TELECOM INFRA PROJECT

# Playbook – OpenRAN Trials w/ Vodafone Turkey

**OpenRAN Project Group**

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# Contents

# Glossary

| Term | Definition |
|---|---|
| 3G | third-generation mobile networks |
| 4G | fourth-generation mobile networks |
| ADSL | asymmetric digital subscriber line |
| APN | access point name |
| CE | customer edge |
| CWS | converged wireless system |
| DNS | domain name server |
| E2E | End-to-End |
| EPC | evolved packet core |
| GPRS | general packet radio service |
| GTP | GPRS tunneling protocol |
| GTP-C | GPRS tunneling protocol control plane |
| GTP-U | GPRS tunneling protocol user plane |
| HLD | high-level design |
| HLR | home location register |
| HNG | HetNet Gateway |
| IOT | interoperability testing |
| IP | internet protocol |
| IPsec | internet protocol security |
| LLD | low-level design |
| LTE | long-term evolution |
| massive MIMO | extension of MIMO (multiple-input, multiple-output), which essentially groups together antennas at the transmitter and receiver to provide both better throughput and spectrum efficiency |
| MME | mobility management entity |
| NMS | network management system |
| NOC | network operations center |
| OAM | operations & maintenance |
| OPCO | operations company |
| PE | provider edge |
| PGW | packet gateway |
| PoC | proof of concept |
| SGSN | serving GPRS support node |
| SGW | serving gateway |
| SON | self-organizing network |

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| | |
|---|---|
| VLAN | virtual local area network |
| VRF | virtual routing & forwarding [table] local to router |

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# 1 Trial Overview

Vodafone has always been at the forefront of embracing technology innovations. It has also been open to new ways of building telecommunications networks—specifically in the RAN space, where legacy and proprietary vendor lock-ins have been dominant to date. Being heavily dependent upon a single vendor, the pace of innovation is tightly linked with that of the latter's hardware solution.

Vodafone joined the Telecom Infra Project (TIP) in 2017. At that time virtual RAN was discussed within the industry but considered impractical to implement and deploy for commercial grade traffic.

Today OpenRAN is an initiative with which Vodafone sees new ways to define and build 2G, 3G, and 4G RAN solutions. It's based on general-purpose, vendor-neutral hardware and software-defined technology that opens the door to more and faster innovations.

OpenRAN architectures eliminate proprietary lock-ins. Over time this promotes a faster pace for software innovations; these are currently limited or time consuming due to tight integration and coupling with existing RAN.

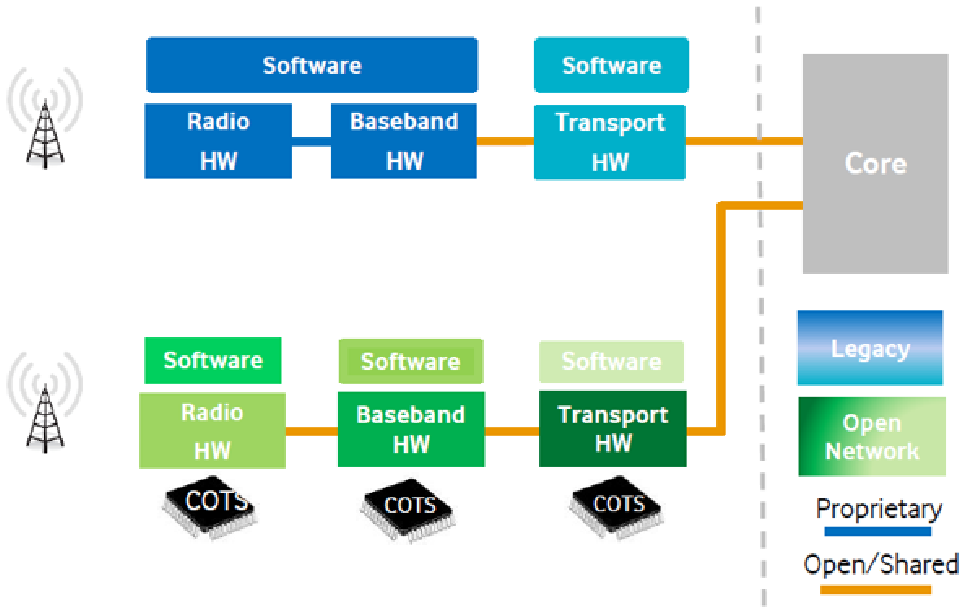


*Figure 1 –Architecture Overview*

To realize this, these are the key OpenRAN work areas and benefits:

- Open interfaces
- Leverage COTS GPP-based architectures
- Reduce dependencies on FPGA or ASICs
- Virtualize the platform to bring flexibility and efficiencies
- Enable easy market entry for new players

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A request for information (RFI) was issued to understand how the overall ecosystem was developing and to determine the status of vendors. Opportunities for field trials were seen as important for overall ecosystem development.

## 1.1 TIP OpenRAN Project & Deliverables

Vodafone launched a joint RFI with TIP in June, 2018, to better understand:

- which vendors were driving innovation in the OpenRAN space
- their current state of products and roadmaps
- how aligned they were with respect to telco-grade deployments

Parallel Wireless was one of the most compliant with respect to all technologies and open solutions, as it aligned with the stated RFI requirements. This resulted in its being selected to undertake a field trial to prove the platform and solution capabilities. Turkey was selected as the trial location.

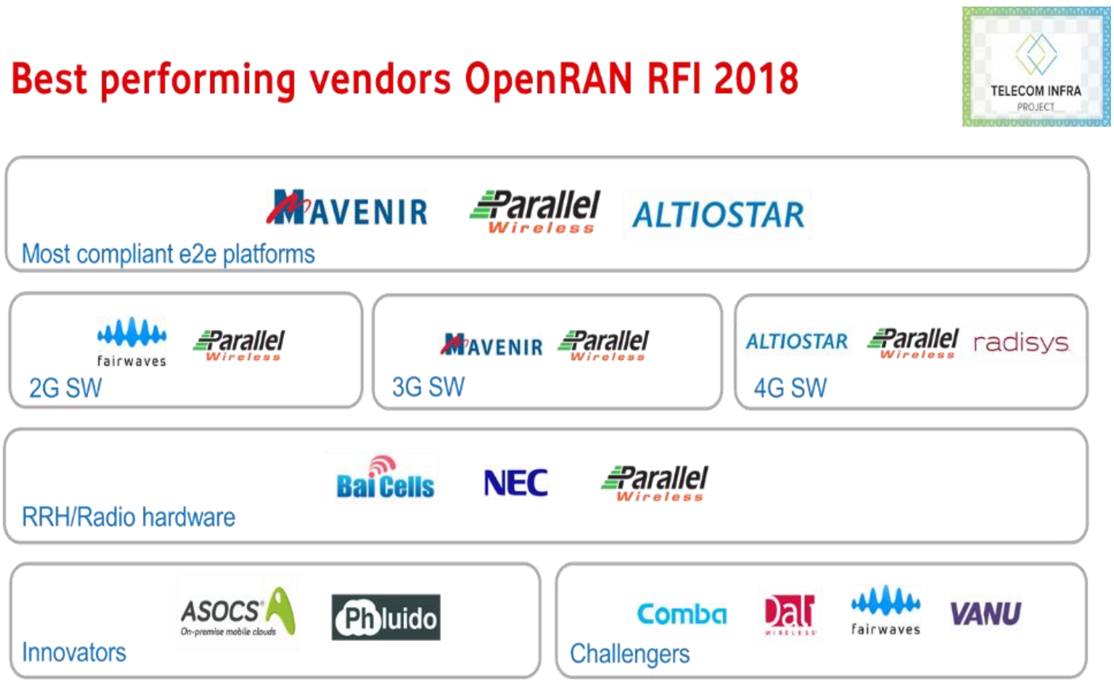


*Figure 2 – Best performing OpenRAN RFI vendors in 2018*

Based on compliance shared in the 2018 RFI, products and solutions for the trials were based on the (GPP-based) ALL G single platform architecture proposed by Parallel Wireless.

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# 2 Case Study

## 2.1 Project Structure and Responsibilities

### Project Organization

A *clear all* party project organization forms the basis of any successful project. Parallel Wireless had to execute its OpenRAN trial with Vodafone's network support organization in Turkey. Parallel Wireless engaged local partner to undertake equipment installation. Its local knowledge helped solve many issues with site-related services.

The organization was very well defined at project onset (Figure 3):

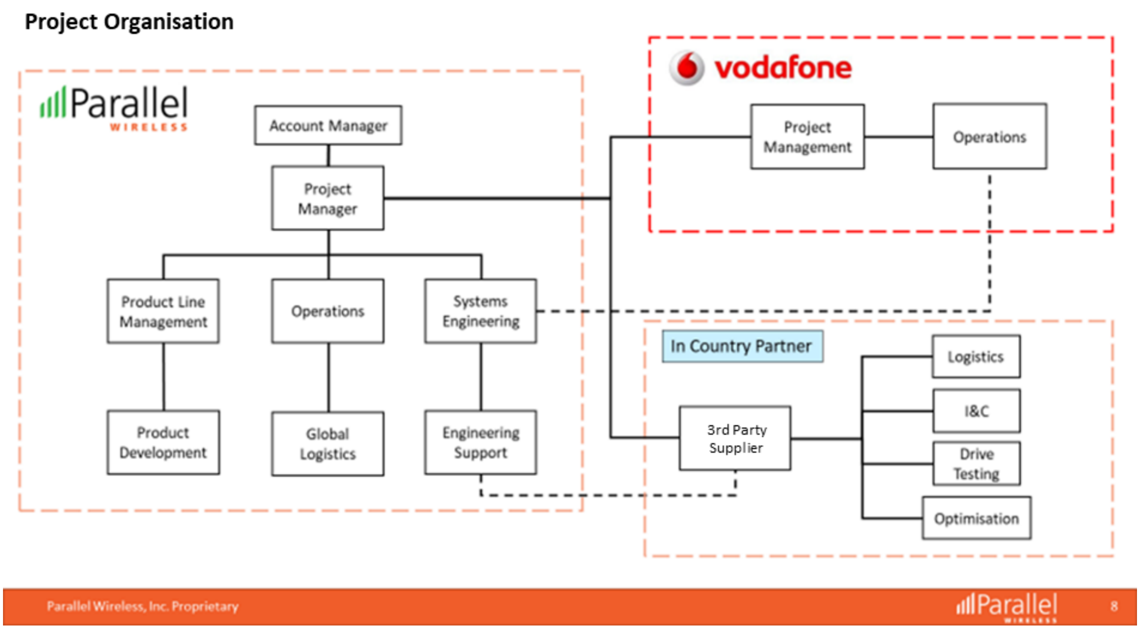


*Figure 3 – Project organization for Vodafone Turkey field trial*

### Internal Parallel Wireless Organization

As the main responsibility of carrying out this trial was with Parallel Wireless, an effective internal organizational structure outlining roles and responsibilities was a prerequisite. Being well defined, the team and structure were shared with Vodafone to execute this Turkish OpenRAN initiative per Figure 4:

