivity and efficient resource collaboration across space, ground and sea can be realized, supporting the deployment of applications across all scenarios and services.

3. Target Architecture and Network Features of AON 3.0

3.1. Overall Target Architecture of AON 3.0

To achieve the vision of “Optical-Cloud-Intelligence Convergence, Optical-Sensing-Service Convergence, Space-Ground-Sea Convergence” and to meet the core concept of “All-Optical Intelligent Connectivity”, a series of innovative technologies need to be introduced. The white paper believes that the target architecture of “AON 3.0” should possess the following six fundamental features:

1. Ubiquitous and Collaborative All-Domain Optical High-Speed Connectivity (Ubiquitous Optical High-Speed Connectivity)

Optical networks are rapidly evolving toward ubiquitous coverage and space-ground-sea convergence, aiming to build an infrastructure with high reliability and high-bandwidth communication that spans the globe and supports all scenarios.

Covering various data centers, optical networks are further extended to the edge, achieving deep coverage of homes, enterprises, campuses, and industrial devices, and meeting the universal demands for high-speed, low-latency, and highly-reliable optical communication from millions of households and industries.

To build a global space-ground-sea integrated optical network, comprehensive collaboration is required between space, ground and submarine optical networks in areas such as resource planning, network management, and Service Level Agreement (SLA) assurance, in order to construct a network that is always connected and with services always online. Resource planning collaboration refers to ensuring seamless coordination of network resources during space-ground-sea network planning, based on service forecasts and SLA requirements. Network management and control collaboration refers to unified management and control of space-ground-sea optical networks, integrated service provisioning, and unified network operations. SLA assurance collaboration means selecting corresponding network resources and combinations based on SLA indicators such as latency and availability, to ensure end-to-end service guarantees through coordinated transmission.

Optical network technologies continue to evolve, with significant increase in the speed. The long-haul single-carrier rate will be increased to 800Gb/s or 1.6Tb/s, the medium-/short-haul single-carrier rate will be increased to 1.6Tb/s or 3.2Tb/s, the access single-carrier rate will be increased to over 100Gb/s~200Gb/s, and the indoor optical link single-carrier rate will be increased to 25Gb/s~50Gb/s.

2. New Ultra-Broadband All-Type Optical Media (New Optical Media)

Optical networks continue to innovate in terms of spectrum and media, expanding multi-band transmission capabilities while introducing novel optical fibers and space optical communication media, comprehensively enhancing network capacity, performance, and coverage.

In terms of spectrum expansion, bands including O, E, S, C, L and U have been applied in optical communication systems. For instance, the O and E bands are used in fronthaul scenarios, while the U band plays a role in access networks. With continuously growing service demands, spectrum usage is being further expanded for certain communication technologies or scenarios. For example, long-distance transmission is expected to extend from the traditional C+L bands to S+C+L bands, and the access segment may also be potentially extended to the C band.

Regarding optical fibers and cables, new solutions have emerged such as Hollow-Core Fiber (HCF), Space-Division-Multiplexing (SDM) fibers, and large-core-count fiber cables based on Single-Mode Fiber (SMF). HCFs can reduce latency and improve transmission performance. SDM fibers and large-core-count fiber cables can significantly increase network capacity.

Air and vacuum serve as new media for "AON 3.0", enabling space optical communication including vacuum-based laser communication between satellites, as well as air-based laser communication between satellites and ground gateways, and between stations, and aerial platforms.

3. Elastic and Agile Optical Links for All Scenarios (Dynamic Optical Links)

Through elastic connectivity, elastic bandwidth, elastic spectrum, and elastic computing power technologies, optical networks achieve intelligent scheduling capability with on-demand link establishment, self-adaptive rate adjustment, and flexible spectrum allocation, enabling efficient mission-critical service provisioning and optimal network resource utilization.

To address mission-critical applications, rapid service provisioning, and network efficiency optimization, optical networks leverage elastic connectivity, bandwidth, computing, and spectrum technologies to enable agile dynamic linking through available paths.

Elastic Connectivity: For transport private lines, through minute-level provisioning and decommissioning of wavelength and Optical Service Unit (OSU) to rapidly deliver link resources, the optical networks fulfill mission-critical on-demand scheduling and time-division multiplexing requirements. For Passive Optical Network (PON)-based private lines, leveraging user-side gateways as anchor points, the system delivers application-level real-time identification and tagging, along with cross-layer, multi-domain end-to-end rapid link provisioning and decommissioning capabilities.

Elastic Bandwidth: On the one hand, the system enables line-rate elastic adjustability, with a single Optical Transform Unit (OTU) card supporting flexible rate tuning from 400Gb/s to 1.2Tb/s. On the other hand, leveraging Optical Service Unit (OSU) bandwidth elastic expansion, dual-layer Dynamic Bandwidth Allocation (DBA) mechanism with bandwidth scaling, and application-level access network slicing capabilities, the system delivers application-level bandwidth elasticity for diverse user requirements.

Elastic Spectrum: The system enables flexible wavelength spacing adjustment to match the efficient transmission with different rates, thereby achieving multi-rate wavelength hybrid transmission within a single optical layer.

Elastic Computing: Leveraging edge computing resources including Optical Line Terminals (OLT), intelligent government and enterprise gateways, and Fiber-to-the-Room (FTTR) devices, the system fulfills the requirements of AI agents and applications for elastic deployment, scheduling, and orchestration of local computing and storage resources.

4. Multi-Layer Native Entire Lifecycle Optical Intelligence (Native Optical Intelligence)

Based on native AI technologies in each layer of the network, Native Optical Intelligence establishes a "Three-Layer Native Intelligence" architecture that comprehensively empowers the entire lifecycle of "planning, construction, maintenance, optimization, and operation" in optical networks.

Under the framework of new-generation cloud-network operation systems, the optical network is built upon Native Optical Intelligence, deeply integrating advanced technologies such as Integrated Sensing and Communication, Digital Twin, and AI. This provides "self-configuration, self-healing, self-optimization and self-service" AON-wide intelligent services for thousands of industries, enabling network planning to predict service demands more accurately , network construction to install and debug more efficiently , network maintenance to handle faults more quickly, network optimization to discover hidden risks and make adjustments more timely, network operation to meet diverse service demands more agilely , thus realizing intelligent optical networks in the AI era.

AI-based Native Optical Intelligence comprises three-layer capabilities: network intelligence layer, operation intelligence layer, and service intelligence layer. Network intelligence layer includes precise perception of multiple parameters, rapid acquisition of data, digital twin of network elements based on small models (realizing "twin-on-connection"), and analysis of healthiness. Operation intelligence layer includes agent-based optical network Operation and Maintenance (O&M) large models, open control & management, fault tracing, performance evaluation and multi-factor optimal routing based on latency/performance margin. Service intelligence layer encompasses agile service provisioning, SLA risk prediction, user quality of experience monitoring, resource analysis & scheduling, AI-driven decision making and differentiated assurance.

5. Internal Awareness and External Exploration Multi-Dimensional Optical Sensing (Multi-Dimensional Optical Sensing)

Through comprehensive improvements in perception capabilities, optical networks support high-reliability and high-quality network and service assurance (internal cognition), while exploring service provisioning capabilities for societal governance (external exploration).

For internal cognition, at the network sensing level, it includes co-trench and co-cable monitoring for optical cable networks, optical cable flash interruption detection, Geographic Information System (GIS) restoration of optical cables, digitalized Optical Distribution Network (ODN), data collection for devices, links and networks, full-parameter sensing, and fault sensing. This enhances the quality, security, and rapid provisioning capabilities of services. At the service sensing level, it enables identification of service application types and characteristics, application-level SLA intelligent sensing, and service quality perception.

For external exploration, leveraging the ubiquitous interconnected optical cable network as a sensing medium and combining AI technologies, it establishes real-time and accurate optical cable sensing capabilities. This forms products with environmental perception functions, enabling visual management of passive resources while simultaneously supporting services such as earthquake prediction and construction warning. It provides sensing services, including earthquake prediction, construction warning, perimeter security, smart transportation, as well as the bridge and road collapse detection.

6. Quality-Guaranteed Hierarchical Optical Bearing (Hierarchical Optical Bearing)

The system establishes a multi-tier SLA, high-quality deterministic transport architecture to support Network-as-a-Service (NaaS) capabilities and differentiated experience assurance for diversified services.

Leveraging the advantages of optical networks–including ultra-low latency, deterministic performance, flexible scheduling, high reliability, and lossless transmission, and integrating with Internet Protocol (IP) networks and the Fifth Generation Mobile Communication (5G) networks, the system provides end-to-end, multi-tier SLA, high-quality deterministic transport capabilities (e.g., guaranteed bandwidth, bounded latency, committed packet loss rate, etc.) for diversified services, including inbound computing and inter-computing interconnection, enabling NaaS.

Multi-tier SLA encompasses multi-dimensional Key Performance Indicator (KPIs) such as bandwidth, latency, network availability, service activation time, security, and differentiated graded metrics. These can be tailored to different types of users and services, such as enterprise (2B) and home (2H), forming product offerings such as low-latency premium private lines, tiered SLA subscription-based network value-added services. This ensures tired service experience assurance based on corresponding tiered SLA capabilities.

