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Title

Modernization and Commissioning of Telecom Sites

Supervision, Installation and Integration of New Sites

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Dedication

All praise is due to Allah, by whose grace all good deeds are accomplished, and who has enabled me to complete this humble work.

I dedicate this work to my dear parents, who have always been my greatest support and source of strength throughout my academic journey, and to all my family members who continuously encouraged and supported me.

I also dedicate this work to my respected professors who illuminated my path with knowledge and guidance, and to everyone who contributed, directly or indirectly, to the completion of this work.

Finally, I dedicate this effort to my friends and colleagues who shared this academic journey with me, as a token of appreciation and gratitude.

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Finally, I would like to sincerely thank everyone who assisted me in any way, whether through academic support or moral encouragement, and who contributed to the completion of this work.

May Allah guide us all to success.

Abstract

English:

This text describes the global shift from 2G/3G networks to 4G LTE and 5G, highlighting the growing importance of network modernization for mobile operators. It studies the process of telecom base station modernization, including installation, commissioning, and integration into the RAN. The results show that a structured approach improves key performance indicators such as accessibility, call drop rates, and network reliability, with signal quality (RSRP and SINR) playing a key role in overall performance.

Français:

Ce texte présente la transition mondiale des réseaux 2G/3G vers la 4G LTE et la 5G, ainsi que l'importance de la modernisation des réseaux. Il analyse le processus de mise à niveau des stations de base télécoms, de l'installation à l'intégration dans le réseau RAN. Les résultats montrent qu'une approche structurée améliore les indicateurs de performance (accessibilité, coupures d'appel, fiabilité), tandis que la qualité du signal (RSRP et SINR) reste déterminante pour les performances du réseau.

العربية:

يتناول النص التحول العالمي في شبكات الاتصالات من 2G و3G إلى 4G و5G، وأهمية تحديث الشبكات لمواكبة هذا التطور. كما يشرح دراسة عملية لعملية تحديث محطات الاتصالات بدءاً من التركيب والتشغيل وصولاً إلى دمجها في وتظهر النتائج أن اعتماد منهجية منظمة يحسن مؤشرات الأداء مثل الجاهزية، وتقليل انقطاع المكالمات، شبكة RAN. تلعب دوراً أساسياً في تحسين الأداء (RSRP و SINR) ورفع موثوقية الشبكة، مع التأكيد على أن جودة الإشارة

Keywords:

Telecom modernization, LTE, 5G NR, eNodeB, gNodeB, commissioning, OSS/NMS, KPI, RSRP, SINR, RAN integration, drive test, O-RAN, network supervision.

List of Abbreviations and Acronyms

Acronym	Expanded Form
3GPP	3rd Generation Partnership Project
AMF	Access and Mobility Management Function (5G Core)
ATP	Acceptance Test Procedure
BBU	Baseband Unit
BTS	Base Transceiver Station (2G)
C-RAN	Centralized / Cloud Radio Access Network
CDMA	Code Division Multiple Access
CQI	Channel Quality Indicator
CU / DU	Centralized Unit / Distributed Unit (5G RAN)
DAS	Distributed Antenna System
DT	Drive Test
eCPRI	Enhanced Common Public Radio Interface
eMBB	Enhanced Mobile Broadband
eNodeB	Evolved NodeB (4G LTE base station)
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
gNodeB	Next-Generation NodeB (5G NR base station)
GSMA	Global System for Mobile Communications Association

Acronym	Expanded Form
HO	Handover
KPI	Key Performance Indicator
LTE	Long Term Evolution
Massive MIMO	Massive Multiple Input Multiple Output
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
MOP	Method of Procedure
NFV	Network Function Virtualization
NMS	Network Management System
NR	New Radio (5G)
NSA	Non-Standalone (5G architecture)
O-RAN	Open Radio Access Network
OFDMA	Orthogonal Frequency Division Multiple Access
OSS	Operations Support System
PCI	Physical Cell Identity
PIM	Passive Intermodulation
PRB	Physical Resource Block
QoS	Quality of Service
RAN	Radio Access Network
RET	Remote Electrical Tilt
RRC	Radio Resource Control
RRH / RRU	Remote Radio Head / Remote Radio Unit

Acronym	Expanded Form
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SA	Standalone (5G architecture)
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDN	Software Defined Networking
SINR	Signal to Interference plus Noise Ratio
URLLC	Ultra-Reliable Low-Latency Communications
VSWR	Voltage Standing Wave Ratio

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Introduction

Mobile telecommunications networks have undergone continuous evolution since the early 1980s, progressing from analog 1G systems to digital GSM networks, and later to high-capacity packet-switched technologies such as LTE and 5G NR. This evolution has been driven by increasing demand for mobile broadband services, improved spectral efficiency, and enhanced user experience [1], [2].

According to GSMA Intelligence (2024), global 5G adoption has grown rapidly, with the number of 5G connections exceeding 1.5 billion by the end of 2023, making it the fastest-growing mobile communication technology to date [3].

In addition, the Ericsson Mobility Report (2024) forecasts that 5G subscriptions will reach approximately 6.3 billion by 2030, accounting for nearly two-thirds of all mobile subscriptions worldwide [4].

This rapid expansion places significant pressure on Mobile Network Operators (MNOs) to continuously modernize their radio access networks. As a result, legacy 2G and 3G infrastructures are progressively being upgraded or phased out, while LTE and 5G networks require densification, optimization, and advanced planning to handle increasing traffic demand and service requirements [2], [5].

This thesis focuses on the technical aspects of this modernization process, structured around three main pillars:

- **Network supervision**, including monitoring systems and performance analysis tools used to ensure real-time visibility of network behavior;
- **Physical installation**, covering engineering practices, deployment procedures, and safety requirements for telecom infrastructure;
- **Network integration**, which includes configuration, commissioning, and validation processes required to bring modernized sites into operational service within the existing radio access network [1], [5].

Chapter 1: Evolution of Cellular Networks and Radio Access Architectures

1.1 Overview

The cellular concept, originally introduced by Bell Laboratories in the 1970s, is based on partitioning a geographic region into smaller coverage units known as cells, each served by an individual base station. This structural design enables the reuse of frequency bands in geographically separated cells, thereby significantly enhancing spectral efficiency and overall network capacity. The principle of frequency reuse has become a foundational element of modern mobile communication systems and has guided the evolution of cellular networks from first-generation (1G) systems to contemporary mobile technologies [1], [2].

1.2 Generational Evolution of Mobile Standards

1.2.1 Second Generation (2G/GSM)

The Global System for Mobile Communications (GSM) marked a major transition from analog to digital cellular networks through the adoption of Time Division Multiple Access (TDMA). This digitalization improved spectral efficiency and introduced essential services such as voice telephony and Short Message Service (SMS). Subsequent enhancements, including General Packet Radio Service (GPRS), enabled packet-switched data transmission with peak theoretical rates of up to 114 kbps, while Enhanced Data rates for GSM Evolution (EDGE) further increased throughput to approximately 384 kbps under optimal conditions.

The GSM radio access network, known as the Base Station Subsystem (BSS), is composed of Base Transceiver Stations (BTS) managed by Base Station Controllers (BSC), which are responsible for radio resource management and handover control within the network [3], [4].

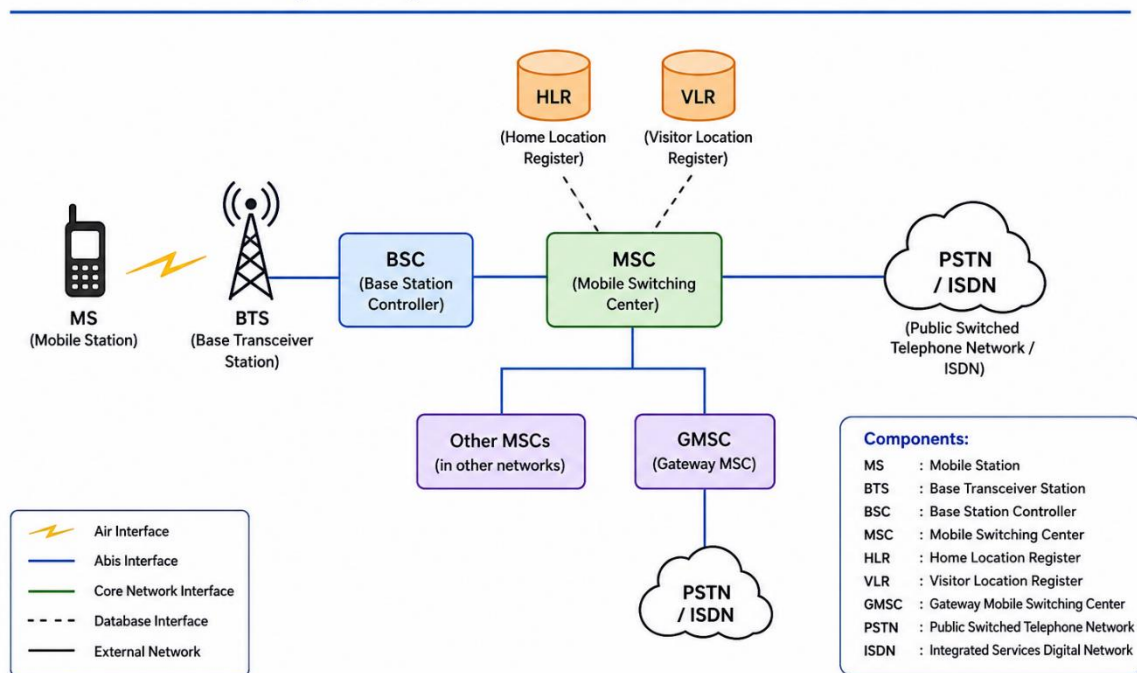


Figure 1. 2G (GSM) Network Architecture

1.2.2 Third Generation (3G/UMTS)

The Universal Mobile Telecommunications System (UMTS) introduced Wideband Code Division Multiple Access (W-CDMA), enabling higher data capacity and improved spectral efficiency compared to GSM. In its initial Release 99 configuration, UMTS supported peak downlink data rates of up to 384 kbps.