# Project Structure

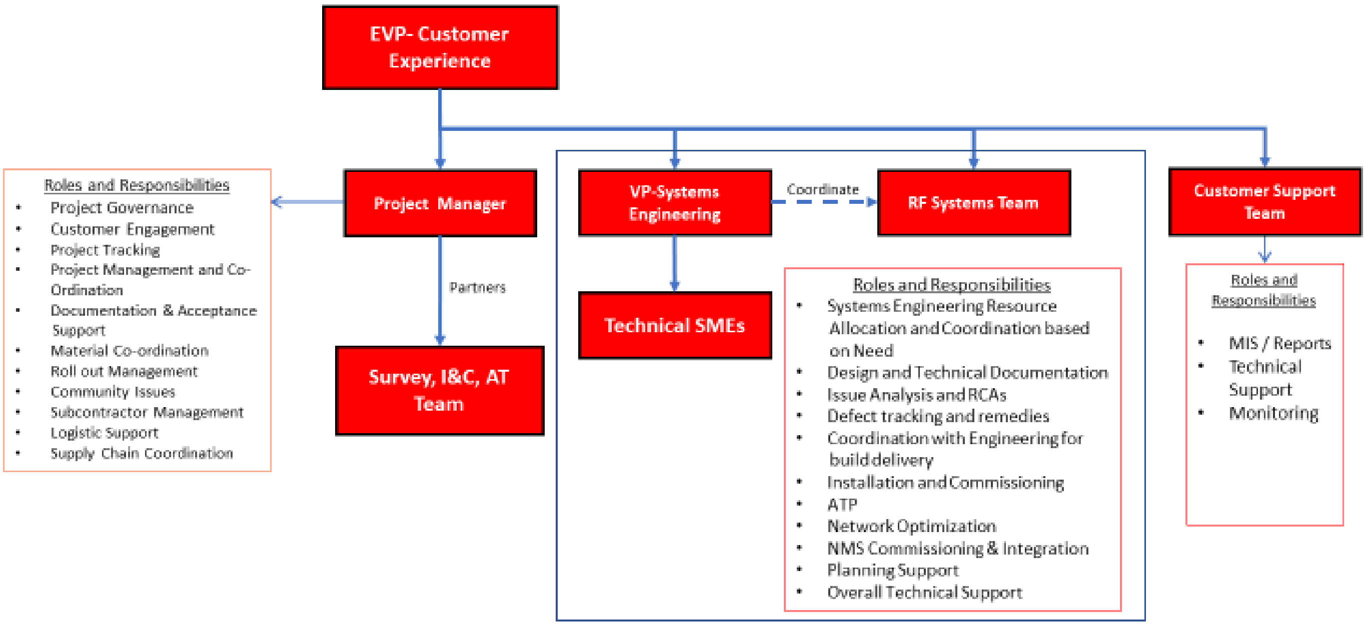


*Figure 4 – Vodafone internal team structure*

## Responsibilities

All agreed upon the following responsibility matrix with these defined deliverables:

- Network selection and definition
- RF planning
- EMS
- Project management
- Services
- IP network

*Table 1 – Deliverable matrix*

| | | **Responsible Party** | |
|---|---|---|---|
| **S No** | **ACTIVITIES** | **Parallel Wireless** | **Vodafone** |
| | **Sites (2G – 3G – 4G)** | | |
| 1 | Site identification | | R |
| 2 | Power and infrastructure provisioning | | R |
| 3 | Information gathering (input requirements of design/node integration) | R | S |
| 4 | Site engineering activities (site survey) | R | S |
| 5 | Install internal/external cable trays, for ID sites if required | | R |
| 6 | Provide main AC/DC power supply, including circuit breaker according to site design | | R |

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| | | | |
|---|---|---|---|
| 7 | Provide lightning protection and earthing systems panels | | R |
| 8 | RF antenna delivery at site | S | R |
| 9 | Equipment and installation material delivery to site | R | |
| 10 | Site installation | R | |
| 11 | RF antenna installation | R | S |
| 12 | Provide access to building and work sites for Parallel Wireless staff | | R |
| 14 | Transport readiness and bandwidth (BW) provisioning up to EPC and EMS | | R |
| 15 | Connect power, transmission on Parallel Wireless-supplied node | R | S |
| 16 | Providing test equipment (e.g., dongles/mobile/USIMs) and testing support | R | S |
| 17 | Provide access transmission systems (bandwidth provisioning, IP connectivity, outers, and switches configuration) | S | R |
| 18 | Site commissioning | R | A |
| 19 | Node configuration (according to design) | R | |
| 20 | Site integratation with core nodes | R | S |
| 21 | Test call and basic test | R | A |
| 22 | Test network elements per node acceptance test document (per mutually agreed format) | R | A |
| 23 | Acceptance test preparation | R | |
| | **RF Planning** | | |
| 1 | Cluster identification | | R |
| 2 | Propagation model calibration | R | I / S |
| 3 | Coverage requirement analysis – link budget, coverage planning condition | R | I / S |
| 4 | Coverage planning | R | I / A |
| 5 | RF plan approval | I | R |
| 6 | Single cell function test (SCFT) | R | S/A |
| 7 | Drive test for eNB site installed | R | – |
| 8 | Report submission of drive test | R | – |
| 9 | Retuning of site parameters, if required | R | – |
| 10 | Submission of all RF design documents | R | A |
| 11 | Cluster optimization | R | S/A |
| | **EMS** | | |
| 1 | Site survey | R | S |
| 2 | Provide space, power system, cooling, cables, infra per requirements | S | R |
| 3 | Installation and commissioning | R | |
| 4 | Integration with SNOC | R | S |

| | | | |
|---|---|---|---|
| | **Project Management** | | |
| 1 | Parallel Wireless' project management office | R | S |
| 2 | Project schedule, project plan, project progress, project management, and controlling | R | A |
| 3 | Resource planning | R | A |
| 4 | Workforce management | R | A |
| 5 | Project documentation | R | A |
| 6 | Reviews and reports (regular project progress and GAP analysis) | R | S/A |
| 7 | Periodic meeting (regularly per project requirement) | R | S |
| 8 | Site issue escalation of to Vodafone. Onsite issue, owner lease issue, any emergency issue, local authority issues | R | S |
| 9 | Provide proof documents for subcontractors as per labor commissioner law and compliance per Turkish government | R | |
| 10 | All license provisioning for riggers/technicians for tower climbing, safety tools, and equipment for outdoor/indoor activities per standard health and safety (H&S) guidelines/government guidelines and Vodafone safety guidelines | R | |
| | **Services** | | |
| 1 | Management of Parallel Wireless' network equipment delivery and related services to meet contractually agreed-upon goals for schedule and quality | R | |
| 2 | Setting up an E2E delivery chain. Defining demand planning and supply procedures | R | |
| 3 | Planning activity for producing detailed radio design for the modernized sites | R | |
| 4 | Provide core network | | R |
| 5 | Provide transmission to site with sufficient bandwidth and quality | | R |
| 6 | Supply of antennas and installation | S | R |
| 7 | Possible adaptations on sites to provide power, space | S | R |
| 8 | Installation planning, installation, commissioning, and integration of Parallel Wireless provided network elements—within agreed time schedules and in accordance with Parallel Wireless manuals and test procedures | R | A |
| 9 | Parallel Wireless to finetune the LTE network to provide a high performing network | R | A |
| 10 | Networking Operating Center (NOC), First Line Maintance (FLM) | R | |

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| | IP Network Requirement | | |
|---|---|---|---|
| 1 | Analyze IP network architecture | R | S/C |
| 2 | CRD (customer requirement document) | R | S/C/I |
| 3 | Naming and numbering design | R | S/A |
| 4 | Network topology design and routing design | R | S/C |
| 5 | IP network element inter-working design | R | S/I/A |
| 6 | HLD (high level design) document | R | S/I/A |
| 7 | LLD (low level design) document | R | S/I/A |
| 8 | Coordination among third-party vendors and operator for integration | R | S/C |
| 9 | Perform IP network integration test | R | S/I/A |