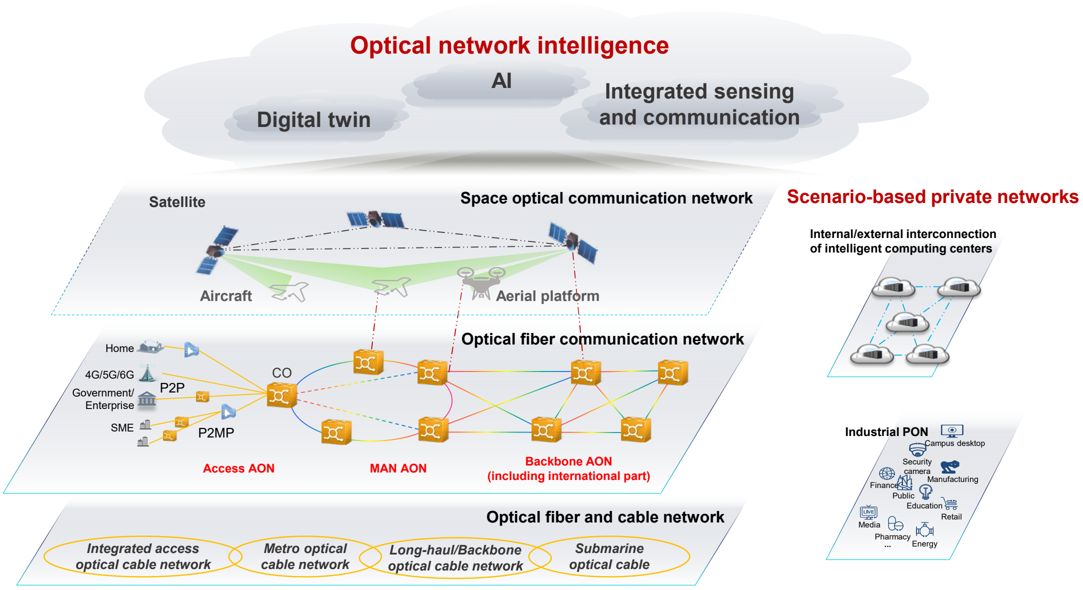

Figure 1 Target Architecture of “AON 3.0”

Figure 1 illustrates the target network architecture of “AON 3.0”, encompassing optical fiber & cable networks, optical fiber communication networks, space optical communication networks, scenario-based private networks, and intelligent optical network systems. The optical fiber communication network is hierarchically structured into backbone, Metropolitan Area Network (MAN) and access networks. Scenario-specific architectures are constructed for AI computing center networks and industrial PONs. Intelligent optical network capabilities are introduced, forming an entire lifecycle intelligent system represented by AI, digital twin, and integrated sensing and communication.

3.2. Target Architecture of Optical Cable Network

The optical cable network aims to achieve **wide coverage, low latency, multiple routes, and enhanced sensing capabilities** through rational planning, deployment, and construction across different optical cable network layers and timely introduction of new technical solutions.

China Telecom's cable network, aligned with national strategies and corporate development goals, will expand network layout of global submarine and terrestrial cables, building a high-efficiency, stable, and secure domestic-international integrated infrastructure, achieving global connectivity covering major countries and regions, and enhancing network resilience and service capabilities.

The international optical cable network will be established into a diversified and balanced global transmission infrastructure through coordinating submarine and terrestrial deployment strategies, and combining both construction and procurement approaches. The submarine optical cable network will be built by adopting multi-region and multi-route deployment configurations. Based on requirements, "Open Cable" architecture and integrated intelligent monitoring technologies will be adopted to strengthen the submarine risk assessment capabilities and enhance comprehensive proactive early-warning systems, which will be ultimately establish secure and reliable international communications. Meanwhile, it is necessary to actively explore trans-border terrestrial cable resources in the Middle East, Central Asia, South Asia, and the Greater Mekong Subregion of Southeast Asia, to expand terrestrial channels and promote multiple submarine-terrestrial combined channels, thereby providing robust traffic sharing and security backup.

The domestic backbone optical cable network, centered on national computing power hub nodes, will be established into a stereoscopic layout that combines high-efficiency direct connections (low latency) and strategic infrastructure (wide coverage), effectively interconnecting hyper-scale and large-scale data centers while covering hubs, core equipment buildings, connecting International Communication Gateway Bureaus (ICGBs) and Submarine Cable Landing Stations (SCLSs) with linking Asia, America, and Europe. A new structure with backbone cables terminated in urban areas will be built and equipment room infrastructure layouts will be optimized to reduce urban detour routes, optimize the latency and enhance network security. G.654.E optical cables will be fully deployed to meet the deployment requirements of transmission systems with single-wave rates of 400Gb/s and higher.

The metropolitan optical cable network will break through administrative regional networking constraints, realizing the nearest interconnection by directly deploying cross-county (-town) optical cables between adjacent cities. The multiplex layers of metropolitan optical cable network will be progressively intensified its mesh configuration to meet the requirements of the MAN flat architecture and the deployment of WDM/Optical Transport Network (OTN) technology at the edge layer of MANs.

For new-type optical fibers and cables, HCFs can be introduced in the routs with high low-latency requirements according to actual needs. In the scenarios such as co-construction and co-sharing, as well as limited pipeline resources, the application of high-core-count optical cables will be gradually promoted. The SDM fiber technology will be given attention in special application scenarios such as data center intra-connection and submarine optical transmission.

The optical cable network should possess the capability to monitor the condition of the fibers themselves and the surrounding environment, supporting applications, such as optical communication systems, urban infrastructure health monitoring, and earthquake early warning.

The realization of the target architecture for the optical cable network will mainly relay on advancements in new-type fibers and cables, supporting technologies, as well as the maturity of sensing technologies.

3.3. Target Architecture of Optical Fiber Communication Network

3.3.1. Target Architecture of Backbone Optical Fiber Communication Network

The goal of the backbone optical fiber communication network is to build a comprehensive cloud/data center (DC)-centric transport network that **converges the multiple layers of networks in China, integrates domestic and international networks, and coordinates ground networks and satellite space networks**, providing network capabilities, such as **ultra-large bandwidth, ultra-high reliability, ultra-low latency, high elasticity & agility, multi-dimensional perception, and intelligent operation**.

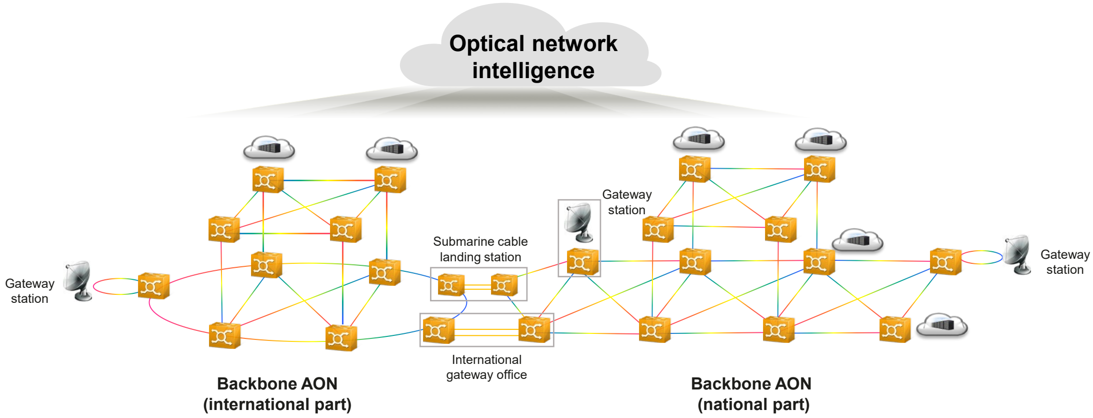

Figure 2 Target Architecture of Backbone Optical Fiber Communication Network

Multi-layer converged networking in China: Based on the converged networking of inter-provincial and intra-provincial backbone networks, the architecture covers all-optical fundamental backbone layer and three-dimensional efficient scheduling layer will be built to achieve efficient integrated transport of multi-rate, multi-type services and fast agile disconnection and establishment of links.

International and domestic integrated networking: To strengthen the integrated planning, construction, and management & control of domestic and international networks (including terrestrial and submarine cable systems), a globally integrated private line network featuring high speed large bandwidth, low latency, fast provisioning, flexible scheduling, high security, high efficiency and unified operation will be built, realizing end-to-end rapid provisioning and unified management & control of cross-national and cross-regional services, and address the demands of public and private line customers for efficient data transmission while meeting the requirements of different countries for network compliance.

Ground and space optical network synergy: A ground backbone fiber communication network featuring efficient interconnection at the device layer and intelligent coordination at the control layer with the satellite space network can be built by precise coverage of ground gateway stations and introduction of a unified management & control system.

The implementation of the target architecture of the backbone optical fiber communication network mainly relies on the high-speed large-capacity all-optical transmission, all-optical switching technology, the integrated management, and control technology, etc.