Subsequent High Speed Packet Access (HSPA) enhancements (Releases 5 and 6) significantly increased peak downlink rates up to 14.4 Mbps, while HSPA+ (Releases 7 and 8) further improved performance to approximately 42 Mbps through advanced modulation schemes such as 64-QAM and the introduction of MIMO techniques.

The UMTS radio access network architecture incorporates the Radio Network Controller (RNC), which serves as an intermediary between NodeB base stations and the Core Network, managing mobility, radio resources, and handovers [5].

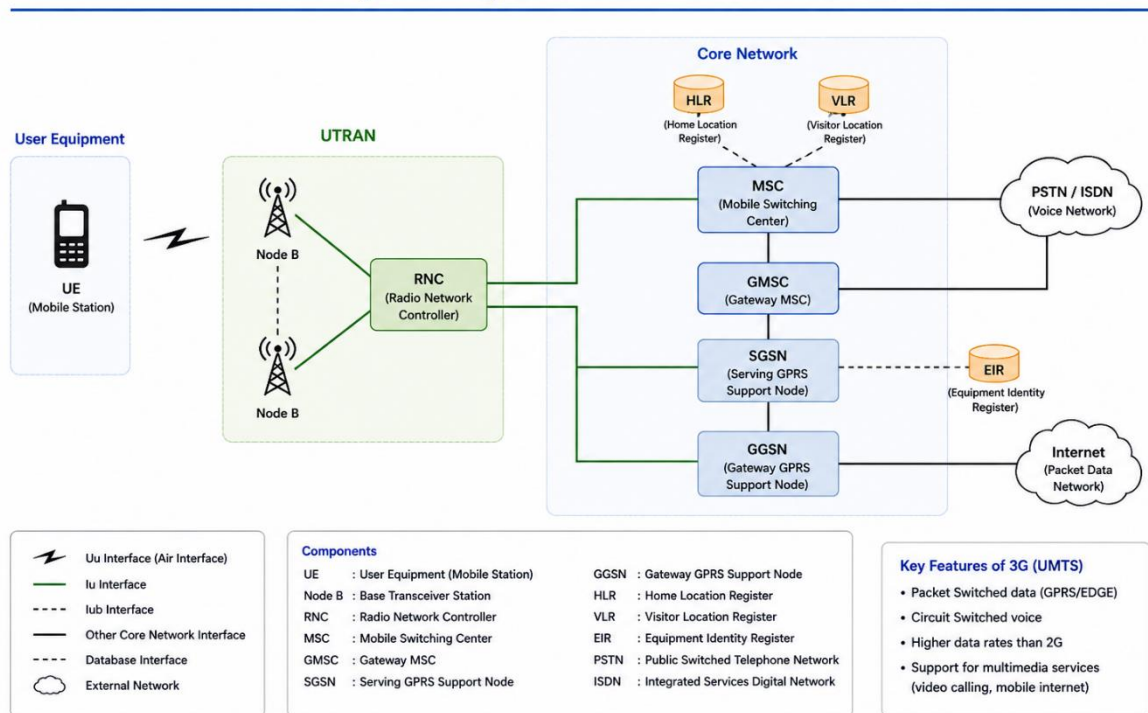


Figure 2. 3G (UMTS) Network Architecture

1.2.3 Fourth Generation (4G/LTE)

Long Term Evolution (LTE), standardized by 3GPP from Release 8 onward, introduced a fully IP-based network architecture through the Evolved Packet Core (EPC). LTE also adopted Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink, significantly improving spectral efficiency and system performance.

In Release 8, LTE achieved peak downlink rates of up to 150 Mbps under ideal conditions (2x2 MIMO with 20 MHz bandwidth), while LTE-Advanced (Release 10) extended theoretical peak rates to 1 Gbps using techniques such as carrier aggregation and higher-order MIMO configurations.

The LTE radio access network is centered around the eNodeB (evolved NodeB), which integrates functionalities previously distributed between BTS and RNC in earlier generations, thereby simplifying network architecture and reducing latency [6].

As of recent global deployments, LTE has become the dominant mobile broadband technology, covering a substantial majority of the global population and serving as the primary connectivity layer in many regions.

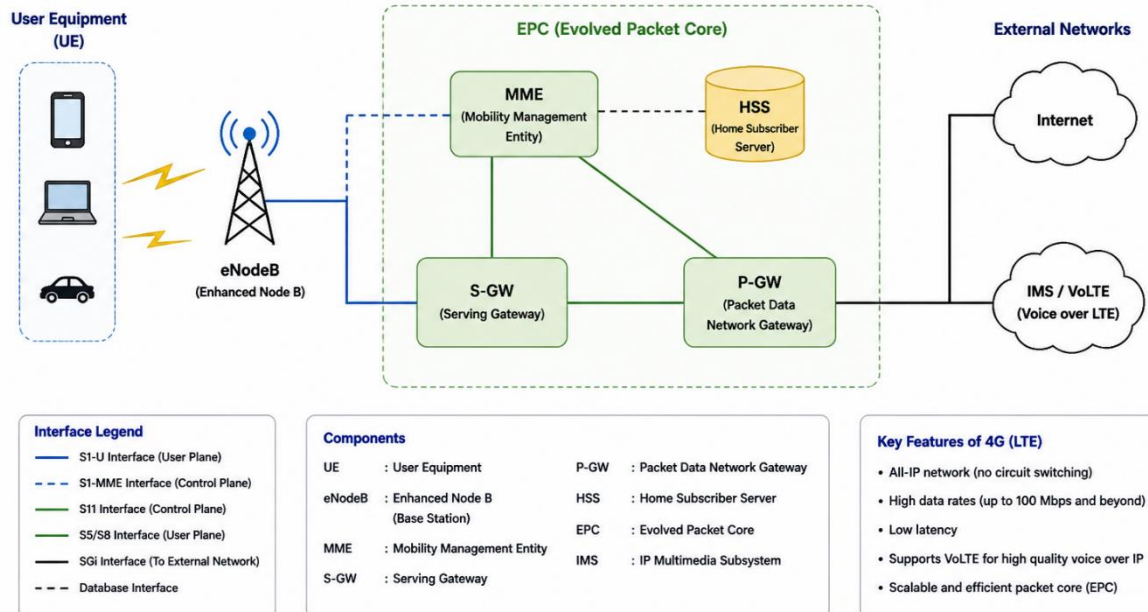


Figure 3. 4G (LTE) Network Architecture

1.2.4 Fifth Generation (5G NR)

5G New Radio (NR), standardized in 3GPP Release 15 and beyond, represents a significant evolution in mobile network design, supporting three primary service categories: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and Ultra-Reliable Low-Latency Communications (URLLC).

5G networks are designed to support peak data rates exceeding 10 Gbps under optimal conditions, ultra-low latency communication approaching sub-millisecond levels in URLLC scenarios, and massive device connectivity for IoT applications.

The 5G radio access network introduces a flexible functional split architecture composed of Centralized Units (CU) and Distributed Units (DU), enabling deployment in Cloud-RAN (C-RAN) and Open RAN (O-RAN) environments. This separation improves scalability, network efficiency, and support for edge computing integration [7].

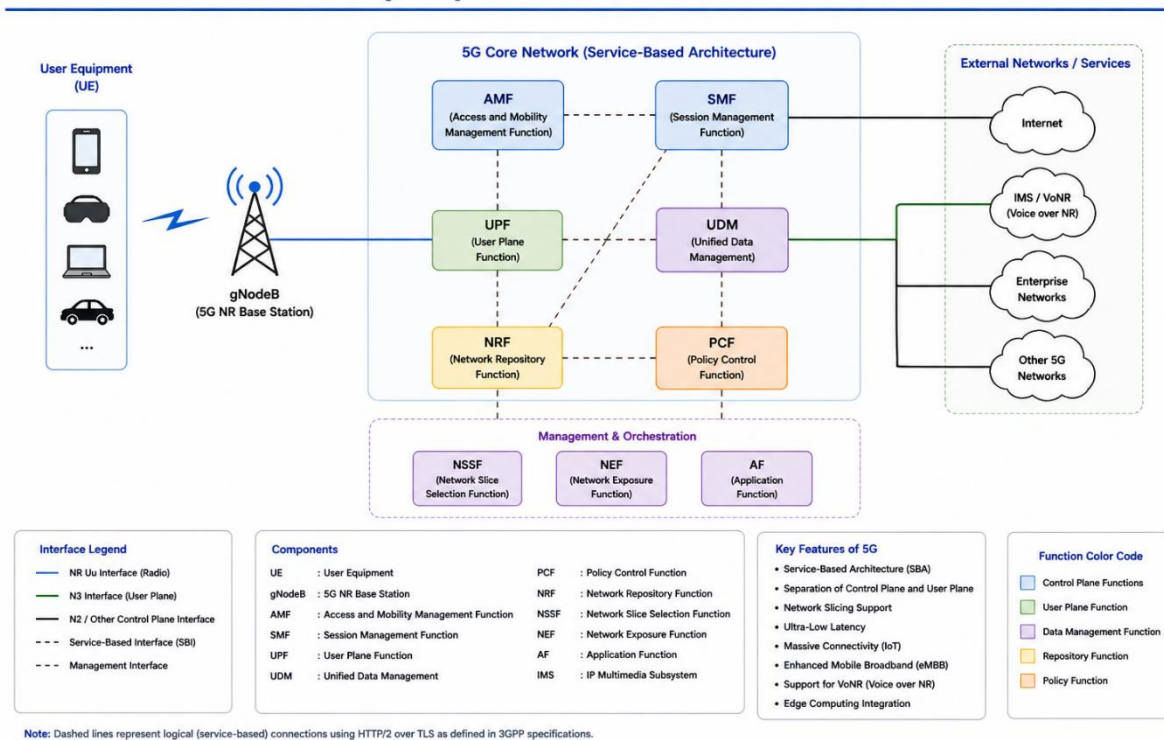


Figure 4. 5G (NR) Network Architecture

1.3 Summary: Generation Comparison

Table 1. Generation Comparison

Generation	Standard	Peak DL Rate	Duplex	Key RAN Node	Core Network
1G	AMPS / NMT	Analog	FDMA	Base Station	PSTN
2G	GSM / GPRS / EDGE	384 kbps	TDMA / FDD	BTS + BSC	MSC / SGSN
3G	UMTS / HSPA+	42 Mbps	W-CDMA / FDD	NodeB + RNC	MSC / GGSN
4G	LTE / LTE-A	~1 Gbps	OFDMA / FDD+TDD	eNodeB	EPC (MME, S-GW, P-GW)
5G	NR (Rel-	>10 Gbps	OFDM /	gNodeB	5GC (AMF,

Generation	Standard	Peak DL Rate	Duplex	Key RAN Node	Core Network
	15+)		FDD+TDD	(CU/DU)	UPF, SMF)

1.4 Radio Access Network Architecture

1.4.1 Classic vs. Distributed Architecture

Traditional cellular base stations integrated all baseband processing and radio frequency functions within a single physical unit. However, modern architectures adopt a distributed model in which Baseband Units (BBU) are separated from Remote Radio Units (RRU/RRH), interconnected via high-speed fronthaul interfaces such as CPRI or eCPRI.