## 2.2 Deployment Timeline and Project Plan

**VF – FB Agreement and Work Packages**

**VF – TK Agreement and Work Packages**

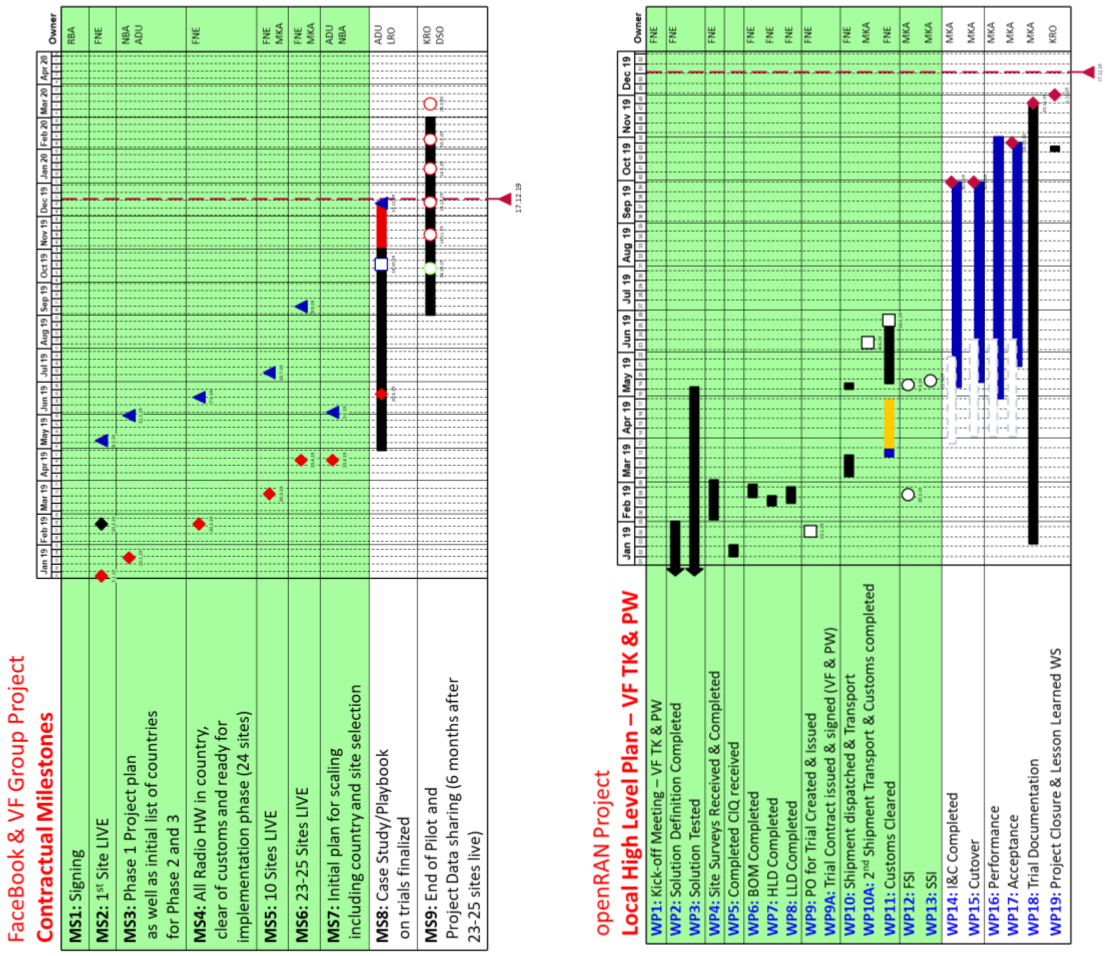
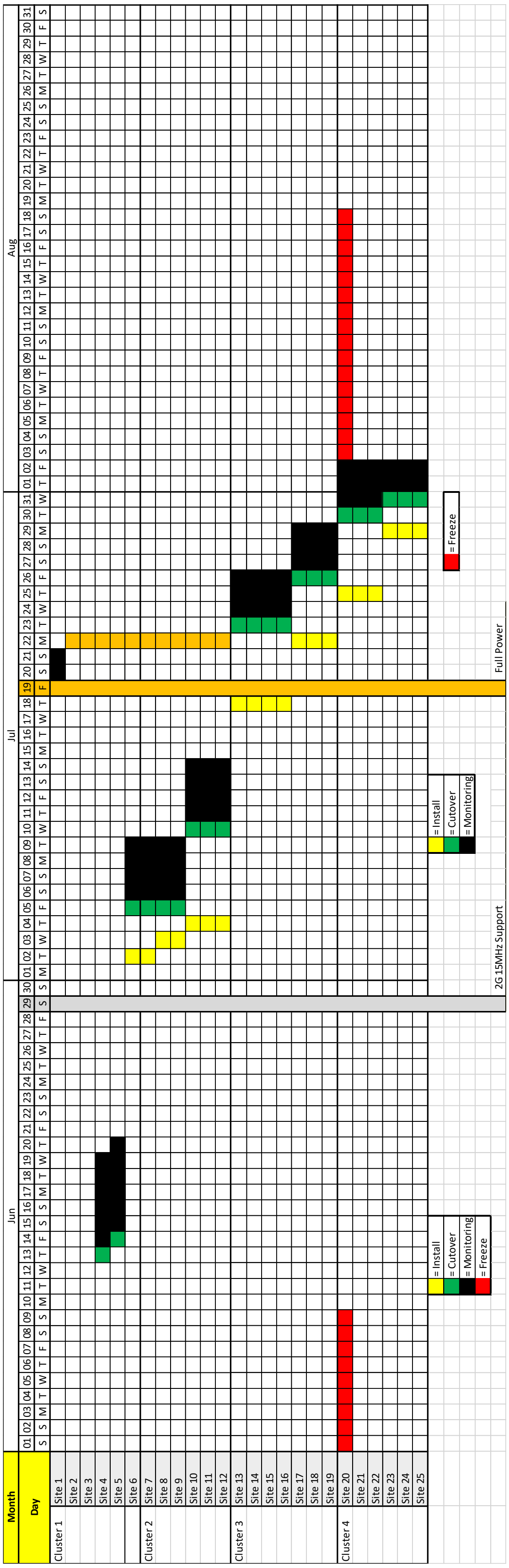



*Figure 5 – Project plans and timelines*

## Timelines

*Table 2 – Project timelines*



## Project Plan Phases and WP Breakdown

*Table 3 – Project plan phases and work package breakdown*

| Task No | Task Name |
|---|---|
| | Cluster Deployment – Six (6) Sites per Cluster |
| **Work Package 1 – Site Prep** | |
| 1 | Staging and configuration of equipment |
| 2 | Confirm power and transmission with Vodafone |
| 3 | Confirm drive test routes with Vodafone |
| 4 | Confirm core network and ops informed by Vodafone |
| 5 | Confirm site access arranged by Vodafone |
| 6 | Confirm VF region aware of activity and cutover date |
| 7 | Transport to site |
| 8 | Predeployment drive test |
| 9 | Site set and ready for installation |
| **Work Package 2 – Hardware Installation** | |
| 1 | Install CWS |
| 2 | Install antenna cabling |
| 3 | Install power and earth cabling |
| 4 | Install fiber optic cabling |
| 5 | Install site switch |
| 6 | CWS installed |
| **Work Package 3 – Hardware Cutover** | |
| 1 | Connect CWS to power |
| 2 | Turn on CWS |
| 3 | Check CWS config |
| 4 | Connect Parallel Wireless site switch to transmission |
| 5 | Ensure CWS connects with HNG |
| 6 | Ensure CWS locked |
| 7 | Clear current site lockdown with VF NOC |
| 8 | Ensure VF NOC have locked down site |
| 9 | Disconnect current cables from antenna and connect CWS |
| 10 | Connect CWS antenna jumper cables to antenna |
| 11 | Unlock CWS |
| 12 | Carry out SCVT |
| **Work Package 4 – Post-Deployment Drive Testing** | |
| 1 | Post-deployment drive test |
| 2 | Post-deployment drive test analysis |
| 3 | Post-deployment KPI analysis |
| 4 | Post-deployment drive test and KPI report |
| 5 | Post-deployment drive test and KPI review |

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| Work Package 5 – Post Installation Acceptance Testing | |
|---|---|
| 1 | Monitoring period |
| 2 | Post-deployment acceptance testing |
| 3 | Post-deployment acceptance test report |
| 4 | Cluster – completed and accepted |

### 2.2.1 Governance

Three layers of governance have been implemented:

Layer 1 – **Project Management:** Covered the overall project management between Facebook, Vodafone Group, Vodafone Turkey, and the Parallel Wireless global team. Daily calls were held as well as a weekly project review meeting. This resulted in a weekly project status report being shared with all parties.

Layer 2 – **Technical Management:** Covered overall technical performance issues and solutions management between Vodafone Group, Vodafone Turkey, and the local Parallel Wireless team. Weekly calls were held as well as a weekly performance review meeting. This resulted in a weekly performance status report to achieve stable KPIs.

Layer 3 – **Project Execution:** Daily calls and meetings were held between Vodafone Turkey and the in-country Parallel Wireless project manager. Such local meetings were essential to the smooth running of the project.

### 2.2.2 Project Communication

Regular communication was set up between TIP, Vodafone, and Parallel Wireless with weekly/daily calls between Facebook, Vodafone Turkey and the Parallel Wireless global team.

## Communications with Facebook and Vodafone

1. Easy to communicate day and night. Support available as 24/7. Communication was always clear and to the point.
2. Daily calls with Vodafone PM and frequent meetings in person.
3. During rollout there were weekly calls to discuss progress and issues.
4. Issues were then fed back to Parallel Wireless in Nashua team in Nashua, New Hampshire.
5. Weekly calls between Vodafone and the Parallel Wireless.

## Communications with partner

1. Parallel Wireless engaged a 3rd Party supplier to carry out the installation.
2. The 3rd Party supplier has been already responsible for sites before and after deployment.
3. The 3rd Party supplier carried out the drive testing.

4. The 3rd Party supplier's local knowledge helped and solved many issues was and solved all project-related issues, such as finding extra material, supporting all with ad hoc transport, customs, and technical expertise.
5. The 3rd Party supplier's prevous trial experience with Vodafone (wholly different from this one) helped planning the setup. Its expertise in drive tests and reporting has been well accepted by Vodafone.
6. Daily calls and regular meetings helped manage the deployment.