3.3.2. Target Architecture of Metropolitan Optical Fiber Communication Network

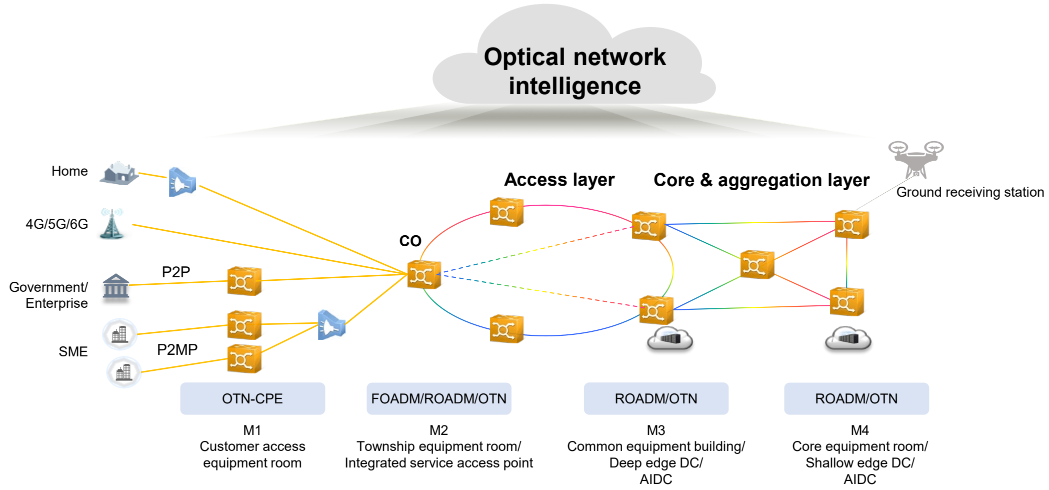

Figure 3 Target Architecture of Metropolitan Optical Fiber Communication Network

The goal of the metropolitan optical fiber communication network is to build a cloud/DC-centric network architecture, gradually realizing the flat architecture evolution from a "core-aggregation-access" three-layer network to a "core & aggregation-access" two-layer network. The MAN expects to achieve the air-ground integrated development through deep coordination with space optical communication, to provide flexible, agile, secure and reliable SLA-capable differentiated service capabilities.

Network Architecture: The core layer and aggregation layer are integrated into a mesh network to provide wavelength-level large-bandwidth direct connection capability. More than three line directions are retained for any one network node. The ROADM all-optical network is established to ensure elastic configuration and flexible scheduling of MAN services, thus reducing electrical layer switching and regeneration and also minimizing network latency and costs. The access layer mainly adopts ring topology networking, and central office nodes support ubiquitous access of multiple services. Some large-scale local access networks can gradually evolve to mesh networks as required.

Air-ground Integration: Combined with the low-altitude drone system, the MAN can cover the ground receiving stations, providing capabilities assurance of multi-layer communication links covering ground receiving stations, low-altitude drones, and satellites. Besides, the architecture provides supplementary coverage in remote areas and enhances network access capabilities in dense areas. These new links can be used as emergency communication exits to improve the reliability of the MAN.

Service Experience: One millisecond (1ms) express access to computing/inter-computing interconnection services can be provided to meet the requirements of urban computing networks. Service flow features can be used to identify applications, and differentiated multi-tier SLA services based on multiple dimensions (such as bandwidth, latency, network availability, and encryption security) can be provided to offer customized and high-quality network service experiences.

The implementation of the target architecture of the metropolitan optical fiber communication network mainly relies on the technologies including low-cost Wavelength Division Multiplexing (WDM), all-optical networking, Metro-optimized Optical Transport Network (M-OTN)/OSU, and application-based multi-tier SLA.

3.3.3. Target Architecture of Optical Access Network

The goal of the optical access network is to build a network architecture with **"Scale 10 Gigabit Optical Broadband-FTTR"** as a core concept to guarantee new experience of smart life in home scenarios, support intelligent manufacturing upgrade in industrial scenarios, support digital transformation acceleration in campus scenarios, and upgrade the fronthaul WDM network rate and capacity as required in fronthaul scenarios to **meet the requirements of the Sixth Generation Mobile Communication (6G) for fronthaul transport networks.**

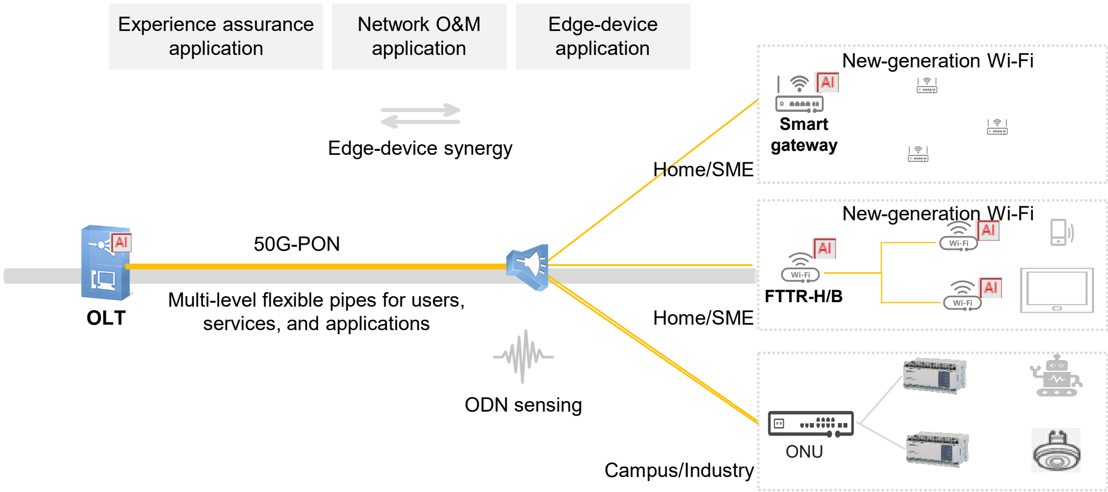

Figure 4 Target Architecture of Optical access network

In Outdoor Scenarios: gigabit optical access networks need to upgrade to 10 gigabit optical access networks on demand for key areas, scenarios and services, and provide 10 gigabit access pipeline capability. On the basis of edge computing power of OLT and related terminals, AI can be used to build distributed agents to support collaborative interaction, elastic intelligent connection, and application-level service guarantee capabilities to improve the access efficiency and service experience. ODN fibers can be used as the media to explore the communication and sensing integration capabilities.

In Indoor Scenarios: based on the customer edge intelligent devices such as FTTR (-H/-B) master/slave nodes and routers, new-generation indoor optical networks can be built with optical fiber as physical-layer links, middleware as software foundation, application agents as hub control, and new-generation Wi-Fi as edge extension. The in-door optical networks will collaborate with gigabit/10 gigabit access optical networks to maximize operators' advantages in cloud networks and service fields.

The implementation of the target architecture of the optical access network mainly relies on 50G-PON, FTTR-H/B, Wi-Fi, AI/Agent, ODN sensing, and 50G/100G fronthaul WDM technologies.

3.4. Target Architecture of Space Optical Communication Network

The target of the space optical communication network is to build a **"space-air-ground" integrated communication network** that is **optical-based, hierarchically coordinated, and dynamically controllable,** with multi-platform collaboration across satellites, aerial platforms, and ground nodes as its core. Meanwhile, it will form a unified architecture that complements and interconnects with terrestrial optical networks, aiming to provide ubiquitous, efficient, reliable, secure, 7×24 online wide-coverage optical communication capabilities. This will support future global-scale optical network interconnection, perception data aggregation, and task data backhaul.

Satellite-to-ground and inter-satellite optical communication networking: A large-capacity and low-latency space backbone network will be constructed by leveraging high-speed laser interconnections among existing Low Earth Orbit (LEO) satellites and through spectrum or pipeline leasing. Together with high-speed satellite-to-ground links between satellites and ground stations, a three-dimensional space-ground data transmission path will be formed.

Aerial platform networking: Optical communication nodes will be deployed on high- and medium-altitude aerial platforms such as aircraft and unmanned aerial vehicles, enabling rapid cross-regional data relay via laser links. Unified scheduling and flexible deployment will be supported through coordinated operation with ground stations and other nodes to meet diverse data transmission requirements.

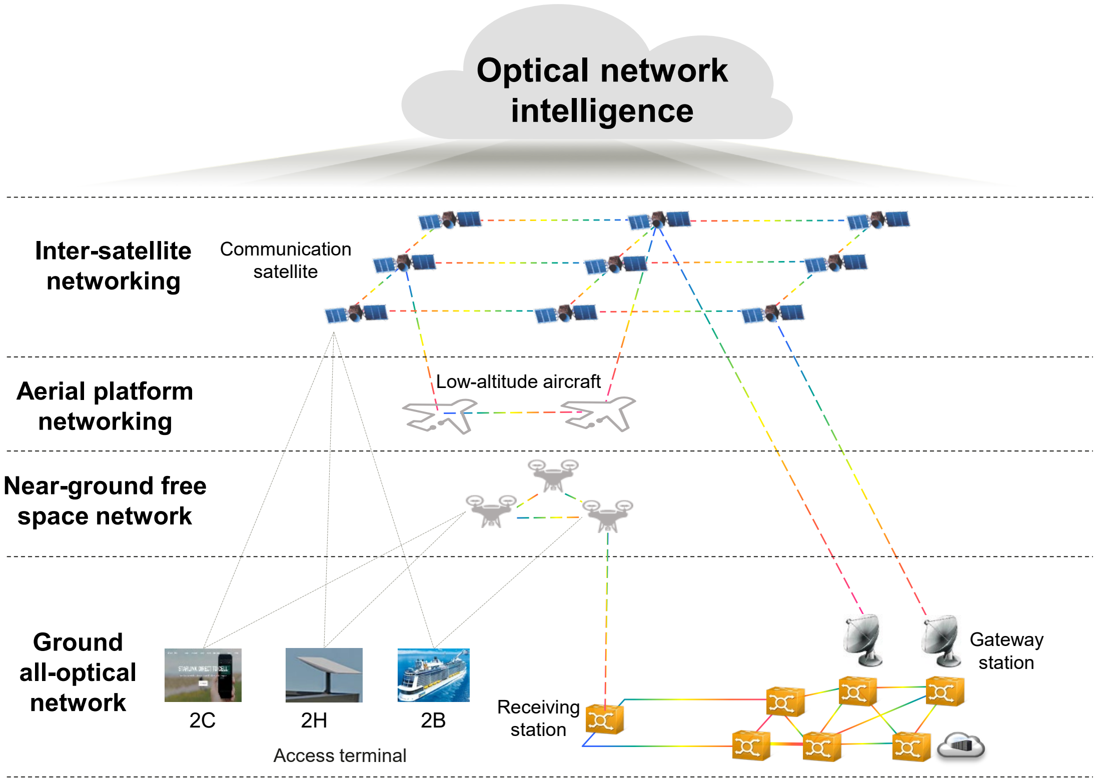

Figure 5 Target Architecture of Space Optical Communication Network

Near-ground Free-Space Optical (FSO) communication networking: In scenarios such as island access, cross-river transmission, and cross-building communication environments, point-to-point short-reach high-speed laser links will be deployed. These will enable cost-effective high-bandwidth networks in areas beyond the reach of optical fibers, effectively extending the boundary coverage of the optical network.