This architectural evolution reduces feeder losses, enhances deployment flexibility for multi-band and multi-standard systems, and forms the foundation for centralized RAN (C-RAN) and virtualized/Open RAN (O-RAN) deployments, which are key enablers of next-generation mobile networks [8].

1.4.2 Frequency Bands

Table 2. Frequency Bands

Band	Frequencies	Primary Use	Generations
700 MHz (B28)	703–748 / 758–803 MHz	Rural coverage	4G / 5G NR
900 MHz (B8)	880–915 / 925–960 MHz	Coverage layer	2G / 4G / 5G
1800 MHz (B3)	1710–1785 / 1805–1880 MHz	Urban capacity	2G / 4G / 5G
2100 MHz (B1)	1920–1980 / 2110–2170 MHz	3G UMTS / 4G	3G / 4G
2600 MHz (B7)	2500–2570 / 2620–2690 MHz	High-capacity urban	4G

Band	Frequencies	Primary Use	Generations
3.5 GHz (n78)	3400–3800 MHz	5G eMBB (C-band)	5G NR
26 GHz (n258)	24.25–27.5 GHz	5G mmWave	5G NR

1.5 Conclusion

This chapter provided an overview of the evolution of cellular networks and radio access architectures. It highlighted the cellular concept and the principle of frequency reuse, which form the basis of modern mobile communication systems.

It then summarized the main developments from 2G GSM to 5G NR, focusing on improvements in data rates, spectral efficiency, and service capabilities across generations.

Finally, the chapter outlined the evolution of RAN architectures from centralized base stations to more flexible distributed and cloud-based designs, which enable higher scalability and performance in modern networks.

Overall, these developments illustrate the continuous advancement of mobile communications toward more efficient, high-capacity, and flexible network systems.

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Chapter 2: Operational and Organizational Overview of ATM Mobilis & UOP Business Units

2.1 Overview

ATM Mobilis is a major telecommunications operator in Algeria, providing mobile voice, data, and digital services while continuously developing its network infrastructure to ensure service quality and meet increasing demand.

The UOP (Operational Units of Network Maintenance) represent the operational structure responsible for executing technical activities such as maintenance, deployment, and network support.

Together, ATM Mobilis and UOP units form an integrated system that links strategic planning with field execution, ensuring service reliability, network performance, and operational efficiency [1], [2].

2.2 Sect 01: Presentation of the ATM Mobilis company

2.2.1 Introduction

ATM Mobilis is one of the leading telecom operators in Algeria. It plays a key role in providing mobile communication services nationwide and ensuring continuous improvement of network quality and coverage.

The organization is structured to connect management, technical operations, and regional units (UOPs), ensuring efficient service delivery and network supervision [1].

2.2.2 History and legal status

ATM Mobilis (SPA) was created following the restructuring of the Algerian telecom sector under Law 2000-03, which introduced competition in mobile telecommunications.

Since 2018, it has operated under a public holding structure alongside Algérie Télécom and Algérie Télécom Satellite.

The company focuses on network expansion, service quality, and digital transformation in the national telecom sector [2], [3].

2.2.3 Organization of ATM Mobilis:

ATM Mobilis is managed by a Chief Executive Officer supported by central divisions and regional directorates.

Its structure follows a separation between operational and functional activities to improve efficiency and control [4].

Main components include:

- Network and Operations Division
- Commercial and Marketing Division
- Finance and Administration Division
- Regional Directorates across the country

This structure ensures national coverage and efficient network management [4], [5].

2.2.4 Missions and values of the company:

Mission

ATM Mobilis aims to provide reliable, accessible, and high-quality mobile services across Algeria while continuously improving its network performance [2].

Values

- Transparency
- Performance and excellence
- Commitment to customers and society
- Agility in adapting to technology changes [2], [5]

Objectives

- Strengthen market leadership
- Improve network quality and coverage
- Increase customer satisfaction
- Modernize telecom infrastructure (4G/5G evolution) [5], [6]

2.2.5 Offers & Services:

- ATM Mobilis provides:
- Prepaid and postpaid services
- Corporate solutions
- Roaming and international services
- Digital mobile services [3]

.

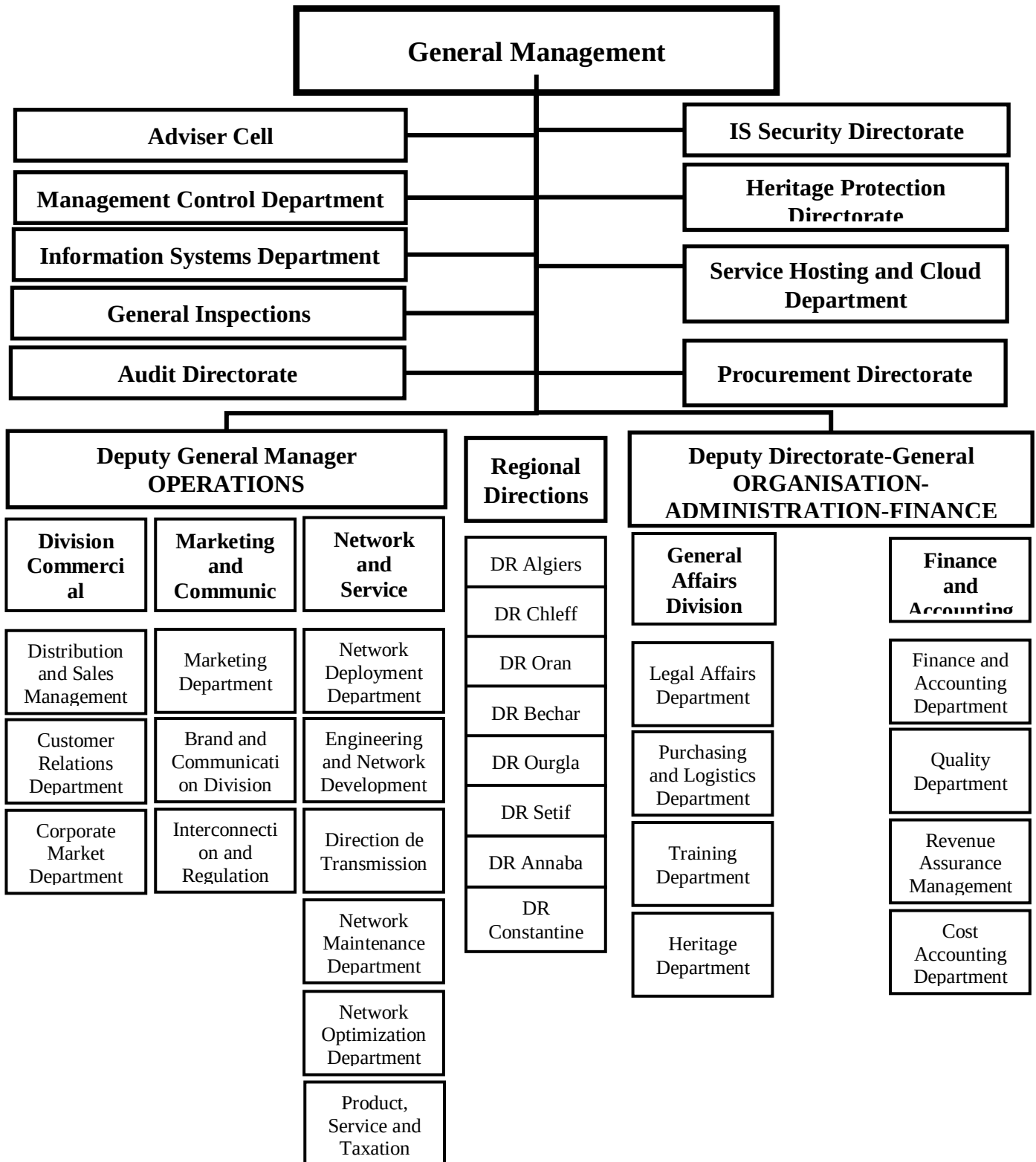


Figure 5. Organisation of MOBILIS [9]

2.3 Sect 02: Presentation of the UOP Business Units

2.3.1 Definition of UOP

UOP units are technical operational teams responsible for maintaining mobile network equipment and ensuring service continuity across all sites [6].

2.3.2 Main missions

UOP teams handle:

- Fault detection and repair (Trouble Tickets)
- Field maintenance planning
- KPI monitoring and reporting
- Site commissioning and acceptance

These activities follow standard telecom operational frameworks used in OSS/NMS systems [7], [8].