## 2.3 Approach to Selecting Trial Geography

As trial cluster selection was very important, the following were considered for OpenRAN selection criteria:

- A rural district, but also with a good mix of dense urban, suburban and rural sites
- Sites with ready tower, power, and backhaul to minimize rollout time
- All technologies(2G/3G/4G) were targeted for testing
- Possible introduction of a newer technology layer over existing service (and for multi-technology on the same CWS)

Going with the TIP agenda of connecting the unconnected, rural districts were immediate considerations. And since this was more of a technology trial, an area was sought that would be easier from an operational standpoint. The best fit for all of this criteria was the Bozüyük district.

The district has a good mix of rural, urban, and semi-urban areas, wherein all technologies (2G/3G/4G) over 25 sites were scoped with bands and a technology mix.

Further challenges were added by enabling multiple technology on the same 900Mhz band layer with co-existence of 2G and 4G on the same radio hardware.

## 2.4 Vendor Equipment Description and Lab Testing Baseline

### Parallel Wireless Products – Radios and Solution Architecture

In support of newer communications standards such as 4G (and eventually 5G), by virtue of their original design it's impossible to reconfigure legacy 2G and 3G networks using a software-based approach.

Parallel Wireless technology is designed for open interoperability through its GPP-based baseband processing platform, radio hardware, software, and simplified business model. Together these virtualize and automate *all* current and future Gs to provide better service to end users. As with the Turkish trial, RF and digital processing happens in a base station.

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Converged wireless system (CWS) components from Parallel Wireless disaggregate hardware and software (Figure 7):

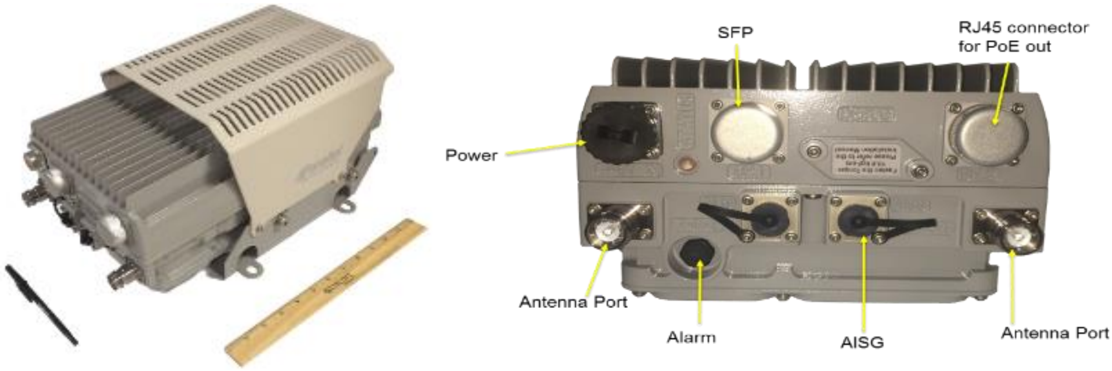


*Figure 6 – Parallel Wireless CWS components*

CWS-3050 is its latest model in the CWS series (2×40W). Its key features are:

- Software-defined, multi-technology, multi-carrier radio unit
  - ✓ clear technology evolution from 2G to 3G/4G/ 5G
  - ✓ GPP-based (COTS)
  - ✓ Ability to upgrade capacity by bringing a COTS-based vBBU to use split 6 with an existing CWS
- Supports all three radio access technologies (RATs) 2G/3G/4G in the same form factor, all software-defined
  - ✓ simultaneous 2G, 3G, and 4G operation
  - ✓ superior data and voice services to Vodafone customers
- Auto-configured and managed by the OpenRAN controller (HNG)
  - ✓ Permits deployment and maintenance without specialized staff or training

*Table 4 – Parallel Wireless CWS component specifications*

| | |
|---|---|
| **Flexibility** | High-capacity platform for cost-effective, resilient coverage<br>✓ Self-configuring ✓ Self-healing<br>✓ Self-optimizing ✓ Multi-radio backhaul mesh |
| **Band Combinations** | FDD or TDD variant<br>Both FDD or TDD support at same time depends on frequency requirement |
| **Air Interface** | • 2G/GSM • 3G/UMTS • 4G/LTE |
| **Supporting Operating Bands** | Major bands are supported |
| **Channel Bandwidth** | 5, 10, 20 MHz channel bandwidths |
| **Wi-Fi AP** | Support of any Wi-Fi AP via PoE connection |
| **Software Upgrade** | Available |
| **Resilience** | Full hardware and software redundancy, hot-swappable standby as well as high-availability software methods |
| **Interference Management** | Fully automatic via HetNet Gateway |
| **Antenna** | Any preferred external antenna |
| **Noise Sound Power Level** | Silent (no fans) |
| **Operating Temperature** | −40° to +55°C |
| **Relative Humidity** | 95%, non-condensing |
| **Protection Level (IP)** | IP66 |
| **Mounting Options** | ✓ Wall mount ✓ Pole mount ✓ Rooftop mount<br>(CWS can be cabinet installed if required for aesthetic requirements) |
| **Screws** | Tamperproof (for security) |
| **LEDs** | One RGB LED |
| **Venting** | Gore® vent or equivalent |

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## Parallel Wireless Products – OpenRAN Controller and Network Software (HetNet Gateway/HNG)

The Parallel Wireless controller and software suite enables OpenRAN through the complete decoupling of hardware and software functionality. Based on available backhaul/fronthaul options for 2G/3G/4G/5G, such separation lets the software support any protocol split between DUs and CUs.

Consolidation of disparate 2G/3G/4G/5G RAN functionalities on the platform reduce complexity. This provides simpler, less resource-intensive, and more cost-effective network maintenance.

Running on any COTS x86–64 servers with minimum hardware dependencies, the controller software helps manage multi-vendor networks while providing lowest TCO.

The server hardware specification is based on the expected call model and varies accordingly.

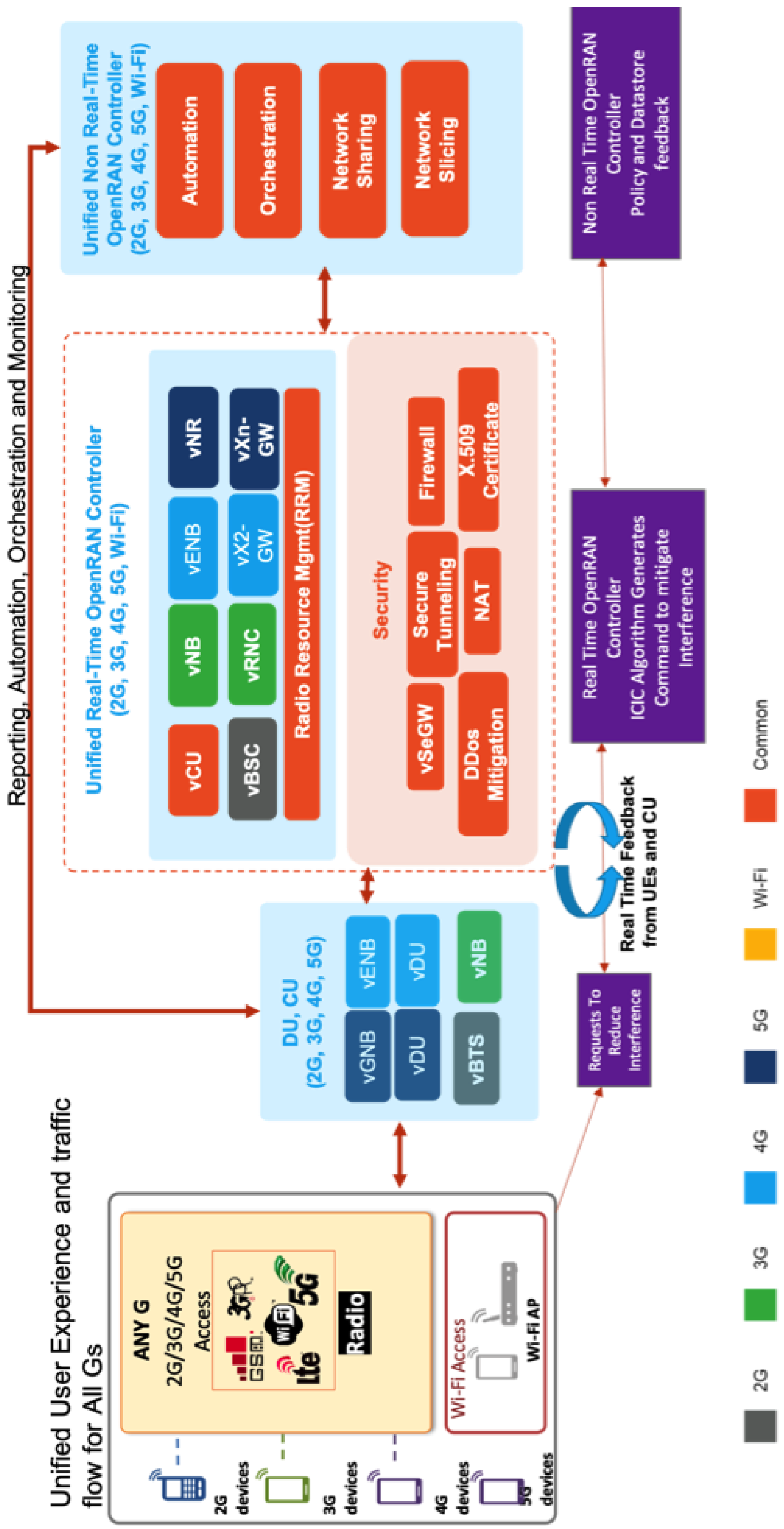


*Figure 7 – Parallel Wireless software architecture*

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Key Features to Reduce Deployment Cost and Complexity

- Open RAN architecture
  - ✓ Standards-based and open interfaces between network components
  - ✓ Open interoperability on the GPP-based baseband processing platform, radio hardware, and software
- Architecture simplification and architectural unification across all Gs and Wi-Fi
  - ✓ Virtualizes all G RAN and core functions on COTS (e.g., vBSC for 2G, vRNC for 3G, small cell and core gateways for 4G)
- Self-optimizing network (SON) automation
  - ✓ Easy integration of new RAN products into the network core
  - ✓ Hands-free maintenance with self-optimization
- Seamless mobility on 2G/3G/4G/5G
- High availability—including geographical redundancy
- Deployed as virtual network function (VNF) or bare metal

The OpenRAN controller oversees radio connection management, mobility management, QoS management, edge services, and interference management. Its current release can virtualize a vBSC/2G gateway, 3G gateway/vRNC, 4G gateway/X2 gateway, Wi-Fi gateway, or any combination thereof. As 5G standards become finalized, it can be software-upgraded to 5G controller functionality as non-standalone (NSA) and standalone (SA).