The implementation of the target architecture of the space optical communication network mainly relies on atmospheric turbulence compensation, Doppler shift compensation, Acquisition, Tracking, and Pointing (ATP) technologies, etc.

3.5. Target Architecture of Scenario-Based Private Network

3.5.1. Target Architecture of Intelligent Computing Center Optical Network

The target of the intelligent computing center optical network is to build an all-optical, high-speed network that spans both inter- and intra-center connections. This includes interconnections between intelligent computing centers, intra-connections within each center, and the integration of intra- and inter-center networks. The target is to enable the efficient sharing of computing power and network resources. Through computing-network synergy, the architecture supports flexible interconnection of local and remote resources, enabling dynamic construction of geographically distributed clusters. It addresses key requirements such as ultra-broadband transmission, lossless low-latency communication, and flexible scheduling of computing resources for diverse workloads including inference and training.

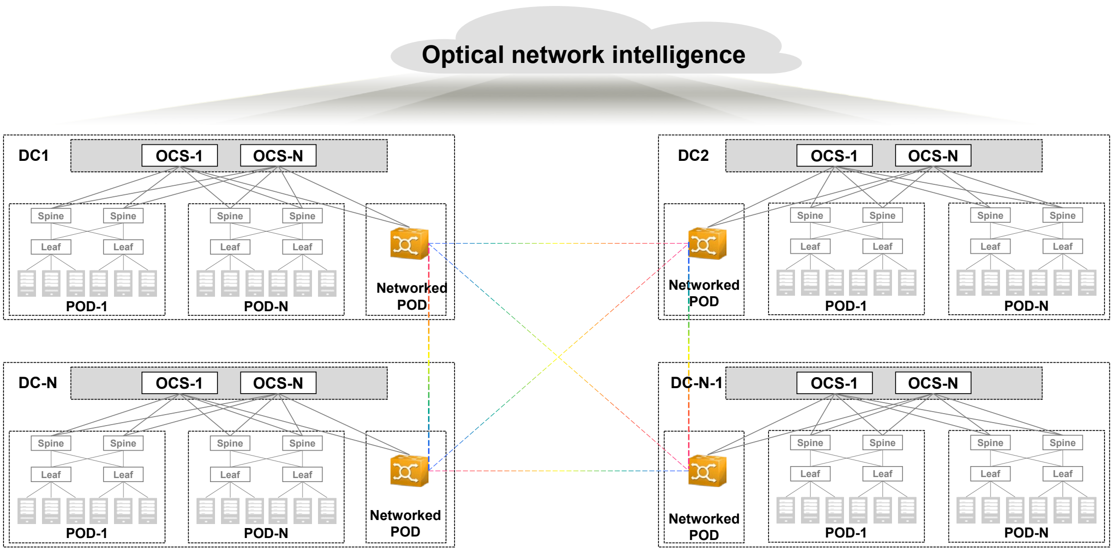

Figure 6 Target Architecture of Intelligent Computing Center Optical Network

Interconnection across Geographically Distributed Intelligent Computing Centers: Based on the MAN or the backbone network, and the 400G/800G ROADM logical plane, ultra-high-bandwidth and ultra-high-reliability optical connections can be established across geographically distributed intelligent computing centers. Lightweight optical transport devices will be deployed as required between business-intensive metropolitan intelligent computing centers over short distances. To ensure high reliability of network connections and achieve lossless transmission, 50ms wavelength rerouting restoration technology will be explored.

Large-Scale Intra-Center Computing Power Interconnectivity: The optical circuit switches (OCS) will replace the core-layer switches with the traditional electrical architecture in the selected ultra-large-scale DCs, and will even be deployed in super-nodes in the future to implement large-capacity non-blocking interconnection among the computing nodes within an intelligent computing center. In the future, to further enhance the interconnect bandwidth density while reducing inter-card power consumption and latency, advanced photonic integration technologies such as chip-level optical input/output and Co-Packaged Optics (CPO) are expected to be introduced. These innovations will support higher scalability and computing efficiency within intelligent computing centers.

Integration of Intra- and Inter-DC Networks: Seamless integration of intra- and inter-DC networks requires coordination at both the control and device layers. OTN devices is able to recognize the Remote Direct Memory Access (RDMA) protocol to ensure lossless data transmission between the intelligence computing centers. Relying on cross-domain computing-network orchestration, the integrated network enables real-time awareness and unified scheduling of computing resources via an integrated operations platform. By incorporating dynamic wavelength provisioning and teardown capabilities, optical-layer resources can be precisely allocated based on workload type and traffic patterns, significantly improving the agility and efficiency of optical resource management. Ultimately, the construction of a fully optical interconnection path—from chip to rack to cluster—will unlock the full performance potential of intelligent computing networks.

The implementation of the target architecture of the intelligent computing center optical network mainly relies on the following technologies: ultra-reliable elastic bandwidth, 50ms wavelength rerouting restoration, OCS, and advanced optoelectronic co-package technology.

3.5.2. Target Architecture of Industrial PON

The goal of the industrial PON is to build communication infrastructure capable of **ubiquitous connectivity, deterministic transport, and high intelligence**, with **computing-network integrated** optical foundation as its core, to achieve multi-subnet integration of the enterprise information network, industrial control network, and device connection network.

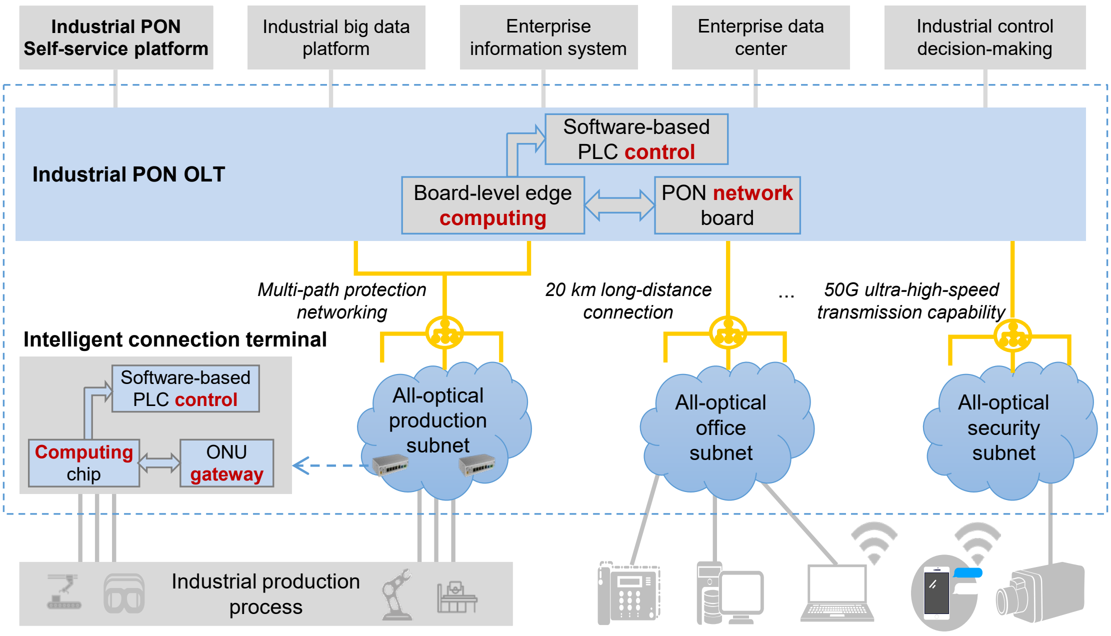

Figure 7 Target Architecture of Industrial PON

Device Form: New OLT and ONU devices with computing power and edge industrial applications support the integration of edge computing power, network terminals, and software-based Programmable Logic Controller (PLC) to achieve intensive empowerment for a single node.

Network Communication: Differentiated deterministic service guarantee capabilities need to be constructed based on multi-level collaborative deterministic technology to address the deterministic transmission requirement of multi-source heterogeneous big data in intelligent manufacturing.

Optical Network/Industrial Control Convergence: Time synchronization and real-time control linkage will be optimized to provide more efficient convergence solutions for industrial applications.

Management and Control Mode: All-optical industrial configuration can be built and simplified and customized capabilities for industrial services can be provided based on the hierarchical open interfaces of the PON, to ease the difficulty of the implementation of the industrial PON.

The implementation of the target technical architecture of industrial PON relies on multi-level collaborative deterministic technology, computing, network and control integration technology, and industrial configuration technology to promote deep convergence of Communication Technology (CT) and Operational Technology (OT).