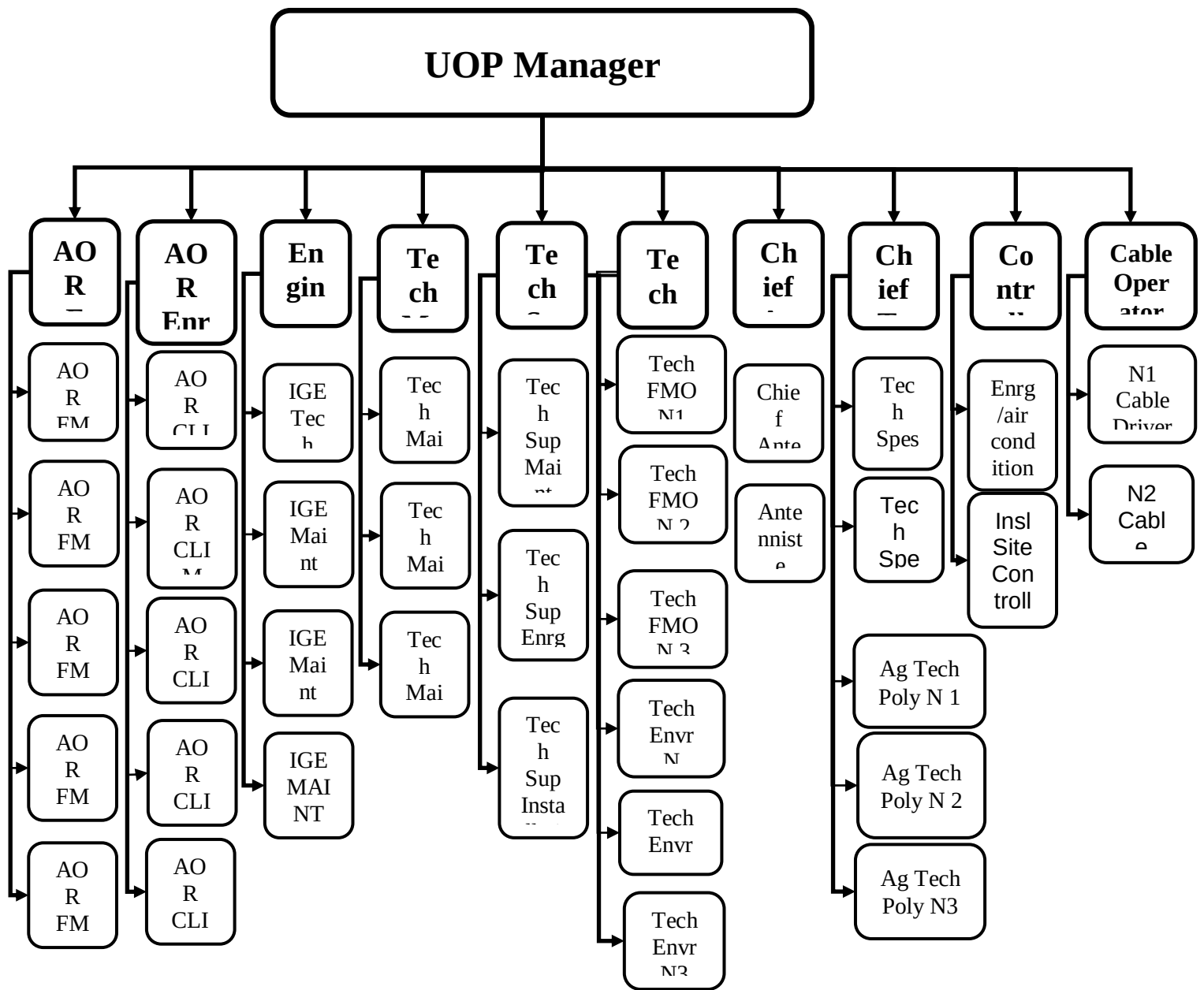


Figure 6. Current UOP Organizational Chart [9]

2.3.4 The UOP Manager:

The UOP Manager supervises technical activities in the field and ensures:

Site availability and performance

Maintenance planning and execution

Validation of field reports

Team coordination and performance management

Compliance with technical procedures [6], [8]

2.3.5 Field Teams (Technicians / Antennists)

Field teams are responsible for:

On-site maintenance and troubleshooting

Equipment installation and testing

RF and transmission measurements

Execution of work orders and repair tasks

These roles are essential for maintaining network quality and SLA compliance [7].

2.3.6 Conclusion

ATM Mobilis is organized through a structured model combining central management and decentralized operational units (UOPs). This structure ensures efficient network operation, high service quality, and continuous improvement of telecom infrastructure.

Chapter 3: Network Deployment, Integration and Operation

Overview

Network Deployment, Integration, and Operation refers to the complete end-to-end process of planning, installing, configuring, integrating, and maintaining telecommunications network infrastructure. It includes the rollout of new network elements, their seamless integration into existing architectures, and their continuous operation to ensure service continuity, high availability, and optimal performance. The process also covers monitoring, troubleshooting, and optimization activities aimed at maintaining efficient and reliable network operation throughout the network lifecycle [1], [2].

Sec1: Network Supervision, Alarms, and KPI Management

3.1.1 Introduction

Efficient supervision of Radio Access Networks (RAN) is fundamental to ensuring Quality of Service (QoS) and enabling proactive maintenance strategies. Operations Support Systems (OSS) and Network Management Systems (NMS) provide centralized, real-time visibility of network behavior, allowing operators to detect anomalies, analyze performance trends, and perform corrective optimization actions. This section discusses OSS/NMS architecture, alarm handling mechanisms, and key performance indicators (KPIs) used for network evaluation [3].

1.2 OSS/NMS Architecture

1.2.1 Functional Layers

Telecom network management architectures are commonly structured according to the ITU-T Telecommunications Management Network (TMN) model. This model defines a hierarchical structure consisting of the Element Management Layer (EMS), Network Management Layer (NMS), Service Management Layer (SMS), and Business Management Layer (BMS), in addition to the physical network element layer itself.

In practical deployments, operators rely on commercial OSS platforms such as Nokia NetAct, Ericsson Network Manager (ENM), Huawei eSight/M2000, and ZTE NetNumen. These systems provide end-to-end management capabilities including configuration control, fault

monitoring, performance analysis, and inventory tracking across heterogeneous network environments [3], [4].

1.2.2 Key Management Functions

Network management operations are typically grouped into four primary domains:

Configuration Management (CM): Responsible for provisioning, parameter configuration, and lifecycle management of network elements.

Fault Management (FM): Handles alarm detection, correlation, prioritization, and ticket generation for troubleshooting.

Performance Management (PM): Collects and analyzes KPI counters, typically at 15-minute intervals, for performance evaluation.

Inventory Management (IM): Tracks physical and logical network assets, including hardware and software resources.

1.2.3 Standardized Interfaces

Standardization ensures interoperability between OSS platforms and network elements. 3GPP TS 28.532 defines management and orchestration interfaces for mobile networks, including the Itf-N interface between OSS and network elements.

Modern networks widely adopt NETCONF/YANG for structured configuration management, while SNMP continues to be used in legacy systems for alarm reporting and monitoring functions [5], [6].

1.3 Alarm Management

1.3.1 Alarm Classification

Table 3. Alarm Classification

Severity	Color Code	Definition	Typical Triggers
Critical	Red	Service-affecting fault requiring immediate action	Total site loss, power failure, fiber cut
Major	Orange	Significant degradation; may be service-affecting	Sector loss, transport degradation
Minor	Yellow	Limited impact; attention required	Partial radio degradation,

Severity	Color Code	Definition	Typical Triggers
			temperature alarm
Warning	Blue	Potential issue; no immediate impact	Threshold approaching, preventive maintenance due
Informational	Green	No impact; awareness only	Configuration change, software update

1.3.2 Alarm Processing Workflow

In modern Network Operations Centers (NOC), alarm handling follows a structured workflow: detection at the OSS level, correlation and de-duplication to eliminate redundant alerts, prioritization based on severity and business impact, assignment to appropriate engineering teams with automatic ticket creation, and finally resolution and closure with documentation.

Increasingly, artificial intelligence and machine learning techniques are integrated into alarm correlation engines to improve root-cause analysis accuracy and reduce Mean Time to Repair (MTTR) [7].

1.4 Key Performance Indicators (KPIs)

1.4.1 KPI Classification Framework

3GPP defines KPI frameworks for LTE and modern networks under TS 32.4xx specifications. KPIs are generally categorized into five domains: accessibility, retainability, mobility, integrity, and availability, providing a comprehensive view of network performance [8].

1.4.2 Radio KPI Benchmarks

Table 4. Radio KPI Benchmarks

KPI	Definition	Industry Target	Source
RRC Connection Setup Success Rate	% of RRC establishment attempts that succeed	> 99%	[8]

KPI	Definition	Industry Target	Source
E-RAB Setup Success Rate	% of E-RAB (data bearer) establishments that succeed	> 99%	[8]
Call Drop Rate (CDR)	% of established connections that terminate abnormally	< 0.5%	[8]
Handover Success Rate	% of intra-LTE handovers that complete successfully	> 98%	[8]
DL / UL Throughput	Average user-plane data rate in downlink / uplink	Operator-specific	[8]
PRB Utilization	% of Physical Resource Blocks used across the cell	< 70% (busy hour)	[8]
Cell Availability	% of scheduled time the cell is in service	> 99.9%	[3]

1.4.3 RF Signal Quality Thresholds

Field studies in real LTE deployments confirm that RSRP values around -85 dBm to -90 dBm generally correspond to good coverage conditions, while SINR is the dominant factor affecting throughput under interference-limited scenarios [9], [10].