**Real-Time Controller** – Real-time SON provides complete RAN orchestration—including self-configuration, self-optimization, and self-healing. All new radio units are self-configured by the software, thereby reducing the need for manual intervention (essential for 5G deployments of massive MIMO and small cells for densification).

The self-optimization works across different RANs, using available data from macros, massive MIMO, and small cells from the analytics module. In contrast to the legacy reactive optimization approach, this predictive method optimizes resource use in providing an improved, consistent user experience on data-intensive 5G networks.

**Non-Real-Time Controller** – Provides non-real-time RAN intelligent controller (RIC) functionality for all network elements:

- configuration management
- performance management
- device management
- lifecycle management
- fault management

Controller functions include network slicing, security, and role-based access control. An intelligence layer can gather telemetry data to provide timely insights into operations. With reporting provided through a single pane of glass, this helps operators further understand and optimize the network.

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*Figure 8 – Hewlett Packard DL360 Gen9 server*

The Parallel Wireless software can be installed on standard, Intel-based COTS servers that meet its minimum defined CPU, memory, and interface requirements:

Hardware

- HP DL360 Gen9 or equivalent 2 socket x86 servers
- Intel Xeon E5-2697v4 (18 core), 2.3 GHz
- Total processors: 2
- 128GB of RAM
- Intel X710 or 82599-based NICs
- 256GB disk space
- Hardware RAID controller
- Dual power supplies (for redundancy)

Power/Space and Cooling

- 2U rack space for HNG pair operating in redundancy
- Max 500W with 94% efficiency
- Temp 10° to 35°C at standard operation

**Uni-Manage and advanced reporting**

Uni-Manage and advanced reporting are part of the non-real-time controller. Uni-Manage is a web-based element management system (EMS) application for managing and monitoring of all Parallel Wireless network elements. It can be deployed on an Intel-based server (per the above specifications) as well as in a virtualized environment.

Uni-Manage consolidates and displays alarms, statistics, inventory information, and health status of managed devices. Device deployment is simplified through auto-discovery of converged wireless systems once a real-time controller is configured. Device grouping lets operators efficiently perform actions (e.g., upgrades) on multiple units.

Device Grouping

- Groups can be used to filter views across various functions, such as Network Map, Alarm/Fault Management and upgrade management
- Standardized interfaces to raise alarms (via SNMP) and provide statistics (via REST interface) for all managed devices
- Real-time reporting of alarms raised by all managed devices
- Email triggering to specific personnel to reduce issue resolution time
- Upgrade scheduling for groups of devices and track real-time status

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- Security group capability; multiple groups of users with varying security privileges can access and maintain the network
- Audit capability tracks logs for each performed operation
- OSS/northbound interface support
- Browser support—latest Google Chrome, Mozilla Firefox, or Microsoft Internet Explorer versions

Uni-Manage and Advanced Reporting

Through its advanced reporting function, Uni-Manage enables operators to analyze device statistics. Such items as KPI formula, chart type, and report structure are completely customizable to help them immediately identify network performance trends and potential issues. And all dashboards can be modified, exported, or imported to enable portability and ease of maintenance.

Users can run real-time and historical reports using all of the statistics collected by Uni-Manage from the real-time controller and its CWS—including viewing trends on network capacity, usage, throughput, performance, and errors/issues.

For this field trial, Uni-Manage and Parallel Wireless were deployed in a virtualized environment using a KVM-based hypervisor running on an HP DL 360 Gen 9 server. Advanced reporting platform provided KPIs and statistics for all technologies.

- Predefined statistics/KPIs
- Predefined superset of dashboards per technology
- Custom KPI creation
- Drill down capability
- Custom dashboards
- KPI Lab

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### Solution Architecture for Parallel Wireless Solutions in the Trial

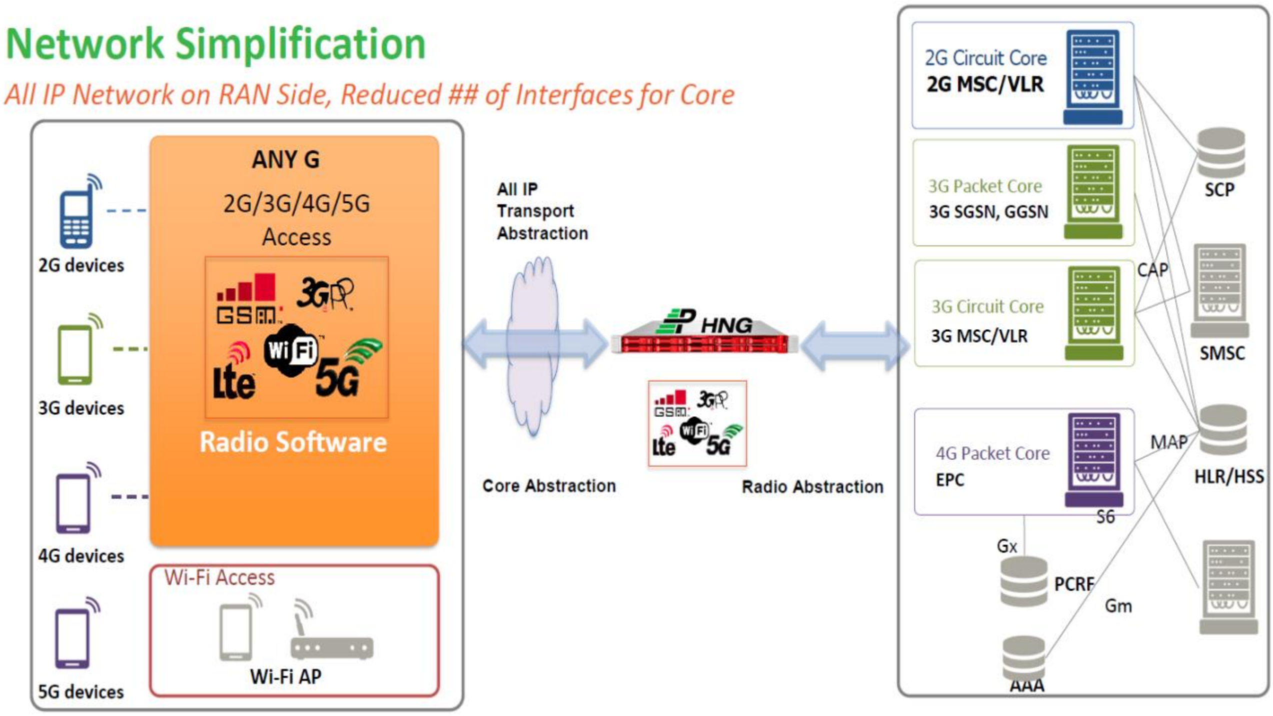


*Figure 9 – Parallel Wireless solution architecture*

#### 2.4.1 Test Plans

Field trial announcements were immediately followed by lab trials for Parallel Wireless 2G/4G systems. This was successfully completed by November 2018. A 3G lab trial commenced Q12019.

#### 2.4.2 KPIs to Measure

Lab ATP results were for basic functional tests; performance KPI were to be monitored in field. Key KPI and targets were defined as follows:

*Table 5 – Targeted KPIs*

| 2G KPIs | Target |
|---|---|
| Availability | 99.90% |
| CSSR (Call Setup Success Rate) | 99.00% |
| SDCCH Access Success Rate | |
| TCH Congestion Rate | 0.05% |
| Handin Success Rate | 99.00% |
| Handout Success Rate | |

| 4G KPIs | Target |
|---|---|
| Availability | 99.90% |
| RRC Setup Success Rate | 99.00% |
| LTE ERAB Setup SR | |
| Intra HO SR | |
| Inter HO SR | |
| CSFB SR | |

#### 2.4.3 Test Setup and Test Tools

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A Parallel Wireless HetNet Gateway (HNG) is integrated into the Vodafone Turkey core network at MTX data center. Aggregating GSM, UMTS, and LTE technologies, the HNG has a logical interface toward Vodafone's existing 2G, 3G, and 4G core networks. The HNG acts as a virtualized BSC (vBSC) to 2G core, a vRNC to 3G core, and a virtual eNodeB (veNodeB) to 4G core.