3.6. Target Architecture for Intelligent Optical Networks

The target of intelligent optical network is centered on "elastic agility, intelligent network empowerment, internal cognition and external exploration, and hierarchical experience", built **upon native optical intelligence and grounded in open control and management**, enabling real-time data acquisition, unified data sharing, and coordinated management and control across vendors and domains, deeply integrating emerging technologies such as digital twins, integrated sensing and communication, and AI, thus forming a **"three-layer native intelligence" architecture**.

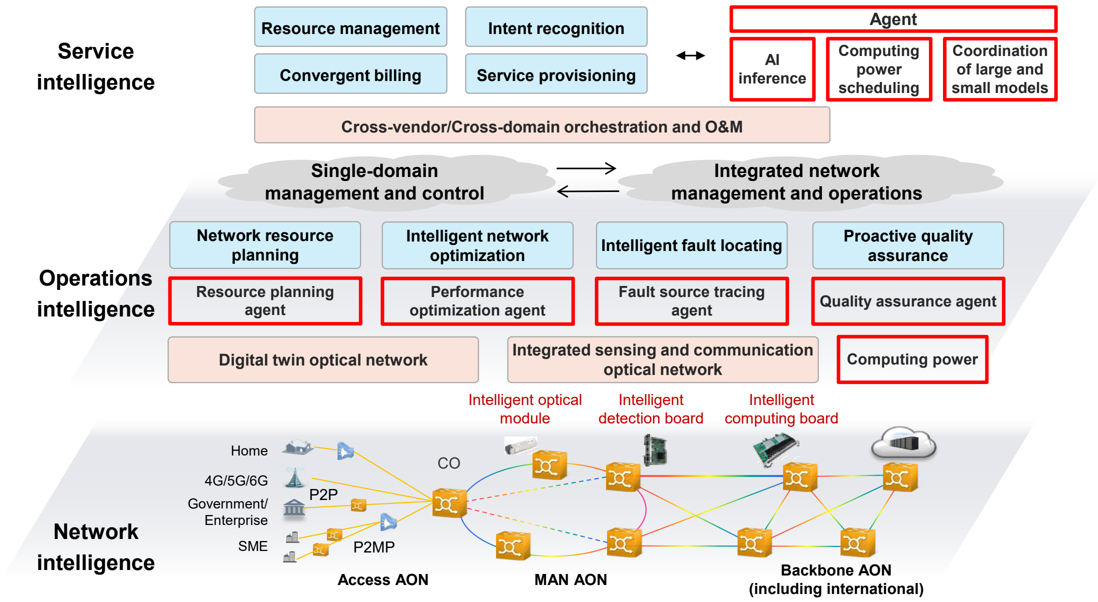

Figure 8 Target Architecture of Intelligent Optical Networks

Network Intelligence Layer: By integrating technologies such as distributed sensing, Digital Signal Processing (DSP), embedded native computing power, and real-time AI inference capabilities, enabling precise sensing and rapid acquisition of multidimensional physical parameters in fiber links and devices. It drives a transformation of network elements from "passive response" to "active sensing–decision–optimization", and shifts network control from "static rules and strategies" to "dynamic model and agent-driven" intelligence, greatly enhancing network transmission efficiency and resource utilization.

Operation Intelligence Layer: Through the deep fusion of digital twins, AI, and large models, an intelligent management and control system is built, enabling end-to-end collaborative management of connected intelligent dispatch, network healthiness assessment, and fault tracing. Based on an open architecture that integrates multi-vendor device capabilities, this layer supports closed-loop of flexible policy generation and automated operations and maintenance, promoting the transformation of optical network from "manual intervention" to "intent driven, autonomous closed-loop" operation.

Service Intelligence Layer: This layer achieves intelligent agents for experience assurance and edge applications, accomplishes objective defining, task chain planning, and user intent and environmental event perceiving, collaborates with cloud-based general intelligent agents and digital human applications on demand. By deeply integrating intelligent capabilities with service scenarios, and through dynamic sensing and intelligent decision-making systems, this layer supports service agile release, SLA risk prediction, and resource elastic scheduling, establishes an intelligent closed loop of "demand–policy–execution", driving the optical network from "reactive service" to "proactive service", and provides a highly reliable and autonomous intelligent service experience.

3.6.1. Target Technical Requirements of Integrated Sensing and Communication Optical Networks

The integrated sensing and communication optical networks enhance state monitoring of optical networks and external environments beyond traditional capabilities, forming **three core competencies: network sensing, service sensing, and environmental sensing**, thereby strengthening optical network resilience and intelligent capabilities.

Network Sensing: Multi-dimensional perception enhancement such as fiber quality, fiber routing, and system performance are achieved with distributed optical fiber sensing, DSP optical signal monitoring and other technologies as the core. It upgrades the existing Optical Time Domain Reflectometry (OTDR) and DSP analysis capabilities to realize high-sensitivity capture of fiber link flash break abnormalities. It introduces Distributed Acoustic/Vibration Sensing (DAS/DVS) technology to perceive the external vibration characteristics of the fiber and realize the risk warning of fiber co-routing. Based on node performance and configuration data, it actively senses the system performance, establishes a digital view of ODN, and combines physical topology to realize active fault detection and audit of optical paths.

Service Sensing: Millisecond-level monitoring and service characteristic identification technologies enhance service quality perception, enabling monitoring and optimization of quality degradation in critical applications to support application-level SLA assurance. Concurrently, millisecond-level traffic monitoring facilitates service bandwidth expansion and enables the perception and localization of issues such as packet loss and bit errors caused by sudden traffic bursts.

Environmental Sensing: Based on distributed optical fiber sensing technologies, this layer detects environmental anomalies such as vibration and temperature changes, improving the perception capability of conditions surrounding optical fibers. It enables timely identification of fault risks such as fiber cuts from construction activities on land or anchor damage to submarine cables. The sensing capabilities can also be opened up to expand environmental monitoring potential, supporting applications such as campus perimeter intrusion detection, urban traffic condition monitoring, bridge health assessment, and submarine earthquake early warning.

3.6.2. Target Technical Requirements of Digital Twin for Optical Networks

The digital twin system for optical networks, as an enhanced management technology, can be deployed either integrated with or independently from existing control systems. Centered on "digital-physical mirroring, intelligent closed-loop, and full-domain orchestration", it encompasses a four-tier architecture (**data layer, model layer, service layer, and interaction layer**), enabling layered decoupling and cross-domain convergence to support the entire lifecycle intelligent management of optical networks.

Data Layer: Accurate Perception and Efficient Governance. The digital twin for optical networks collects data of components, devices, topology, networks, and services in physical space to build corresponding twin models. The embedded intelligent engines preprocess raw data at the network element side and integrate multi-domain data at the network and service side, constructing a unified global resource view and providing a high-quality data foundation.

Model Layer: High-Fidelity Virtual Model Construction. Based on foundational models, functional models, and knowledge repositories, this layer achieves precise mapping between physical entities and their digital counterparts, and high-fidelity simulation of network operation status is synchronized in real time, supporting cross-vendor, cross-domain and multi-level collaborative modeling.

Service Layer: Intelligent Decision-Making and Closed-Loop Control. With capabilities in simulation, evaluation, and optimization, this layer provides services such as network planning, fault prediction, and resource scheduling. For instance, a causal inference engine enables root-cause fault tracing within seconds, while reinforcement learning is used to generate dynamic optimization strategies that drive network self-healing and proactive SLA assurance.

Interaction Layer: Intra-Domain Interoperability and Cross-Domain Coordination. Within the digital twin network, standardized internal interfaces support single-domain data exchange and functional collaboration. Northbound interfaces enable intent translation and capability invocation, southbound interfaces support high-speed data acquisition and control command delivery, internal interfaces facilitate model interaction. Additionally, the digital twin architecture supports cross-domain intelligent architecture and interactive collaboration with other fields, and realizes cross-domain applications through open standardized interfaces. Furthermore, the digital twin system can realize human–machine interaction, significantly improving the transparent management and agile response capabilities of complex systems.

3.6.3. Target Technical Requirements for AI in Optical Networks

To meet the stringent demands of emerging AI-era services, optical networks need to build the key capabilities of **"intelligent resource collaboration, proactive risk prevention, and autonomous O&M closed-loop"**. On top of automated control, a multi-agent system incorporating both large and small AI models should be established to enable full-lifecycle intelligent capabilities across network "planning, construction, maintenance, optimization, and operation".

Network Planning and Construction: Build a highly reliable, low-latency, and agile network. Based on service demand and resource prediction planning, it ensures agile service provisioning. Through latency assessment planning, precise coverage of computing-network latency-sensitive zones is achieved. Leveraging digital twin-based planning, the solution optimizes high-reliability topology design, equipment selection, and site placement to eliminate single points of failure, delivering high-availability services.

Network Maintenance: Enhance fault handling efficiency. Millisecond-level sensing enables precise localization of micro-interruptions, while intelligent optical modules diagnose failure causes. AI algorithms achieve root-cause alarm identification, and large language models power interactive operation assistants for accurate fault localization. Leveraging integrated sensing and communication, real-time monitoring and analysis of optical cable vibrations and ambient environmental disturbances are implemented.

Network Optimization: Enables automatic identification of network anomalies and proactive optimization. It automatically identifies co-trench/co-cable fibers and proactively optimizes fiber routes at the fiber and cable layer, evaluates and optimizes optical link performance and proactively conducts latency detour risks warning and topological optimization at the network layer, proactively detects poor application performance and automatically provides high-priority connections to ensure SLA compliance at the service layer.