Table 5. RF Signal Quality Thresholds

Parameter	Excellent	Good	Fair	Poor	Very Poor
RSRP (dBm)	> -80	-80 to -90	-90 to -100	-100 to -110	< -110
RSRQ (dB)	> -10	-10 to -15	-15 to -20	< -20	–
SINR (dB)	> 20	10 to 20	0 to 10	-10 to 0	< -10

1.4.4 Transmission KPIs

Table 6. Transmission KPIs

KPI	Definition	Target Value
Transport Link Availability	% uptime of backhaul/fronthaul link	> 99.99%
IP Packet Loss Rate	% of IP packets lost in transmission	< 0.01%
Round-Trip Latency (RTT)	End-to-end propagation delay on transport	< 5 ms (fiber)
Jitter	Variation in packet inter-arrival delay	< 2 ms
Bit Error Rate (BER)	Bit error rate on microwave links (if applicable)	< 10^{-7}

1.5 Field Measurement Tools

1.5.1 Drive Test

Drive testing is widely used for validating network performance using specialized tools such as TEMS Investigation, NEMO Outdoor, and XCAL. These tools collect RF parameters (RSRP, RSRQ, SINR), throughput metrics, and signaling traces to generate coverage maps and optimization reports.

In parallel, modern operators increasingly use AI-based analytics to predict KPI degradation based on historical counters, environmental factors, and traffic patterns, enabling a shift from reactive to predictive network maintenance [11].

1.6 Conclusion

Network supervision systems, KPI frameworks, and field measurement tools collectively form the operational intelligence layer of modern telecom networks. These systems ensure continuous service monitoring and enable data-driven optimization, forming the foundation for maintaining high-quality mobile network performance.

Sec2: Installation, Commissioning, and Network Integration

3.2.1 Introduction

The deployment and integration of telecom infrastructure is a multidisciplinary engineering process involving civil works, RF installation, transmission engineering, power systems, and software configuration. It follows a structured lifecycle from site survey to final acceptance and integration into the live network [1], [2].

3.2.2 Project Lifecycle Overview

Table 7. Lifecycle Overview

Phase	Key Activities	Deliverables
1 – Planning	Site audit, KPI baseline, BOM definition, MOP preparation	Site survey report, project plan
2 – Logistics	Equipment ordering, transport, reception QC	Goods receipt note, asset inventory
3 – Civil / Tower Work	Antenna removal/installation, RRH mounting, cabling	As-built drawings
4 – Shelter / Active Equipment	BBU installation, power system, transmission	Equipment installation report
5 – Commissioning	Software load, GPS sync, cell activation, loopback tests	Commissioning checklist
6 – Acceptance (ATP)	VSWR, PIM, throughput, drive test	Signed ATP report
7 – Integration	X2/S1 configuration, neighbor relations, optimization	Network integration report
8 – Project Closure	Documentation (as-built), CMDB update, handover	Final acceptance certificate

3.2.3 Site Audit and Pre-Planning

Site audits are essential for ensuring deployment success. They include physical inventory checks, RF baseline KPI extraction, structural load verification, power system assessment, and backhaul capacity validation. These steps ensure that the site can support the planned modernization without introducing bottlenecks.

3.2.4 Tower Work and RF Installation

3.2.4.1 Antenna Systems

Modern LTE and 5G deployments utilize multi-band, multi-port antennas as well as Active Antenna Units (AAU), which integrate radio and antenna functions into a single system. The evolution of antenna technology has progressed from 2T2R configurations in early LTE deployments (Release 8) to advanced Massive MIMO configurations such as 4T4R, 8T8R, 16T16R, and up to 64T64R in 5G New Radio (NR) systems. These advancements significantly enhance spectral efficiency, beamforming capabilities, and overall network capacity [1], [2].

Antenna installation on towers requires specialized certified rigging teams operating under strict occupational safety regulations. Personnel must use appropriate Personal Protective Equipment (PPE), including safety harnesses, helmets, and protective footwear, in accordance with telecom tower safety standards [3].

3.2.4.2 RF Cable Quality

RF feeder systems play a critical role in ensuring optimal radio performance. Voltage Standing Wave Ratio (VSWR) should typically be maintained below 1.5, corresponding to a return loss greater than 14 dB, to minimize reflected power and signal degradation.

Industry best practices for RF cabling include correct torque application on 7/16-DIN connectors (typically 25–30 Nm), proper weatherproofing using self-amalgamating tape and UV-resistant sealing materials, adherence to minimum bend radius specifications for coaxial cables, and proper grounding and bonding of cable shields at defined intervals to reduce interference and lightning risk. Passive Intermodulation (PIM) performance should remain below -107 dBm to avoid intermodulation products that may interfere with uplink reception [4], [5].

3.2.4.3 eCPRI Interface

In modern distributed RAN architectures, the Baseband Unit (BBU) and Remote Radio Head (RRH) communicate through standardized fronthaul interfaces such as CPRI and its enhanced version, eCPRI (enhanced Common Public Radio Interface). Unlike traditional

CPRI, eCPRI is based on Ethernet transport, offering improved scalability and reduced bandwidth requirements.

eCPRI is designed to support strict latency constraints, typically below 100 microseconds for fronthaul Class A applications, ensuring real-time transmission of IQ data between baseband and radio units. In addition to user-plane IQ samples, the interface also carries control, synchronization, and management information required for coordinated radio operation in distributed architectures [6], [7].

3.2.5 Commissioning Procedures

3.2.5.1 Standard Commissioning Sequence

LTE eNodeB commissioning follows a standardized operational procedure widely adopted across major vendors such as Ericsson, Nokia, and Huawei. This process ensures that all hardware, software, and transmission components are correctly installed and fully operational before network integration.

The commissioning workflow typically includes the following steps:

1. **Power-on verification:** validation of -48 V DC power supply within the acceptable operating range (-40 V to -57 V).
2. **Software verification:** confirmation of correct software version and feature license activation via OSS or local management interface.
3. **GPS synchronization:** verification of successful synchronization and PPS (Pulse Per Second) lock within a defined acquisition time window.
4. **Backhaul connectivity test:** validation of IP connectivity for S1 and X2 interfaces using ping and traceroute, ensuring RTT < 10 ms toward core network elements such as the MME.
5. **OMC/OSS connectivity:** confirmation of operational and maintenance channel establishment between the eNodeB and the network management system.
6. **Cell activation:** enabling radio sectors and ensuring zero critical alarms in the OSS alarm dashboard.
7. **RF loopback testing:** verification of transmitter output power, receiver sensitivity, VSWR levels, and spectral integrity using RF measurement tools.
8. **UE attachment test:** validation that a test UE can successfully attach to the network, establish a data bearer, and achieve expected throughput performance [1], [2].

3.2.5.2 LTE Radio Configuration Parameters

LTE eNodeB configuration parameters are defined in 3GPP TS 36.300 and related specifications. These parameters determine radio behavior, coverage, and mobility performance:

EARFCN: identifies the operating frequency channel based on standardized raster definitions.

PCI (Physical Cell Identity): used for cell identification during synchronization, ranging from 0 to 503.

Transmit power (EIRP): configured per cell to achieve planned coverage while respecting regulatory limits.

Handover parameters: include A3 offset, hysteresis (typically 3 dB), and Time-To-Trigger (160–640 ms), which control mobility behavior.

MIMO configuration: defines antenna port configuration (e.g., 2T2R, 4T4R, 8T8R).

RET (Remote Electrical Tilt): used to adjust antenna coverage patterns dynamically, typically between 0° and 10° electrical tilt [3].

3.2.6 Acceptance Test Procedure (ATP)

The Acceptance Test Procedure (ATP) is a formal validation stage conducted jointly by the contractor and the operator prior to site acceptance. Its objective is to ensure that all installation and performance requirements are met according to contractual and technical specifications.

ATP typically includes the following tests:

RF passive testing: measurement of VSWR using a vector network analyzer, with acceptance criteria typically set at $VSWR < 1.5$.

PIM testing: evaluation of Passive Intermodulation products, with thresholds generally below -107 dBm at defined carrier power levels.

Transport testing: assessment of latency, jitter, and packet loss across backhaul and fronthaul links.

Radio performance testing: throughput verification under controlled conditions, typically targeting more than 50% of theoretical peak LTE capacity for 20 MHz 2x2 MIMO configurations.

Drive testing: validation of real-world coverage and mobility performance, including RSRP > -85 dBm in the intended service area and successful handover behavior [4], [5].

3.2.7 Network Integration

3.2.7.1 S1 and X2 Interface Configuration

Per 3GPP TS 36.413 (S1AP) and TS 36.423 (X2AP), integration of a new eNodeB into the LTE network requires configuration of the S1 interface toward the MME (for signaling) and toward the S-GW (for user data), as well as X2 interfaces to neighboring eNodeBs to enable direct handovers without routing via the core network [6].

3.2.7.2 Neighbor Cell Relations

According to 3GPP TS 36.413 and TS 36.423, LTE network integration requires configuration of the S1 interface between the eNodeB and the core network (MME/S-GW), as well as X2 interfaces between neighboring eNodeBs. These interfaces enable control-plane signaling, user-plane traffic exchange, and direct inter-eNodeB handovers without routing through the core network [6].

3.2.7.3 Post-Integration Optimization

Post-integration optimization is typically conducted over a period of 2 to 4 weeks following site activation. This phase includes KPI monitoring, mobility parameter tuning (e.g., A3 offset and hysteresis adjustments), antenna tilt optimization based on drive test results, and load balancing between multi-band carriers to ensure optimal performance and stability.

3.2.8 Health and Safety

Telecom site deployment activities are governed by strict occupational health and safety regulations. Key requirements include certified working-at-height training for tower personnel, enforcement of electromagnetic field (EMF) exposure limits in accordance with ICNIRP guidelines, electrical safety procedures such as lockout/tagout (LOTO), and controlled site access to prevent unauthorized entry [8].

3.2.9 Conclusion

The commissioning and integration methodology described in this chapter provides a standardized and repeatable framework for LTE and 5G network deployment. Each phase—from commissioning to acceptance and optimization—directly influences the final RF performance and KPI outcomes. Proper execution of these processes is essential to ensure network reliability, service quality, and compliance with operator performance targets, as further demonstrated in the subsequent practical case study.

Sec3: Case Study – LTE Site Modernization Project

3.3.1 Project Context and Objectives

This section presents a practical case study of an LTE modernization project performed on a macro-cellular site located in a peri-urban area. The existing site infrastructure initially supported legacy 2G and 3G technologies and was upgraded to a Multi-RAT platform capable of simultaneously supporting GSM 900, UMTS 2100, and LTE 1800 services.