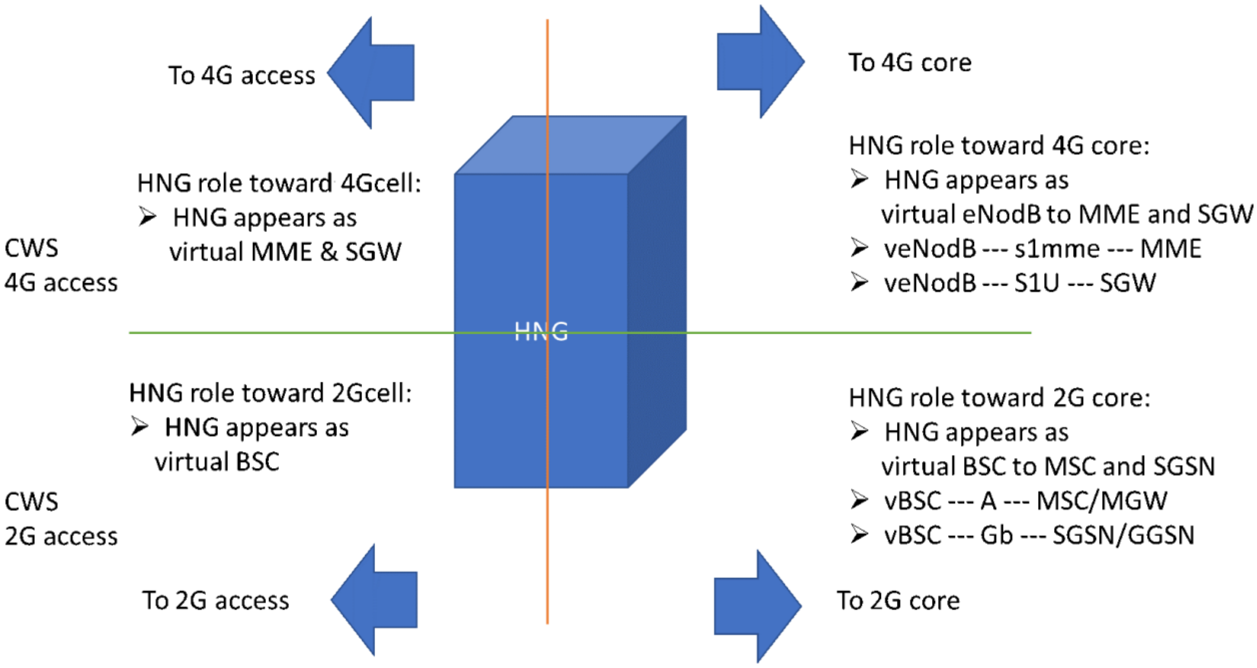


*Figure 10 – Test setup and tools*

The HNG orchestrates Parallel Wireless CWS 2G/3G/4G multi-carrier base stations to provide cellular connectivity. The solution was integrated in the data center, and acceptance tests were performed with a Parallel Wireless CWS multi-RAT solution on 2G, 3G, and 4G against Vodafone Turkey's core network elements.

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Figures 12–14 illustrate the lab setup for 2G, 3G, and 4G acceptance tests in the data center:

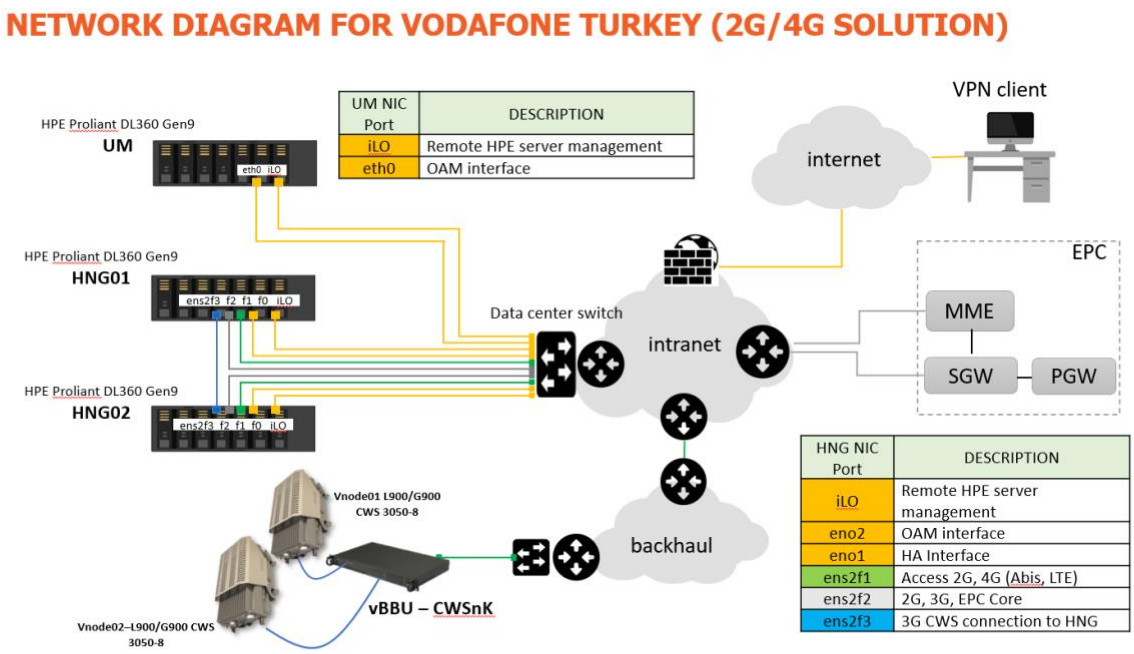


*Figure 11 – Vodafone Turkey GSM/LTE multi-RAT network solution*

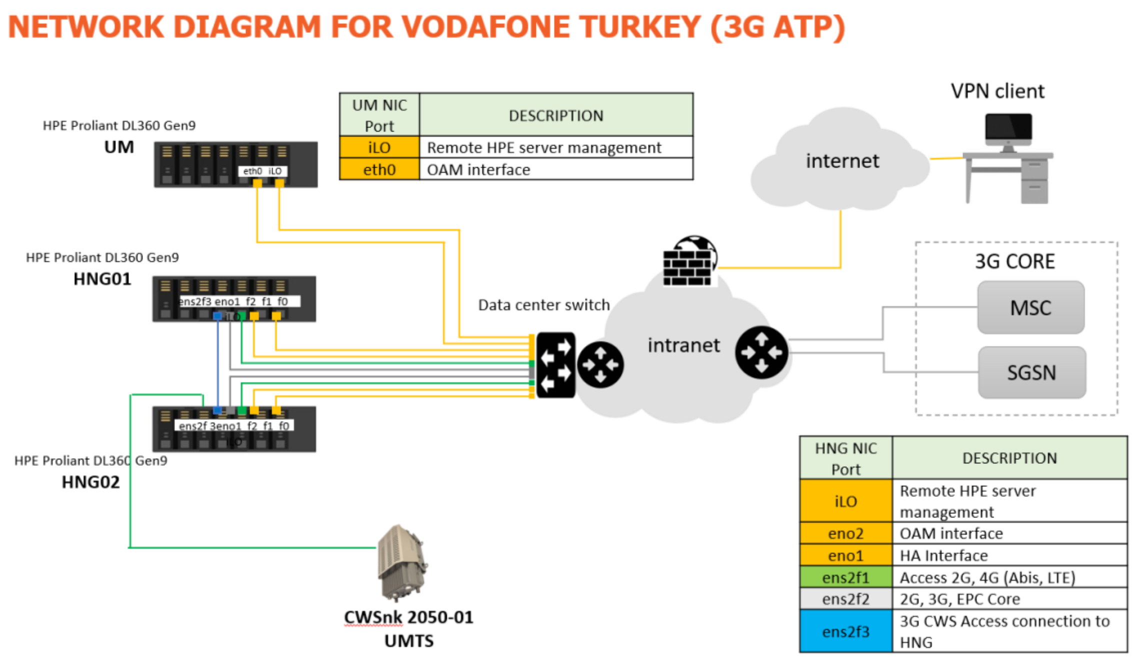


*Figure 12 – Vodafone Turkey 3G ATP network solution*

## 2.5 Network Planning and Design

### 2.5.1 Radio Design and Optimization

Spectrum Allocation

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*Figure 13 – Radio spectrum allocation*

*Table 6 – Frequency and Location*

| Technology | GSM | LTE |
|---|---|---|
| **Frequency band** | 900 MHz (B8) | 900 MHz (B8) |
| **Bandwidth** | 7.4 MHz | 5 MHz |

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### 2.5.2 Transport Design and Capacity Planning

The same transport capacity design approach was used for the OpenRAN trials as was done for similar technology for incumbents. Also, the current transport for backhaul was ready with capacity for supporting new 5Mhz LTE activations onsite. All sites were on microwave links and maximum was below 70%, thus indicating no transport blocking for the trial areas.

### 2.5.3 Physical Tower and Infrastructure Changes

The selected sites had existing towers and an adequate power supply for the trials. No new infrastructure or onsite upgrade was required to accommodate OpenRAN equipment. Also, the Parallel Wireless CWS was lightweight, so no tower strengthening had to be undertaken.

### 2.5.4 Site Planning

Each site was surveyed by the local partner. CWS positioning was based on available space and mast loading. Documentation for this activity is held by the local partner.

A summary of each site requirement was recorded; below is an example:

**Site_2** Technologies, Power and No. of CWS

- **3 sector site**
- **G900 and L900**
  - 3 Rev-C 3050 with 2G and 4G co-located (3 CWS)
  - 20 W per technology
  - All technologies on same subnet on CWS side (VLAN tagging off)
- **Total CWS = 3**
- **6 MM optical SFPs**
- **Antenna height is 48.6m**
- **HNG side VLAN 3607 (tagging enabled):**
  **CWS traffic from 2G, 3G, and 4G carried in IPsec tunnels**

Logical site topology was created and used to ensure the correct connectivity following the installation. This information was recorded in the high-level design document.