Network Operation: Improve both service agility and user satisfaction. Intent-based multi-factor routing planning builds automatic wavelength provisioning capabilities, enabling minute-level service provisioning. Digital twin technology simulates service configuration and routing adjustments to support rapid provisioning and intelligent scheduling of the services. Leveraging elastic computing power, the solution implements differentiated SLA application-level experience assurance through optical cable quality sensing, flexible deployment of distributed agents, and coordinated computing-network intelligent control. AI-powered local service agents deliver domain-specific services, including natural language interaction, knowledge questions and answers, and intelligent customer service.

4. AON 3.0 Phased Evolution Strategy

4.1. 2030 Target and Evolution Strategy

1）Optical Fiber Cable Network

The international optical cable network will be strengthened the construction of submarine cables in the main directions, and added new submarine cable systems using the “Open Cable” model in Asia-Pacific, Asia-Europe, Asia (South) and Asia-Africa directions, and adopted a submarine-terrestrial combined model consisting of trans-border terrestrial optical cables + SCLSs + international submarine cables, to expand export directions and channels, ultimately enhancing resilience. Enhance the optical cable levels of international extension sections and cross-border sections, and integrate the access sections of the ICGBs and the Pass and Earth Stations (PESs) into inter-provincial backbone optical cable networks, thereby increasing the quality and security of the international optical cable network. For the domestic backbone optical cable network, the replacement project of backbone optical cable built before 2000 using G.654.E optical cables and the new structure with backbone cables terminated in urban areas will be finished, while the construction of optical cable network with high-efficiency direct connections will be basically completed. The field trails of new-type fiber will be carried out. For example, the high-core-count optical cables based on single-mode fibers with ⩾ 288 cores will be carried out in special scenarios such as building interconnection within hyper-scale and large-scale DCs, the areas crossing long-distance river, and co-construction and sharing routes. The HCFs will be trialed in the scenarios of financial exchanges and data centers interconnection with strong computing power demands. The applications of SDM fibers will be tracked and their application in data centers intra-connection and submarine optical transmission will be promoted at an appropriate time.

The metropolitan optical cable network will continue to be densified grids to achieve multiplex routes at the core/aggregation layer and at least two routes at the access layer, meeting the evolution requirements of ROADM and WDM/OTN in metropolitan area networks, and further improving the quality of metropolitan optical cable networks. Meanwhile, the field trail of route visualization management and fault location capabilities will be launched in some metropolitan optical cable networks.

2）Optical Fiber Communication Network

Backbone Optical Fiber Communication Networks: Maintain an inter-provincial and intra-provincial backbone networks integrated architecture. The 400Gb/s ROADM network achieves near-universal extended C+L band integration. Leveraging this optical layer, 800Gb/s wavelength channels are deployed on high-traffic routes and regions, enabling hybrid multi-rate ROADM all-optical switching networking.

100Gb/s ROADM networks deploy redundant OTU ports as auxiliary detection light sources, while 400Gb/s+ ROADM networks employ filler light for auxiliary detection. Software-driven scheduling enables recovery route performance testing and fault localization, enhancing network reliability and continuously improving wavelength restoration success rates. Under adequate network resources, single-point cable failures achieve 98% average service restoration success rates.

Integrating submarine and terrestrial cable resources provides international triple-route capability across regions. Coordinating with satellite optical networks extends coverage to terrestrial gateway stations. A unified cross-domain, multi-vendor control system enables integrated bearer services and end-to-end provisioning for government and enterprise leased lines.

Improve network agility and flexibility and match the evolution and development trend of intelligent computing networks. The network evolves from static connection to dynamic on-demand demolition and construction capabilities, providing minute-level dynamic demolition and construction capabilities for in-computing and joint computing services.

Further improve network operation efficiency. When network resources are available, the optical channel issuance time evolves from the sky level to the hour level and the minute level, and at the same time, it provides resource prediction and tuning capabilities for scenarios with multi-rate and multi-bandwidth bearings.

Deploy optical system detection points on demand, such as Optical Performance Monitoring (OPM), DAS, OTDR, etc., upgrade network digital capabilities and provide a definite service experience.

Further simplify the optical network and complete the chain wave division system to withdraw the network, and all public services are carried by the ROADM network.

Metropolitan Optical Fiber Communication Network: Large and mega cities will basically achieve flat integration of core & aggregation layers with mesh networking. The access layer will gradually implement the capability of rapid access to computing, and the core areas of large and medium-sized cities can achieve one millisecond access to computing/inter-computing interconnection. DC interconnections will introduce single-carrier of 800Gb/s or 1.6Tb/s to achieve large bandwidth connections. The dynamic and flexible small-particle service bearer technology based on M-OTN/OSU gradually replaces the Synchronous Digital System (SDH)-based Ethernet service over SDH (EoS), realizing end-to-end service activation scheduling and bandwidth adjustment. The network will support identifying the type of application through the characteristics of service flow and provides hierarchical SLA differentiated services. Explore the application of IP and optical equipment collaboration, O-band WDM and other technologies in the metropolitan fiber optic communication network.

Optical access network: Large-scale deployment capabilities for 50G-PON based scale 10-gigabit optical network solutions will be possessed (supporting three-generation coexistence, 50G-PON channel uplink dual-rate reception, and other characteristics), with key areas and scenarios achieving 10-gigabit optical broadband upgrades and coverage. Key technologies and leading applications for next-generation Very High Speed PON (VHSP) (tentatively 200G-PON) will be explored. For homes and small-medium enterprises, 10G rate FTTR deployment capabilities will be possessed, supporting intensive Wi-Fi management and control capabilities, network quality differential labeling systems, and closed-loop optimization capabilities to achieve diversified application interconnection and inter-control capabilities. This will provide high-speed, stable, and flexible data access and lossless transmission capabilities for AI applications. Field trails for 50G/100G fronthaul optical modules oriented toward future 6G service requirements will be explored.

3）Space Optical Communication Networks

Complete laboratory inter-satellite and satellite-to-ground laser link technology verification. In emergency communication scenarios, near-ground FSO communication technology is introduced to enable minute-level communication recovery during natural disasters, and to support data interconnection for islands and maritime communities.

4）Scenario-Specific Networks

Intelligent Computing Center Optical Networks: Enables high-speed interconnection among computing power centers across multiple regions. Some metropolitan area networks introduce 50ms telecom-grade WSON restoration capabilities based on fast wavelength-switching lasers, along with lossless transmission capabilities, to ensure high reliability of network connections. Pilot deployment of OCS in some data centers. The integrated internal-external network of the intelligent computing centers has begun to support cross-domain computing resource scheduling. Pilot projects for computing-network collaborative operation platforms have been launched, enabling resource status awareness, on-demand orchestration, and unified scheduling. Exploring a new service model that offers government and enterprise customers integrated "network + computing power" solutions.

Industrial PON Optical Networks: For vertical industries, break through key technologies of high-speed real-time all-optical field networks, promote the deep integration of CT/OT. Build the level-level openness of PON networks, develop all-optical industrial configuration software, and promote the application of industrial PON optical networks.

5）Optical Network Intelligence

Based on the knowledge-wide awareness, it fully supports the management of optical cable quality, transmission performance and service SLA. Implement single-domain twinning of optical networks, with the capabilities of simulation modeling, topological mapping, dynamic synchronization, state prediction and fault deduction. Explore the integration of large models and agent technologies into the entire lifecycle of the optical network, independently complete perception, analysis, decision-making and execution tasks, support resource planning, performance at all levels of the network and real-time perception of faults, dynamic business demolition and construction, time-sharing reuse and differentiated quality assurance, and realize closed-loop self-intelligence scenarios such as fault tracing, dynamic tuning, and automatic capacity expansion, and gradually open to provide customers with simple and intelligent services. Based on the intelligent technology of optical networks, millisecond-level perception, minute-level fault tracing and minute-level service distribution are realized, and the optical network reaches a high level of self-intelligence.

4.2. 2035 Target and Evolution Strategy

1）Optical Fiber and Cable Network

The international submarine cable network will continue to be increased the production of submarine cables in the Asia-Pacific, Asia-Europe, Asia (South), and Asia-Africa to increases export directions and channels. The domestic backbone optical cable network does not distinguish the inter-provincial and intra-provincial backbone optical cable networks. The construction of high-efficiency direct connections (low latency) optical cable networks will be completed and the construction of strategic infrastructure (wide coverage) optical cable networks will be basically completed mainly based on G.654.E fiber, covering all provincial capitals, core hub buildings in prefectures and cities, DC, ICGBs, SCLSs and PESs. The replacement project of backbone optical cable network built before 2010 will be finished. HCFs will be deployed as needed in the hotspot areas for the latency, and the field trail of high-core-count optical cables based on single-mode fibers with a capacity of more than 500 cores will be carried out.

The metropolitan optical cable network will generally have multi-routing optical cable capabilities, and the replacement of the metropolitan optical cables built before 2010 will be basically completed, greatly improving the quality, safety, and disaster recovery capabilities.

Furthermore, visualization of optical cable routing is realized, and field trials on intelligent risk warning and environmental monitoring capabilities will be carried out in some urban optical cable networks.