The main objectives of the modernization project were:

Deployment of LTE service in Band 3 (1800 MHz);

Improvement of legacy 2G and 3G network KPIs;

Migration of the transmission infrastructure from a 10 Mbps microwave backhaul link to a Gigabit Ethernet fiber-optic connection in order to eliminate transport bottlenecks and increase network capacity [1], [2].

3.3.2 Pre-Modernization Site Audit

3.3.2.1 Equipment Inventory [3].

Table 8. Equipment Inventory

Element	Description / Model	Condition / Action Required
Tower	Self-supporting lattice tower, 36 m height	Good – structural load check passed
2G Antennas	3× 900 MHz antennas, 16 dBi gain	Degraded – to be replaced
3G Antennas	3× 2100 MHz antennas, 18 dBi gain	Good – retained
BTS (2G)	Legacy integrated BTS	End-of-life – to be replaced
NodeB (3G)	Legacy NodeB	To be migrated to BBU platform
Backhaul	Microwave link 15 GHz, 10 Mbps capacity	Bottleneck – to be replaced with fiber
Power System	DC rectifier 48V / 100A	Capacity upgrade required
Shelter	20-foot container, dual split	Good – retained

Element	Description / Model	Condition / Action Required
	AC	

3.3.2.2 Pre-Modernization KPI Baseline

Operational KPIs were extracted from the OSS over a four-week observation period to establish a performance baseline prior to modernization.

The results revealed multiple performance deficiencies, including low SDCCH accessibility in the 2G network, elevated call drop rates, reduced 3G accessibility, and insufficient HSDPA throughput. Site availability also failed to meet the operator target of 99.9%.

Root-cause analysis confirmed that the limited 10 Mbps microwave backhaul was the primary factor affecting 3G throughput performance, while aging 2G hardware significantly contributed to accessibility degradation and abnormal call release rates [1], [2].

3.3.3 Target Architecture and Bill of Materials

3.3.3.1 Selected Equipment [4].

Table 9. Selected Equipment

Equipment	Model / Reference	Function
Multi-RAT BBU	Ericsson Baseband 6630	2G / 3G / 4G baseband processing
Dual-Band RRH 900/1800 MHz	Ericsson Radio 4419	2G/4G combined radio unit
RRH 2100 MHz	Ericsson Radio 2217	3G radio unit
Dual-Band Antenna	Kathrein 742 265	900/1800 MHz, 65°, 18 dBi gain
Fronthaul Switch	Ericsson MINI-LINK 6352	1 Gbps Ethernet transport
DC Rectifier	Eltek Flatpack2 48V/200A	Equipment power supply

3.3.3.2 LTE Radio Planning Parameters [5].

LTE radio planning was performed according to standard RF engineering practices. All three LTE sectors operated on LTE Band 3 using EARFCN 1300, corresponding to 1745 MHz in the FDD spectrum allocation.

PCI allocation was carefully planned to avoid PCI confusion and collision with neighboring sites, ensuring sufficient separation between cells sharing identical PCI values. Electrical tilt values between 4° and 5° were selected to optimize coverage distribution and minimize inter-cell interference [5].

3.3.4 Installation and Commissioning

3.3.4.1 Tower Works

Tower activities were executed by a certified rigging team during a controlled six-hour maintenance window. The intervention included removal of legacy antennas, installation of new dual-band antenna systems, deployment of RRH units, routing of eCPRI fiber and DC cables, and grounding of metallic structures.

VSWR measurements were performed immediately after antenna connection to validate RF feeder integrity and ensure compliance with installation standards [3], [4].

3.3.4.2 Shelter Works

Inside the shelter, the Ericsson Baseband 6630 was installed and integrated into the equipment rack. Existing 2G and 3G software licenses were migrated to the new platform, while the MINI-LINK 6352 Ethernet switch was connected to the newly deployed Gigabit fiber backhaul.

The rectifier system upgrade to 200A capacity ensured sufficient power availability for all active equipment. [4], [5].

3.3.4.3 Commissioning Execution

The commissioning process was successfully completed within four hours following power-on. GPS synchronization was achieved within 11 minutes, and all LTE sectors were activated without critical alarms.

The eNodeB successfully established S1 connectivity with the MME, achieving an RTT of 2.3 ms over the fiber transport network, confirming stable and low-latency transmission performance [6].

3.3.5 Acceptance Test Results [7].

Table 10. Acceptance Test Results

Test	Method / Tool	Result	Pass / Fail
VSWR – all antenna ports	Vector network analyzer (Anritsu S331L)	< 1.35 on all 6 ports	PASS
PIM test – all ports	PIM analyzer (Anritsu MW82119B) @ 2×43 dBm	-109 dBm (threshold: -107 dBm)	PASS
S1 latency (MME RTT)	ICMP ping from eNodeB to MME	2.3 ms (threshold: < 10 ms)	PASS
GPS sync time	OSS event log	11 min (threshold: < 20 min)	PASS
LTE cell activation (alarms)	OSS alarm dashboard	Zero critical alarms	PASS
DL throughput (close range)	iPerf3 at 20 m from site	72 Mbps (20 MHz, 2×2 MIMO)	PASS
UL throughput (close range)	iPerf3 at 20 m from site	24 Mbps	PASS
Drive test: RSRP > -85 dBm	TEMS Investigation scanner	96% of target zone	PASS

3.3.6 Post-Modernization KPI Results [8].

Table 11. Modernization KPI Results

KPI	Before Modernization	After Modernization	Change
SDCCH Accessibility (2G)	97.2%	99.5%	+2.3 percentage points
TCH Call Drop Rate (2G)	1.8%	0.28%	-1.52 percentage points
RRC Accessibility (3G)	97.8%	99.6%	+1.8 percentage points
HSDPA DL Throughput (3G)	2.1 Mbps	8.4 Mbps	+6.3 Mbps (4× increase)
Site Availability	99.1%	99.87%	+0.77 percentage points
LTE DL Throughput (avg UE)	N/A	26.3 Mbps	New service introduced
LTE Coverage (target zone)	0%	96%	New service introduced

3.3.7 Analysis and Lessons Learned

The analysis of post-modernization results confirms that the primary performance limitation in the pre-upgrade network was the constrained 10 Mbps microwave backhaul, rather than radio access layer deficiencies. The migration to a fiber-based Gigabit Ethernet transport significantly improved throughput, particularly in 3G HSDPA performance, which is consistent with the strong dependency between transport capacity and user-plane performance in mobile networks [1], [2].

The observed improvements in accessibility and call drop rate in the 2G layer are also consistent with known effects of replacing aging BTS hardware and optimizing radio parameters in multi-RAT environments [2], [5].

Furthermore, the results highlight the critical importance of transport dimensioning before radio modernization, as under-dimensioned backhaul links can severely limit the benefits of radio access upgrades. Finally, the excellent PIM test result confirms the importance of proper RF installation practices in preventing self-interference and preserving uplink sensitivity in LTE systems [3].

3.3.8 Conclusion

This case study demonstrated the effectiveness of a structured LTE modernization methodology combining infrastructure upgrade, transport migration, and RF optimization. The project achieved significant improvements in accessibility, throughput, and overall service availability while successfully introducing LTE coverage within the target area.

The results confirm that successful mobile network modernization depends not only on radio equipment upgrades but also on proper transmission planning, rigorous commissioning procedures, and comprehensive post-integration optimization. These findings provide practical insight into the operational challenges and engineering considerations associated with modern LTE deployment projects.

PRACTICAL CHAPTER - Site 28139

Introduction

This practical chapter presents the complete end-to-end deployment process of a new 2G/3G/4G mobile base station, designated Site 28139 (Cité 800 Logements AADL, M'Sila), operated by Algérie Télécom Mobile (ATM / Mobilis). The deployment was initiated to address coverage gaps and traffic congestion in the urban residential district of M'Sila, specifically serving the AADL housing estates comprising 800, 300 and 600 residential units.

The project followed the standard ATM site deployment lifecycle, which is structured into six major phases: (1) Site Planning (SA1), (2) Site Acquisition (SA2 / PV), (3) Technical Survey (SA3), (4) Civil Works and Construction, (5) Equipment Implementation, and (6) Integration, Commissioning, and Acceptance. Each phase is documented hereafter based exclusively on the official project files produced during the deployment.

Sec 1 — Site Planning (SA1)

1.1 Overview

The SA1 (Site Application Form — Step 1) constitutes the first formal document in the ATM site deployment process. It captures the RF engineering requirements, the geographic search area, the preliminary candidate identification, and the initial radio configuration. This form is prepared by the RF engineer responsible for the cluster under study and validated by the RF manager.

1.2 Site Identification and Radio Objectives

The SA1 form for Site 28139 defines the following deployment objective:

"Site for densification and radio coverage improvement of: M'Sila, Cité 800 Logements AADL + 300/600 logements LPA. Radio 2G/3G/4G."

This translates into a deployment targeting multi-technology coverage (GSM900, DCS1800, UMTS2100, LTE1800/2100/2300) over a dense urban residential environment, classified as priority zone per the ATM PA 2024 nominal point file for M'Sila.

1.3 Site Technical Parameters

Table 12. Technical Parameters

Site Name	Cité 800 Logements AADL
Site Code	28139
City	M'Sila
Wilaya	M'Sila
Site Nature	Urban
GPS Longitude	4.515357°
GPS Latitude	35.741825°
Frequency Bands	900 / 1800 / 2100 / 2300 MHz

Technology	2G / 3G / 4G (GSM / UMTS / LTE)
Number of Sectors	3 (Sector 1, Sector 2, Sector 3)
Search Radius	50 m
Priority	P0 — Highest Priority

1.4 Radio Configuration per Sector

Table 13. Radio Configuration per Sector

Parameter	Sector 1	Sector 2
Azimuth (°)	80°	160°
E&M Tilt (°)	2°	2°
Antenna Height (m)	37 m	37 m

Note: Sector 3 (Azimuth 240°, Tilt 2°, Height 37 m) was added in the SA3 revised version following the updated equipment configuration.