The following diagrams depict the Dodurga trial site topology:

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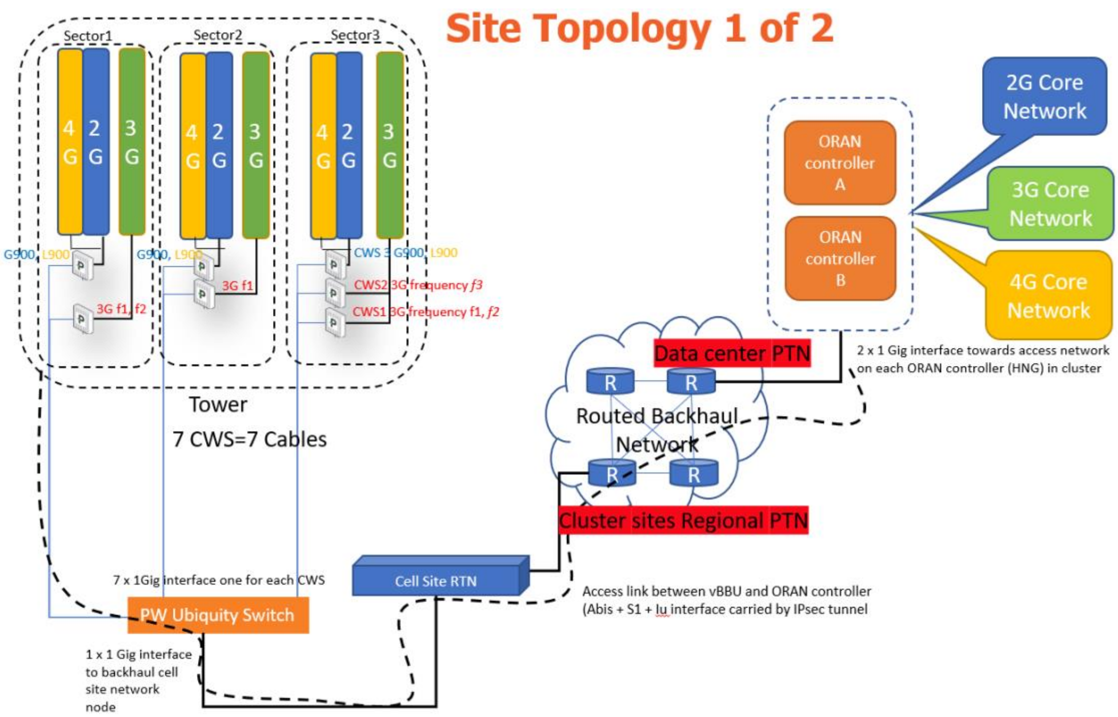


*Figure 14 – trial site topology*

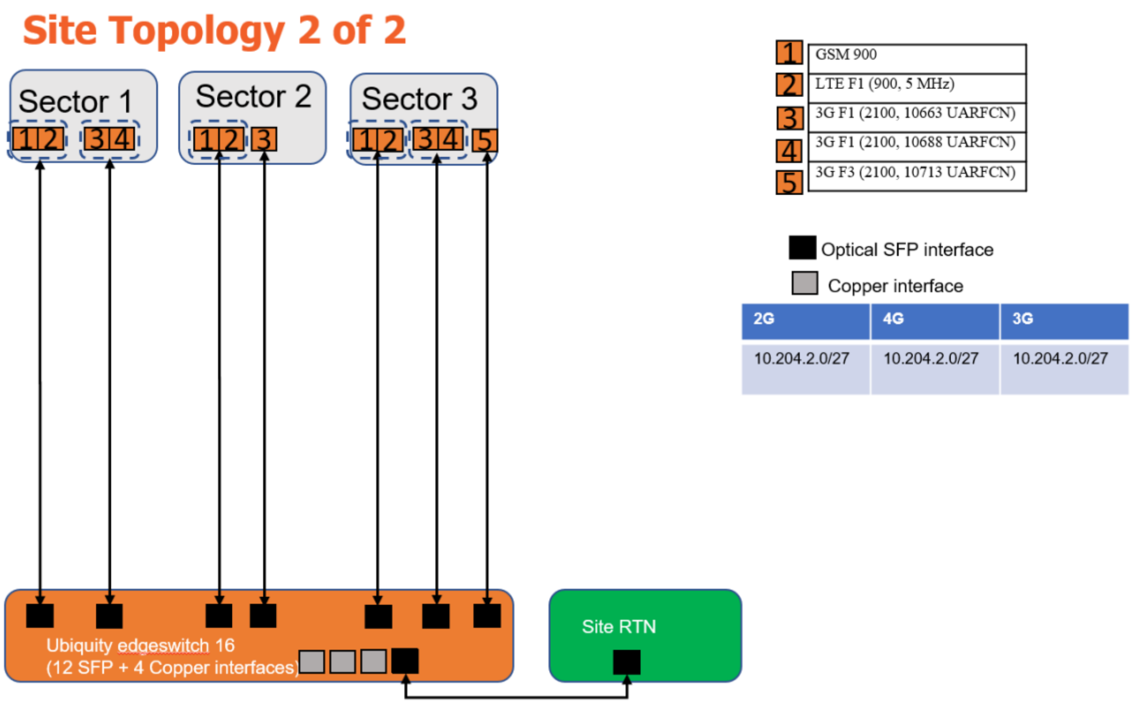


*Figure 15 – Dodurga trial site topology*

## 2.6 Deployment Approach for OpenRAN Sites

This OpenRAN deployment was achieved in the same way as for incumbent vendors. While being the correct way for this project, there may be more efficiencies and cost

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savings to be had as OpenRAN evolves and the available range hardware and software increases.

For this trial, Parallel Wireless engaged a local subcontractor to carry out all deployment aspects. This is possibly the most important factor to consider; local knowledge provides a significant advantage during surveying, equipment installation, and optimization.

The recommendation is to always engage a local contractor familiar with the operator and local areas. This will ensure they're also up to date with the operator's current practices. And the operator will have confidence that the contractor is competent to work on its sites.

Preplanning and adequate time should be allocated for each task of any rollout so as to be fully successful.

### 2.6.1 Technical Site Survey

A comprehensive site survey should be carried out to ensure all relevant information is available. The process is simplified when the operator maintains detailed site files regarding what is onsite. This file should be updated when any site changes are made. But if there is any doubt as to the accuracy of the information, then a site visit should be arranged to undertake a survey.

### 2.6.2 Site Design and Planning

Once site survey data is verified, the planning team can create designs to ensure the new equipment will either fit alongside existing equipment or can otherwise use current site infrastructure.

If the vendor is to be involved in the design and planning process, then they should work closely with the operator teams to ensure site design can be quickly approved.

### 2.6.3 Equipment Installations

The operator usually dictates procedure for equipment installation and commissioning based on its change management policy. Using an approved contractor to take on the work can give the operator confidence that their procedures will be followed and unnecessary delays will be prevented.

### 2.6.4 Optimization

The operator should share its drive test methodology with the vendor if it's expecting the latter to carry out the drive testing and optimization. The vendor should carry out its own pre- and post-drive tests.

Pre-drive test and KPI analysis must be carried out to provide relevant comparison data. An operator will usually only accept a site when the quality of the optimized network drive tests matches the target KPIs.

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## 2.7 High-Level Economic Assessment

Given its architecture, over time OpenRAN systems will yield both CAPEX and OPEX cost efficiencies. As part of this trial, examples of high-level areas considered in TCO are as follows:

**CAPEX**

- All in one – 0% site footprint, no separate BBU cabinet
- Reduced cable configuration
- Simple router at site and agnostic IP backhaul
- Built in GPS antenna
- Optimized software licenses, features, power output, and  CEs
- Virtual core – COTs based
- Outdoor units – AC reduction
- All G core – Open RAN
- Single Operations & Maintance (O&M)

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**OPEX**

- Consolidated core elements decrease complexity and improve cost savings
- SON – optimization savings
- Imbedded security gateway
- Reduction in site space, power leasing, and rentals
- Reduced support fees
- Local data breakout

**High-Level Cost Breakdown**

The majority of costs are incurred in the hardware CAPEX. This can be addressed by TIP and other industry initiatives as follows:

- EVENSTAR Radio
- Evenstar White Box DU/BBU
- Introduction of DU and CU concept to reduce site equipment
- Neutral hosts concepts wherein the BBU HW could be provided as a service

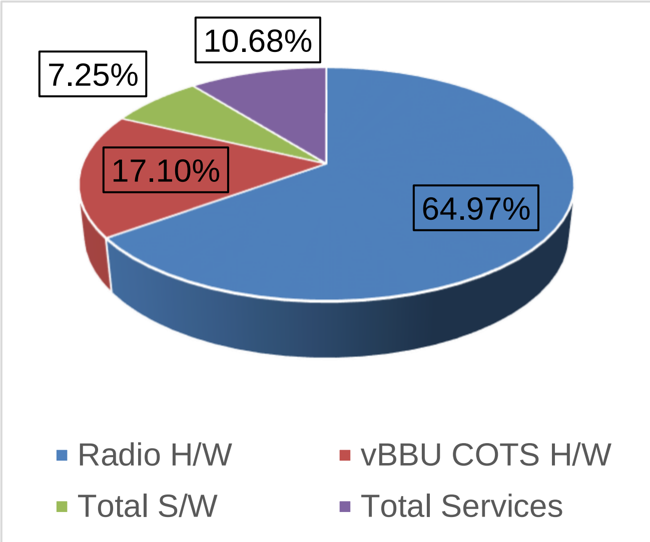


*Chart 1 – Cost breakdown*

Similar OPEX savings can be made by the following:

- Plug & play deployments
- Network automation
- RAN intelligent controller (for optimization)

### 2.7.1 Equipment (Including Installation and Commissioning)

The Parallel Wireless CWSs were very easy to install and commission. There was no need for skilled manpower, as the products were simple to deploy and connections easy to understand. Highlighted during the 2019 TIP Amsterdam Summit, this is best summarized by the following illustration:

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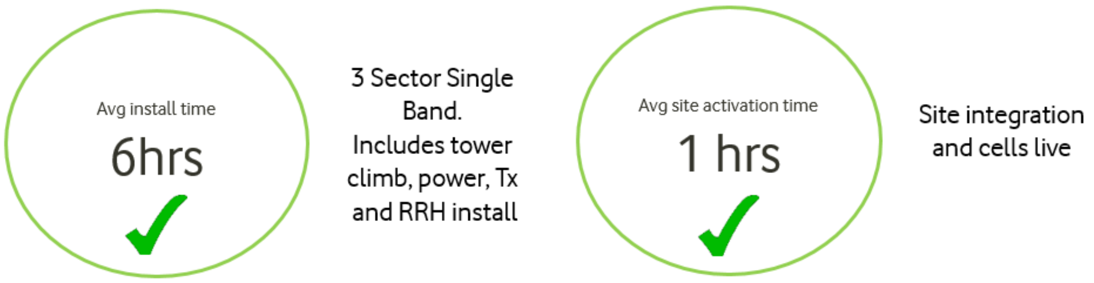


*Figure 18 – Installation and commissioning times*

The multi-functionality HetNet gateway (a RIC) has SON features. This helps optimize the overall services by permitting deployment and maintenance without any need for specialized staff or training.