2）Optical Fiber Communication Network

Backbone Optical Fiber Communication Network: With 400Gb/s and 1.6Tb/s as the evolutionary milestones, the network aims to achieve widespread coverage of 400Gb/s, followed by regional efficiency improvements with 800Gb/s, and the gradual deployment of 1.6Tb/s. Innovations in the C+L+S bands will be commercialized step by step, with the goal of doubling single-fiber capacity in the 1.6Tb/s era. The network will be becoming integrated domestically and internationally, with near-complete coverage of ground gateway stations. Equipment will be interconnected on demand, and unified management for space-ground-sea coordination will be progressively implemented. This will provide end-to-end route visibility, management, and control, as well as capabilities for collaborative planning and protection. New business scenarios such as dedicated encrypted lines/networks and always-on Very Important Person (VIP) high-value dedicated lines will be introduced.

Metropolitan Fiber Communication Network: Large and mega cities will be achieved flattening and integration of core & aggregation layer with mesh networking. The optical spectrum of the core layer in large metropolitan networks will be expanded to the C+L bands, and explore 3.2Tb/s single-carrier technology and its application. The access layer will evolve toward mesh networking, and the aggregation & core layer can be connected to the access layer optical layer to provide direct wavelength capability. By accurately identifying services and leveraging AI technology, differentiated physical pipelines will be provided for various services, enhancing user experience.

Optical Access Network: The 10-gigabit network infrastructure will be deeply deployed, with large-scale construction of 10G optical networks based on 50G-PON technology. AI agent technology will be widely applied, integrating 10-gigabit FTTR technology and high-speed Wi-Fi to extend 10-gigabit capabilities and intelligent operational services to end-users and applications. Field trail of next-generation ultra-high-speed VHSP based on 200G-PON will be explored, along with trial commercialization of network equipment. Research will also be conducted on high-integration, low-power fronthaul optical module technology.

3）Space Optical Communication Network

A space optical communication network integrating "space-air-ground" capabilities will be built through spectrum or pipeline leasing, serving as a complementary enhancement to the terrestrial network by filling coverage gaps. Where feasible, it will support unified orchestration and flexible deployment alongside terrestrial optical cable links. It will support scenarios such as emergency communications, transoceanic shipping, remote access, and cross-border data transmission. Additionally, laser link experiments targeting Tb/s-level inter-satellite and satellite-to-ground transmission capabilities will be conducted in due course.

4）Scenario-Specific Network

Intelligent Computing Center Optical Network: A high-quality, fully integrated regional intelligent computing center network will be established, featuring ubiquitous computing power interconnection, flexible orchestration, and intelligent scheduling capabilities. Leveraging on-chip optical emission technology, full-optical links connecting "chip–cabinet–cluster" will be implemented in selected intelligent computing nodes. Scenario-specific Dense Wavelength Division Multiplexing (DWDM) systems are deployed on demand: 800Gb/s systems for long-distance inter-cluster connections, 1.6Tb/s systems for inter-city links, and 3.2Tb/s systems for short-distance connections between metropolitan data centers. OCS is fully integrated with intelligent scheduling systems to support diverse computing interconnection demands. A telecom-grade computing-network operation platform will be developed to deliver standardized services such as computing resource leasing, cloud-based computing access, and remote collaboration—ensuring the uninterrupted operation of high-value services.

Industrial PON Optical Network: Tailored to the customized needs of vertical industries, scenario-based application innovations will be developed based on new all-optical industrial networks, with efforts to promote large-scale adoption.

5）Optical Network Intelligence

Break through the technology of data integration and strategy linkage throughout the lifecycle to achieve self-intelligence with zero manual intervention, deepen the coordination of large and small models and open control, build a “light-sensing-industry” integrated service, and expand the intelligent scenario of the sky, earth and sea, open network self-intelligence interfaces empower thousands of industries and ensure the sustainable development of technology. Optical networks comprehensively improve self-intelligence. The network has cross-domain twinning and self-evolution capabilities, and can dynamically adapt to unknown business scenarios and external exploration environment changes.

5. Innovation Directions for Key Technological of AON 3.0

5.1. New-Type Optical Fiber and Cable Technologies

Current new-type optical fiber and cable technologies primarily include SDM fiber, high-fiber-count optical cables based on SMF, and HCF.

Among SDM fibers, Weakly-Coupled Multi-Core Fibers (WC-MCFs) demonstrate the highest practical potential, enabling thousand-kilometer drawing from a single preform with crosstalk levels reaching -45dB/100km in the C-band, minimally impacting transmission systems over nearly 1,000km. However, WC-MCFs face challenges including prolonged splicing time, significant loss difference between cores, and system complexity. In addition, amplification issues to reduce system complexity remain unresolved. Future applications are expected in space-constrained scenarios like data centers and submarine cables. High-core-count optical cables based on SMF achieve high core density and small diameter through fiber miniaturization and compact optical units, enabling a single cable to accommodate thousands of cores, reducing construction costs in pipeline-limited scenarios. Technically, there are basically no bottlenecks, but long time and high loss of splicing require to be further resolved. HCF offers advantages such as low loss (achieving minimum attenuation < 0.1dB/km), low latency, and large bandwidth. However, current issues include absorption lines in commonly used bands, lack of standards for diverse structures, high cost, and immature supporting equipment (e.g., OTDR, high-power lasers). Meanwhile, it is necessary to explore construction and maintenance plans. Thus, it can be prioritized for latency-sensitive services in the future.

5.2. High-Speed, Large-Capacity All-Optical Transmission

Technologies

Single-carrier ultra-high speed, ultra-wideband and ultra-long-distance transmission are key technologies to break through the bottleneck of optical communication capacity and performance. In terms of single-carrier ultra-high-speed transmission, the industry has launched a single-carrier 1.6Tb/s commercial product based on about 200GBaud symbol rate, and continues to evolve towards higher speeds. In terms of ultra-broadband transmission, the extended C+L band has begun to be deployed in the operator network in large scale, and the S+C+L band is expected to become the direction of next-generation band expansion. The transmission solution of the full-band (O/E/S/C/L/U) has been initially verified in the laboratory. For ultra-long-haul transmission, single-carrier 400Gb/s systems have reached transmission distances over 2,000km, while 800Gb/s systems are expected to exceed 1,500km, continuously supporting terrestrial backbone and all-scenario optical network evolution. For submarine cable systems, single-carrier 200Gb/s with repeaterless transmission is expected to exceed 15,000km. Technically, increasing single-carrier symbol rates depends on wideband optoelectronic components and high-performance DSP chips enabled by advanced semiconductor processes. Ultra-broadband transmission relies on the maturity of optoelectronic devices across spectrum bands, advanced power management, and impairment compensation mechanisms. Achieving ultra-long-haul performance further depends on innovations in optical fibers—such as ultra-low-loss, large effective area fibers (e.g., G.654.E)-advanced DSP compensation algorithms, and optimized optical amplification technologies.

5.3. All-Optical Switching Technologies

High-dimension Wavelength Selective Switches (WSS), fast restoration in WSON, and OCS are keys to enhance optical network flexibility and reliability.

- As the core component of ROADM, current 1×32 (line group) and 1×40 (local group) WSS are commercially deployed. For multi-route high-traffic scenarios, N×M high-dimension WSS is needed to reduce space and cost.

- WSON, based on "centralized routing + distributed control", combines dummy light monitoring and Optical Signal-to-Noise Ratio (OSNR) modeling to achieve fast restoration route awareness. 50ms-level recovery is achieved via protocols, WSS devices, optical amplifiers, and modules. The technology is currently in prototype validation.

- OCS enables fully transparent switching via 3D Micro-Electromechanical Systems (MEMS) or Liquid Crystal on Silicon (LCOS). It is widely applied in high-speed data center interconnects. Future applications include operator smart cabling, supporting AI clusters and intelligent operation and maintenance.

5.4. All-Optical Access Technologies

The latest technical capability of outdoor optical access is 50G-PON, which adopts single-fiber bidirectional Time Division Multiplexing (TDM) technology, supports 50Gb/s downstream, 25/50Gb/s upstream, compatible with existing ODN networks, and can provide 10 gigabit access capabilities in a large scale. For large-scale commercial deployment, it is necessary to break through key technologies and engineering bottlenecks such as high-power budget, wavelength conflict, and interoperability. The next-generation VHSP is expected to have at least 200G service access capabilities, compatible with multi-generation ODNs, and has two technical routes: IM/DD (Intensity Modulator/Direct Detection, with low cost and low power consumption advantages, but high technical difficulty) and Coherent (with flexible access capabilities, but high cost). Its international technical standards are expected to be initially completed around 2030. Indoor all-optical networking technology FTTR uses Point-to-Multipoint (P2MP) topology to extend fiber in rooms. Rates between master and slave gateways are 2.5Gb/s or 10Gb/s, combined with Wi-Fi 6/7/8 to provide high-bandwidth, low-latency services. For efficient operations and experience assurance, key technologies like intelligent management and control, edge-network-cloud synergy are being developed at the optical access and FTTR system levels.

5.5. Industrial PON Technologies

Industrial PON currently delivers a high-performance, highly reliable optical connectivity backbone for industrial applications. It fulfills the deterministic transmission requirements for multi-scenario, multi-modal industrial control data in intelligent manufacturing, while constructing differentiated communication service tiers—basic, real-time, and isochronous synchronization—enhancing both adaptability and reliability of optical networks in industrial environments. Concurrently, addressing the application demands and network orchestration requirements in industrial scenarios, an all-optical industrial configuration system has been developed. This system standardizes equipment, control, and data interactions through graphical and modular interfaces, lowering development barriers for industrial control systems and accelerating industrial digital transformation with scalable deployment.