1.5 Candidate Site Identification

The SA1 form identifies only one viable candidate (Candidate A), as candidates B and C were marked as unavailable (PAS DISPONIBLE) during the field search phase.

Table 14. Candidate Site Identification

Candidate	A (Selected)
GPS Longitude	4.515357°
GPS Latitude	35.741825°
Description	Bare land adjacent to a primary school, Cité 800 Logements AADL, M'Sila — State-owned property (Etatique)
Candidates B & C	Not Available

Sec 2 — Site Acquisition (SA2 / PV)

2.1 Overview

The site acquisition phase (SA2) formalizes the legal and administrative selection of the land parcel on which the base station will be constructed. In the ATM deployment process, this phase is documented primarily through a *procès-verbal* (PV) — an official field selection report produced by a technical committee assembled at the *daïra* level.

For Site 28139, the PV was issued by the *Daïra de M'Sila* (*Wilaya de M'Sila*) and documents the field inspection conducted by the inter-institutional technical committee. The PV simultaneously covers five sites in the M'Sila area: 28106, 28110, 28139, 28140 and 28141.

2.2 Legal and Administrative Framework

The technical committee assembled for the site selection included representatives from the following institutions:

- Municipality of M'Sila (*Commune de M'Sila*)
- Sub-divisional department of urban planning, architecture and construction
- Land survey and cadastral registry department
- Civil protection (fire and safety) directorate
- Algerian electricity and gas distribution company (*Sonelgaz*)
- Post and telecommunications directorate (PTT / Algeria Post)
- Mobilis / ATM representative

The meeting was chaired by the *Daïra* head, with delegation authority formally confirmed. The PV bears the official stamps and signatures of all parties.

2.3 Selected Land Parcel — Site 28139

Following the field inspection, the committee confirmed the selection of the following plot for Site 28139:

Table 15. Selected Land Parcel

Site Reference in PV	Emplacement (01) — Hai 800 Msken 'Adl' (28139), Commune de M'Sila
Plot Area	150 m ²
Northern Boundary	Road + social facilities (sknat ijtima'i)
Southern Boundary	Vacant land
Eastern Boundary	School 'Salem Ahmed'
Western Boundary	Vacant land
Land Ownership	State-owned (Etatique / Domanial)

The committee confirmed that the plot meets the technical and regulatory requirements for BTS tower construction, subject to the preparation of a construction plan approved by the Urban Planning Directorate (DUC) and compliance with applicable building codes and setback regulations.

Sec 3 — Technical Site Survey (SA3)

3.1 Purpose and Scope

The SA3 is the detailed technical site survey report, completed after the acquisition is confirmed. It covers all dimensions of the site: general topology, access conditions, radio configuration, civil works requirements, energy supply, earthing and lightning protection, transmission (LOS — Line of Sight), and regulatory constraints. The SA3 for Site 28139 was revised on 08/04/2025 to reflect the updated BTS 5900 equipment configuration.

3.2 General Site Information

Table 16. General Site Information

Site Name	Cité 800 Logements AADL
Site Code	28 139
Candidate	A
City / Wilaya	M'Sila / M'Sila
Address	Cité 800 Logements AADL — M'Sila
GPS Longitude	04.5152869°
GPS Latitude	35.741868°
Altitude (ASL)	498 m
Coordinate Source	Map (GPS measurement)
Zone	Urban
Environment	Residential
Site Type	Greenfield (Bare Land)
Existing Antennas on Site	No

3.3 Topology and Site Dimensions

Table 17. Topology and Site Dimensions

Site Type	Bare land (Terrain nu)
-----------	------------------------

Tower Type	40 m Galvanized Lattice Tower (Pylône Tripode)
Site Dimensions	(10 × 15) m ²
Equipment Typology	E1.40 (Outdoor BTS)
BTS Location	Outdoor
New Fence Required	Yes — Concrete perimeter wall
Concrete Slabs	Existing (to be used / extended)

Civil works scope noted in SA3:

- Supply and installation of 40 m galvanized lattice tower with all accessories
- Supply and installation of outdoor BTS (RBS 5900) with accessories
- Full earthing network installation
- Concrete enclosure / fencing with electrical cabinet
- Tower foundation (massif béton) + BTS slab (dalle BTS) + earthing pit (regard)
- Note: Site relocation may be required if a sewage network is confirmed underground

3.4 Radio Configuration (SA3 Revised)

The revised SA3 confirms the BTS model as BTS 5900 with the following multi-technology configuration:

BTS Model	BTS 5900 (Huawei)
Technology Configuration	GSM900 (2-2-2) DCS1800 (2-2-2) U2100 (1-1-1) U900 (1-1-1) LTE1800 (15 MHz) LTE2100 (15 MHz) LTE2300 TDD (MM)
Antenna Type (all sectors)	A12264PD00V06

Table 18. Radio Configuration

Parameter	Sector 1	Sector 2	Sector 3
Azimuth (°)	50°	120°	240°
Antenna Height (m)	37 m	37 m	37 m
Electrical Tilt (°)	2°	2°	2°

Mechanical Tilt (°)	0°	0°	0°
Antenna Type	A12264PD00V06	A12264PD00V06	A12264PD00V06
Feeder Type	Fiber Optic	Fiber Optic	Fiber Optic
Number of Antennas	1	1	1

3.5 Energy Supply

Table 19. Energy Supply

Power Supply Available	Yes
New Connection Required	Yes
Supply Voltage	380 V (Three-phase, 25 KVA, 50 Hz)
Connection Cable	4 × 16 mm ² — from utility pole to TGBT
Cable Routing	Aerial to electrical cabinet, then underground to TGBT
Circuit Breaker	63 A / 300 mA differential
TGBT	AC/DC cabinet for all BTS equipment
Power Source Location	Utility pole 3 m from site boundary
Connection Type	Simple branch (Branchement simple)

3.6 Earthing and Lightning Protection

Table 20. Earthing and Lightning Protection

Earthing Required	Yes — Full new earthing system
Earthing Cable Length (Tower)	40 m — from tower to earthing pit
Earthing Cable Route	From tower base to earthing pit (regard de terre)
AC Earthing Bus	To be installed
Lightning Rod (Parafoudre)	Required — New installation on tower top
Radioactive Lightning Rod	No
PGND Cable Standard	16 mm ² yellow/green per ATM installation standard

3.7 Transmission and Line-of-Sight (LOS)

The LOS study was conducted between Site 28139 (site A) and Hub Site 283007 (site B — Cité AADL M'Sila).

Table 21. Transmission and Line-of-Sight (LOS)

LOS Link	28139 ↔ 283007
Link Distance	0.83 km
Site A Azimuth to Site B	113°
Site B Azimuth to Site A	293°
Site A Antenna Height	40 m tower / 30 m MW antenna height
Site B Antenna Height	40 m tower / 30 m MW antenna height
LOS Result	POSITIVE — Clear Line of Sight confirmed
Access at Site A	Available
Power at Site A	Available
Access at Site B	Available
Power at Site B	Available

3.8 Regulatory and Environmental Constraints

The SA3 survey verified the following constraint categories:

- Historical monuments: None
- Flood zone: None
- Airport zone: None
- Military zone: None
- Seismic zone: Not classified
- Building permit (Permis de construire): To be obtained
- Other operators on site: None

3.9 SA3 Validation Status

Table 22. Validation Status

Radio Validation	Validated — SA3 revised 08/04/2025 per new equipment specs
Civil Works Validation	Validated — 40 m tower + Outdoor BTS + B.S. energy system
CW Note	Confirmation of underground sewage presence required before final positioning
Transmission Validation	Validated
Acquisition Validation	Pending (awaiting signature)

Sec 4 — Civil Works and Construction

4.1 Overview

The construction phase translates the APD (Avant-Projet Détaillé) technical drawings into physical civil infrastructure. For Site 28139, this involved the construction of the tower foundation, BTS slab, earthing system, electrical cabinet enclosure, access road preparation, and perimeter fencing. The phase is formally tracked through a series of official handover documents.

4.2 Construction Sub-phases

4.2.1 Site Opening (Ouverture de Chantier)

The site opening marks the formal start of civil works. It requires the issuance of the construction permit, confirmation of site access, mobilization of the construction contractor, and validation that all pre-construction conditions defined in the SA3 and APD have been met. For Site 28139, pre-conditions included confirmation of the sewage network location and final GPS staking.

4.2.2 Provisional Civil Works Reception (Réception Provisoire Génie Civil)

Upon completion of civil construction activities, a provisional reception is conducted by the ATM site engineer and the construction contractor. This inspection verifies conformity of the following elements against the APD technical drawings:

- Tower foundation (massif de fondation): concrete dimensions, steel reinforcement, anchor bolt alignment
- BTS equipment slab (dalle BTS): surface dimensions, levelness, load capacity
- Earthing pit (regard de terre): depth, dimensions, access cover
- Electrical cabinet foundation and TGBT housing
- Perimeter fencing: height, gate, concrete wall quality
- Cable conduit routing: underground PVC conduits for power and earthing cables

A provisional acceptance report is signed by both parties. Any non-conformities are documented and must be corrected before final acceptance.

4.2.3 Final Civil Works Reception (Réception Définitive Génie Civil)

Following correction of all provisional reception snags, a final civil works inspection is carried out. The final acceptance certificate (Procès-verbal de réception définitive) is signed, releasing the contractor from further civil obligations and authorizing the electromechanical and equipment installation teams to commence their activities.