5.6. Integrated Sensing and Communication Technologies

Integrated Sensing and Communication technology in optical networks leverages the optical communication network, fusing sensing technology to provide highly reliable sensing services for the optical network. Distributed optical fiber sensing, combined with amplification and coding technologies, can achieve spatial positioning of multiple parameters such as temperature, stress, and vibration over ranges of hundreds of kilometers. It focuses on innovative breakthroughs such as multi-parameter fusion, large dynamic high-resolution perception, synesthesia fusion networking, and AI intelligent processing, providing fault risk location and early warning capabilities for submarine and terrestrial cable communication networks. Equipment, link and system sensing can be based on DSP or small AI models for real-time performance status perception and the sensing precision depends on fiber nonlinearity. Service perception relies on traffic characteristics and application identification, supporting application-level SLA assurance and optical performance perception. Breakthroughs in algorithms and high-speed data acquisition bottlenecks are urgently required. ODN sensing utilizes passive device backscattering to enable non-interruptive fault monitoring and environmental perception, improving access network reliability and operational efficiency.

5.7. Digital Twin for Optical Network Technologies

Digital Twin for optical networks currently basically support the mapping of physical networks and digital mirrors. The latest technical capabilities are reflected in the implementation of typical applications enabled through modeling, such as network and resource planning, precise quality of transmission assessment, risk analysis, and intelligent service provisioning. However, it still faces three major problems: First, the physical modeling accuracy of optical devices is insufficient, which affects twin reliability. Second, cross-vendor equipment data and data in different environments have strong heterogeneity, and the model generalization ability is limited. Third, existing systems have poor digital twin capabilities, making it difficult to achieve closed-loop "Perception-Simulation-Prediction Verification-Execution". In the future, the breakthrough direction can focus on the following three aspects: First, developing models with high accuracy and generalization; second, building an open digital twin architecture to achieve unified interfaces for multi-vendor equipment; third, exploring the closed-loop simulation, analysis and verification capabilities of digital twin for optical networks, empowering the entire lifecycle of optical networks, make planning more accurate, construction more efficient, maintenance more quickly (minute-level fault tracing), optimization more timely (rerouting success rate > 95%), and operation more agile (minute-level service issuance), etc.

5.8. Optical Network Artificial Intelligence Technologies

AI technology is deeply empowering optical network control and management, enabling autonomous analysis and dynamic optimization. At present, small AI models have shown significant effects in special tasks such as fiber co-routing detection, accurate fault identification and intelligent Wi-Fi tuning, improving risk identification and positioning capabilities. The large model combines operation and maintenance models, corpus management and fine-tuning to initially form a closed-loop agent, but its applications are not yet widespread. Automated management and control fused with AI enhances capabilities like wavelength/rate optimization, SLA assurance and automatic testing, promoting efficient and agile operations. At present, the development of optical network AI technology still faces two key challenges: First, the reliability, real-time performance, and explainability of AI large/small models for autonomous decision-making are insufficient in complex scenarios; second, automation platforms need to breakthrough system barriers to achieve deeper cross-layer and cross-domain collaboration. Looking to the future, it is necessary to develop next-generation operation and maintenance large models with deep cognitive and complex reasoning capabilities, to build adaptive network knowledge graphs, to overcome close-loop decision-making technologies and to achieve intent-driven, strategy-explainable end-to-end intelligence. This will enable extreme optimization of optical network resources, instantaneous self-healing of faults and intelligent on-demand service configuration with minimal or no human intervention.

5.9. Novel O/E Integration Technologies for All-Optical Connectivity

Silicon-based hybrid optoelectronic integration technology, by increasing the integration level of chips inside optical modules, is gradually becoming the mainstream technical solution for the optical modules whose bitrate is greater than 1.6Tb/s nowadays. It will also be suitable for the development of next-generation single-channel 400Gb/s IM/DD and 200GBaud and beyond coherent optical modules. In this field, it is necessary to build a mature and complete domestic industrial ecosystem, thus reducing reliance on overseas high-end raw materials and manufacturing technique. In the aspect of high-integration and low-power packaging, 2.5D CPO has already provided 3.2Tb/s~6.4Tb/s total bandwidth. 3D packaging will further increase interconnection density, but it still requires tackling issues like thermal management and complex processes. Chiplet-based optical interconnect technology can further improve the energy efficiency for AI computing clusters, offering new development opportunities for silicon photonics. For the traditional pluggables, Linear Pluggable Optics/Linear Receiver Optics (LPO/LRO) may reduce power consumption and latency by eliminating the inside optical DSP, but it still requires standardization for interoperability. Finally, Multi-subcarrier technology is emerging as a key breakthrough path under process and rate constraints.

5.10. Space Optical Communication Technologies

As an important supplement to ground communication, space optical communication needs to break through key technologies such as atmospheric turbulence compensation, Doppler frequency shift compensation and ATP. At present, the inter-satellite optical communication rate has reached 400Gb/s, and a number of technologies based on coherent detection and adaptive modulation have also begun to enter the experimental stage. The current development trend is reflected in the following three aspects: atmospheric turbulence compensation improves link stability and signal quality through multi-input and multiple-output (MIMO) algorithm, adaptive optics, aperture averaging and diversity reception. Doppler frequency shift compensation uses Frequency Locked Loop/Phase Locked Loop (FLL/PLL) feedback and high-speed DSP algorithm to correct GHz-level frequency shift in real time to ensure coherent communication synchronization and phase stability. ATP technology achieves micro-radian-level accuracy direction through coarse aiming, beam acquisition and fine tracking to ensure the stability of inter-satellite links. Looking to the future, space optical communication will realize Tb/s-level networking capabilities, support the integrated communication system between satellites, satellite-ground, and satellite-sea, and play a core role in global broadband access, deep space exploration, disaster emergency response and other fields.

6. Future Prospects of AON

Under the guidance of "Cloudification and Digital Transformation, and Intelligent Empowerment" strategy and the vision of "Cloud-Network Convergence", China Telecom will continue to advance the construction of AON. Aligned with the three core visions of "AON 3.0" — "optical-cloud-intelligence convergence, optical-sensing-service convergence, and space-ground-sea convergence",—we will drive technological innovation to achieve the six defining characteristics: Ubiquitous optical high-speed connectivity, new optical media, dynamic optical links, native optical intelligence, multi-dimensional optical sensing, hierarchical optical bearing. Through phased implementation, we aim to fully realize these capabilities by 2030 and achieve a stable, mature network by 2035, establishing an industry-leading all-optical network that is architecturally robust, agile, and intelligent.

"AON 3.0" is not the end goal but a milestone in continuous evolution. In the intelligent era, as computing power, storage, and network resources deepen their integration, AON will further enhance their intelligence, achieving comprehensive advancements from hardware infrastructure to service applications. This will enable a self-aware, self-optimizing, and self-evolving intelligent network ecosystem.

The future development of AON depends on collaborative innovation among telecom operators, industry, academia, and research institutions. Breakthroughs in key technologies—such as high-performance all-optical transmission, all-optical switching, optoelectronic integration, and AI-powered sensing—are essential. China Telecom is committed to collaborate with global partners to build a self-reliant, secure, and advanced AON industry chain.

Appendix Abbreviations

Abbreviations	Full name
2B	To Business
2H	To Home
5G	Fifth Generation Mobile Communication
6G	Sixth Generation Mobile Communication
AI	Artificial Intelligence
AON	All-Optical Network
ATP	Acquisition, Tracking, and Pointing
CPO	Co-Packaged Optics
CT	Communication Technology
DAS/DVS	Distributed Acoustic Sensing / Distributed Vibration Sensing
DBA	Dynamic Bandwidth Allocation
DC	Data Center
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EoS	Ethernet over Synchronous Digital Hierarchy
FLL	Frequency-Locked Loop
FSO	Free Space Optical
FTTR	Fiber to The Room
GIS	Geographic Information System
HCF	Hollow-Core Fiber
ICGBs	International Communication Gateway Bureaus

Abbreviations	Full name
IM/DD	Intensity Modulation / Direct Detection
IP	Internet Protocol
KPI	Key Performance Indicator
LCoS	Liquid Crystal on Silicon
LEO	Low Earth Orbit
LPO	Linear Pluggable Optics
LRO	Linear Receiver Optics
MAN	Metro-optimized Optical Transport Network
MEMS	Micro-Electro-Mechanical System
MIMO	Multiple-Input Multiple-Output
M-OTN	Metropolitan Optical Transport Network
NaaS	Network as a Service
O&M	Operation and Maintenance
OCS	Optical Circuit Switch
ODN	Optical Distribution Network
OLT	Optical Line Terminal
ONU	Optical Network Unit
OPM	Optical Performance Monitor
OSNR	Optical Signal-to-Noise Ratio
OSU	Optical Service Unit
OT	Operational Technology
OTDR	Optical Time Domain Reflectometry

Abbreviations	**Full name**
OTN	Optical Transport Network
OTU	Optical Transform Unit
P2MP	Point-to-Multipoint
PESs	Pass and Earth Stations
PLC	Programmable Logic Controller
PLL	Phase-Locked Loop
PON	Passive Optical Network
RDMA	Remote Direct Memory Access
ROADM	Reconfigurable Optical Add-Drop Multiplexer
SCLSs	Submarine Cable Landing Stations
SDH	Synchronous Digital Hierarchy
SDM	Space-Division-Multiplexing
SLA	Service Level Agreement
SMF	Single-Mode Fiber
TDM	Time Division Multiplexing
VHSP	Very High-Speed Passive Optical Network
VIP	Very Important Person
WC-MCFs	Weakly-Coupled Multi-Core Fibers
WDM	Wavelength Division Multiplexing
WSON	Wavelength Switched Optical Network
WSS	Wavelength Selective Switch