4.2.4 Site Election / Staking (Élection de Site)

Prior to and during construction, the GPS coordinates of the tower base and equipment slab are formally confirmed through physical staking. The elected coordinates are cross-checked against the SA1/SA3 theoretical coordinates:

Table 23. Site Election / Staking

Theoretical Coordinates (SA1)	Lat: 35.741825° — Long: 4.515357°
Surveyed Coordinates (SA3)	Lat: 35.741868° — Long: 4.5152869°
Altitude	498 m ASL
Offset	< 5 m — within acceptable tolerance
Tower Height	40 m (Galvanized lattice tripod tower)
BTS Slab Dimensions	480 × 600 × 700 cm (per APD)

4.3 APD Technical Specifications

The APD (Avant-Projet Détaillé) document for Site 28139 — reference 28 139 A — defines the following technical specifications:

4.3.1 Tower Structure

- Tower type: 40 m galvanized hot-dip lattice tripod tower

- Tower equipped with: lightning rod (parafoudre), antenna boom arms, MW dish arms, lifeline (ligne de vie), climbing ladder
- Foundation type: reinforced concrete footing (massif en BA) on-grade

4.3.2 RBS Equipment

- RBS type: Outdoor RBS (BTS 5900 — Huawei)
- Mounting: HEA steel structure frame embedded on sealed anchor bolts on a reinforced concrete platform
- RBS dimensions: 480 × 600 × 700 cm

4.3.3 Power System

- Supply: Three-phase 380 V — 25 KVA — 50 Hz
- Meter and disconnect switch at main facade
- Cable: 4 × 16 mm² from meter to TGBT differential circuit breaker (63 A / 300 mA)
- TGBT: AC/DC power cabinet installed in outdoor BTS enclosure

4.3.4 APD Drawing List

The APD package includes the following civil and electrical drawings:

- Site location plan
- Site implementation plan + concrete slab detail
- General layout plan (Plan de masse)
- Elevation plan (Plan d'élévation)
- Earthing and lightning layout + elevation plan
- Safety plan
- Cable ladder plan
- Antenna boom arm plan
- MW antenna arm plan
- Earthing synoptic diagram
- Earthing pit schematic
- Detailed antenna earthing principle plan

- Radio synoptic plan
- Foundation formwork and reinforcement plan + bill of quantities
- BTS slab formwork and reinforcement plan
- Perimeter wall and gate elevation plan

Sec 5 — Equipment Implementation

5.1 Overview

Equipment implementation covers the electromechanical and telecom installation activities that follow final civil works acceptance. This phase is conducted by specialized ATM installation teams in strict conformance with the ATM Installation Quality Standard (V0, 2025) and the Huawei equipment specifications.

5.2 Site Transfer to Equipment Teams

Upon receipt of the final civil works acceptance certificate, the site is formally transferred to the equipment installation team. A site transfer document is issued confirming that the civil infrastructure (foundation, slab, earthing pit, conduits, fencing) has been completed and accepted, and that the site is ready for electromechanical and RF equipment installation.

5.3 Equipment Installation

5.3.1 Tower and Structural Hardware

The 40 m galvanized lattice tripod tower is assembled and erected on its reinforced concrete foundation. The following ATM quality standard requirements apply:

- All bolts and screws must carry 8.8 certification grade
- Bracket verticality must be set to zero (0°) using a calibrated level tool
- All brackets must be connected to the earthing ground bar (PGND)
- After nut tightening, exposed bolt thread must be at least 2 cm beyond the nut face
- PGND cable size: 25 mm² minimum for civil works brackets

5.3.2 Antenna Installation (AAU / A12264PD00V06)

The antenna type deployed on all three sectors is the A12264PD00V06 (Huawei). Installation follows these standards:

- For angular towers: V-bracket fixed from tower front, with rear plate on tower back face
- For tubular towers: V-bracket fixed on both front and rear faces

- Azimuth and tilt values must match the SA3 / EPT configuration exactly
- For MIMO AAU installations: minimum separation between old and new antenna is 35 cm
- New antennas installed above the bracket mounting point
- Azimuth alignment tool (compass) and tilt meter used for verification

5.3.3 AAU Grounding (PGND)

- AAU PGND cable: 16 mm² green/yellow — one end M6 OT terminal to AAU ground port, other end M8 OT terminal to ground bar
- Torque: 4.8 N·m applied to AAU PGND ground bolt
- All cables routed per ATM cabling standard and labeled using a labeling machine (handwritten labels not authorized)
- RRU and AAU PGND cables connected to a single earthing point before the cable bend (courbe)

5.3.4 BTS 5900 Outdoor Unit

The BTS 5900 outdoor unit is mounted on the HEA steel structure frame. Key installation specifications:

- AAU5636 deployed as the active antenna unit across all three sectors
- CPRI optical ports (CPRI0 / CPRI1): DLC connector, 10.3125 or 25.78125 Gbit/s — optical module inserted for fiber connection
- PWR port: Outdoor quick-lock power connector, –48 V DC
- AUX port: DB15 male — for AISU (antenna information sensor unit) carrying AISG signals
- Fiber redundancy: Roxtec cable entry sealing used at cable tray entry points

5.3.5 Power and Cabling

- Power cable: 4 × 16 mm² from utility meter to TGBT differential breaker
- Hydraulic crimping tool used for all cable lug terminations (25 mm², 35 mm² sections)

- Cable sections: 16 mm², 25 mm², 35 mm² — appropriate hydraulic press die used per section
- All cables labeled at both ends using labeling machine

Sec 6 — Integration, Commissioning and Acceptance

6.1 Overview

The final phase of the deployment cycle encompasses network integration, RF commissioning, KPI monitoring, and formal site acceptance. This phase confirms that the newly deployed site is fully operational, meets the defined radio performance targets, and is ready for handover to the network operations team.

6.2 Site Transfer to Integration Team

Following completion of equipment installation and internal quality checks, the site is formally transferred to the integration and commissioning team. The transfer includes a physical walkthrough, verification of all cable connections, labeling, earthing continuity, power supply stability, and preliminary equipment boot-up.

6.3 Network Integration and Configuration

The integration process for Site 28139 involves the following steps:

- Remote configuration of the BTS 5900 via the OSS/NMS platform (OMC-R)
- Cell parameter download: cell identity, frequency plan (900/1800/2100/2300 MHz), neighbor list, handover parameters
- RF parameter configuration: azimuth, tilt, transmission power, MIMO configuration
- Transmission link activation: MW link to Hub Site 283007 on azimuth 113° (distance 0.83 km, LOS confirmed positive)
- Fiber connection verification on all CPRI ports (CPRI0 / CPRI1 of AAU5636)
- Initial cell unlock and RF radiation activation for each sector

6.4 KPI Monitoring and Analysis

Following integration, a KPI monitoring period is conducted to validate the site's contribution to the network. The KPI data extracted from the existing network (GL 28139 cluster) over the period 17–23 May demonstrates the traffic conditions that justified the new site deployment and provides a baseline for post-integration comparison.

Table 24. KPI Monitoring and Analysis

KPI	Observed Value	Assessment
DL Traffic Volume (Gbyte)	Peak ~90 Gbyte/day	High Traffic Load
UL Traffic Volume (Gbyte)	Peak ~10 Gbyte/day	Normal
User DL PDCP Avg Throughput (Mbps)	20–45 Mbps	Acceptable
DL PRB Usage Rate (%)	Peak ~80%	High — Justifies New Site
Average User Count (L.Traffic.User.Avg)	300–530 users	High Density
4G Call Drop Rate — DATA (%)	< 1% (isolated spikes ~3.5%)	Acceptable
Random Access Success Rate (%)	60–88%	Needs Improvement
Intra-freq Handover Out Success Rate (%)	98.5–99.8%	Good

6.4.1 KPI Analysis

The KPI dataset confirms the following observations that motivate the deployment of Site 28139:

- Downlink traffic volume peaks at approximately 90 Gbyte/day, indicating very high user data demand in the coverage zone.
- DL PRB (Physical Resource Block) usage rate reaches up to 80%, which is at saturation threshold for a single carrier LTE deployment and directly justifies the need for additional capacity through the new site.
- The average concurrent user count ranges from 300 to 530 users, confirming the high population density of the AADL residential complex.
- The DL user throughput of 20–45 Mbps is acceptable but is expected to degrade significantly under further traffic growth without the capacity relief provided by the new site.
- The Random Access Success Rate (RACH SR) of 60–88% is below target (<95%), indicating access congestion — a clear indicator of the need for cell splitting through densification.

- The 4G Data Call Drop Rate remains generally below 1%, with isolated transient spikes up to ~3.5%, remaining within acceptable bounds.
- Intra-frequency handover out success rate is consistently above 98.5%, confirming good network mobility management in the cluster.

6.5 Acceptance — HTP (High-Level Test Plan)

Site acceptance (ATP — Acceptance Test Procedure) is the formal process by which ATM confirms that the deployed site meets all contractual, technical, and quality requirements. The HTP covers the following test categories:

6.5.1 Civil Works Acceptance

- Verification that all civil elements (tower, slab, fencing, earthing pit) conform to APD drawings
- Photographic documentation of all completed civil elements
- Confirmation of sewage network clearance (as flagged in SA3 / CW validation)

6.5.2 Equipment Installation Quality Acceptance

- Verification of antenna azimuth and tilt against SA3 values (tolerance: $\pm 5^\circ$ azimuth, $\pm 0.5^\circ$ tilt)
- Verification of antenna height against SA3 values (tolerance: ± 0.5 m)
- Visual inspection of all cable routing, labeling, and sealing quality
- Earthing continuity measurement (resistance $< 5 \Omega$ as per ATM standard)
- Lightning protection system completeness check

6.5.3 RF Performance Acceptance

- Drive test campaign around the site coverage area to verify signal level and quality targets
- Verification of inter-sector coverage boundaries (azimuth accuracy)
- Handover test between Site 28139 and neighboring sites (including Hub 283007)
- Call setup and data session success rate verification

6.5.4 Transmission Acceptance

- Microwave link availability measurement over a 24-hour window
- BER (Bit Error Rate) and link capacity verification on the 28139 ↔ 283007 MW link
- Fiber connection integrity test on all CPRI ports

6.5.5 Documentation Acceptance

- Complete as-built file (dossier as-built) submitted: SA1, SA2/PV, SA3 revised, APD, LOS report, installation photos
- KPI report submitted confirming site performance meets ATM network targets
- All acceptance test results signed by ATM radio, civil, transmission, and acquisition responsible engineers

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