### 2.7.2 Estimating OPEX

The first CWS systems deployed for the Turkish trials are more efficient than the older cabinet-based 2G systems. Moreover, the deployed, multi-technology 2G+4G systems are performing well within the stated equipment specifications.

The following table shows examples of field power consumption with variable load for 2G+4G conditions:

*Table 7 – Power/Load Consumption*

| **BTS Number** | **GSM+LTE (Peak Consumption in Watts)** |
|---|---|
| BTS 1 | 444 |
| BTS 2 | 608 |
| BTS 3 | 793 |
| BTS 4 | 728 |
| BTS 5 | 551 |
| **Total Average Power for 5 Sites** | **625** |

More advanced CWS in planned roadmap coupled with industry-collaborative radio hardware are expected to yield further power efficiencies with regard to current trial-based solutions.

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# Findings

## 2.8 Equipment IOT and Testing Process and Challenges

i) Parallel Wireless had already carried out interoperability testing with major vendors' equipment; therefore deploying and interworking in trials with Vodafone Turkey was not a challenge

ii) Testing was predominantly carried out by Parallel Wireless personnel due to system expertise. Further training was given to VDF personnel to enable them to perform testing. It was also ensured that vendor personnel should be used as technical backup in the following circumstances:

(a) If an issue is found with equipment that is not related to testing

(b) If a test fails, they should perform log recording as required by the software development team

(c) Provide technical assistance when loading bug fixes or new software

iii) Any live testing should follow the detailed analysis of current target site KPIs

- Neighbors should be properly defined, if necessary
- If trial site is a 'coverage island,' this must be considered when performing drive testing and analyzing KPI

iv) Trial site selection should be agreed to ensure optimum chance of success

v) Site backhaul must be thoroughly tested before trial is started and must be periodically checked therafter

## 2.9 Installation and Integration Process

Key considerations and installation/integration process approach were as follows:

i) Vodafone Turkey and Parallel Wireless had mutually agreed on an approved partner to perform the work

ii) Detailed site surveys were to be performed before deployment. Sufficient time should be allocated and all checklists used to avoid delays and later surprises

iii) Power availability and requirements (e.g., AC/DC/battery) must be fully assessed before installation process begins (site survey)

iv) Enough teams and technical support should be available to perform an optimum number of rollouts with proper planning (e.g., if handovers are critical then it's best to replace all affected sites)

v) Dedicated personnel to work closely with regions during process

vi) Expert engineering resource presence in NOC and on the ground during the site activation process

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Hardware should not be switched on unless all functionalities are fulfilled (as required by the operator).

## 2.10 Design Considerations

i) A vendor solution must be theoretically capable of handling current traffic levels for each of the existing installation technologies, as well as projected loads for any new technology

ii) Hardware and software limitations must be considered when designing site parameters; possible gaps should be highlighted

iii) Specific use cases must be identified early and taken into consideration during the site design and planning process

### 2.10.1 Use Case

Being in an early stage, OpenRAN needs to be properly tested with the best possible, minimal requirement considerations. An initial target use case should consider rural markets with low capacity requirements.

Initial multi-technology deployments in the same bands, using the same radios, could be risky in high-density urban areas having challenging load conditions. In addition, such locations are very sensitive to customer experiences .

Accordingly, in trial locations with heavy 3G traffic, OpenRAN testing was limited to a few rural sites with low traffic. The decision was made to focus on 2G and 4G OpenRAN platform capabilities and performance in the remaining cluster sites.

## 2.11 Logistical Challenges

Disaggregation is at the center of OpenRAN, with vendors having excellent inhouse capabilities to create software and manufacture hardware. But when it comes to an opco-grade business model, E2E delivery capability becomes one of the most important factors for timely site rollouts. Useful findings have come from existing trials; Parallel Wireless kept the following in mind during this one:

i) Customs requirements must be fully understood before dispatching equipment

ii) As many materials as possible should be locally procured

iii) A staging area/warehouse must be as close to deployment area as possible

iv) The operator should request and vendor should provide an adequate number of spares

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## 2.12 Measurement Collection Implementation Process and Challenges (to Benefit Scale Deployment)

The current trials have successfully proven the concept of building RAN with GPP platforms. Also, KPIs achieved in rural sites for commercial-grade traffic has boosted confidence in the future of OpenRAN platforms. But there are some challenges that need to be addressed—the industry needs a very active role in standardization, vendors, operators demand on use cases to make this a success for very wide scale deployments across large MNOs.

Further key techno-commercial areas that need work include:

- Standardizing the deployment models and split architecture for true interworking between all GPP hardware and software vendors' stacks to achieve optimal costs
- E2E lifecycle management of each OpenRAN architecture component
- Hardening of GPP platforms and software for commercial-grade security
- Operational excellence with regard to interfaces with current central network management system operators

# Technical Performance Benchmarking

## 2.13 Network Performance

It's relatively difficult to compare legacy and OpenRan KPI values due to site configuration changes after OpenRAN network installation. The target KPIs are given by Vodafone for well-optimized KPI target values to reach optimum network quality targets.

*Table 8 – 4G Network Performance KPIs*

| 4G KPIs | Target Threshold | MWC KPI Achieved | KPI Achieved April 2020 |
|---|---|---|---|
| Availability | >=99.9% | 99.10% | 99.90% |
| RRC Setup Success Rate | >=99% | 97.99% | 98.73% |
| LTE ERAB Setup SR | | 97.96% | 99.12% |
| Intra HO SR | | 99.99% | 99.94% |
| Inter HO SR | | 99.64% | 99.98% |
| CSFB SR | | 99.68% | 99.48% |

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*Table 9 – 2G Network Performance KPIs*

| 2G KPIs | Target Threshold | MWC KPI Achieved | KPI Achieved April 2020 |
|---|---|---|---|
| Availability | >=99.5 | 99.36 | 99.99 |
| CSSR (Call Setup Success Rate) | >=99 | 99.32 | 99.40 |
| SDCCH Access Success Rate | | 98.27 | 99.01 |
| TCH Congestion Rate | <=0.05 | 0.00 | 0.00 |
| Handin Success Rate | >=99 | 97.30 | 93.63 |
| Handout Success Rate | | 95.69 | 93.00 |

The target values will be reached by the end of acceptance period through activations of required features and optimization activities. Handin SR and HO SR KPIs are degradated since MWC due to site location difference. Currently, most of the trial sites are located in rural areas where site-to-site distance is approximately 8–10km.

## 2.14 Deployment KPIs (Time to Deploy, Outage Times for New Radio Sites)

Various deployment activities were performed in building a Parallel Wireless network in Vodafone Turkey's Bozüyük region. Considering dependencies, the following table depicts average time for each activity.

*Table 10 – Average times for each deployment activity*

| Network Deployment Activity | Dependency | Time (hours) | Ownership |
|---|---|---|---|
| Completed CIQ (parameter information and IPs) | | | Vodafone Turkey |
| IP configuration on customer routers and switches | | | |
| Core side provisioning for eNB/VRNC/VBSC | | | |
| Avg. CWS installation time | site type | 2 | Parallel Wireless |
| Avg. CWS commissioning time | CIQ is completed and available | 1 | |
| Avg. CWS integration time | IP config and core side config is ready | 0.5 | |
| Avg. HN-GW installation time | hardware available in data center, rack space and power is available | 4 | |
| Avg. HN-GW commissioning time | CIQ is completed and available | 6 | |
| Avg. HN-GW integration time | IP config and core side config is ready | 4 | |

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Vodafone Turkey has different site configuration types in Bozüyük. Deployment, configuration, and integration times depend on site configuration. The next table shows deployment time for each network configuration.

*Table 11 – Bozüyük site configuration types*

<table>
<tr><th rowspan="2">Vodafone Site Configuration Types</th><th colspan="5">Cell Quantity/Layer</th><th rowspan="2">Deployment Time Onsite (hours)</th><th rowspan="2">Commissioning/ Integration Time (hours)</th></tr>
<tr><th>800 MHz (LTE)</th><th>900MHz (GSM+LTE)</th><th>1800 MHz (LTE)</th><th>2100MHz (LTE)</th><th>2600 MHz (LTE)</th></tr>
<tr><td>Configuration 1</td><td rowspan="2"></td><td rowspan="5">3 + 3</td><td rowspan="3"></td><td></td><td rowspan="4"></td><td>8</td><td>1.5</td></tr>
<tr><td>Configuration 2</td><td rowspan="5">3</td><td>12</td><td>2.5</td></tr>
<tr><td>Configuration 3</td><td rowspan="4">3</td><td>16</td><td>3.5</td></tr>
<tr><td>Configuration 4</td><td rowspan="3">3</td><td>20</td><td>4</td></tr>
<tr><td>Configuration 5</td><td rowspan="2">3</td><td rowspan="2">24</td><td>5.5</td></tr>
<tr><td>Configuration 6</td><td>3</td><td>5</td></tr>
</table>

## Approach to Scale Deployments with OpenRAN

OpenRAN can be described in simple terms as "virtualized software running on open interface hardware." An OpenRAN deployment implies simplicity and flexibility. All software should be interchangeable and able to operate on any vendor hardware. OpenRAN is expected to change the ways networks are built and to lower future costs for MNOs, opening the RAN space to new vendors and encouraging innovations.

Deployment becomes more complicated at the initial stage when an MNO requires OpenRAN technology to interface with its legacy network. Here, sufficient time must be given to its introduction into a network. Detailed planning is essential, and a full understanding of requisite steps when integrating with legacy equipment must be achieved.

Legacy networks will often be using proprietary interfaces, so all interoperational aspects must be assessed. All departments of both vendor and MNO must be fully engaged in designing and implementing a mutually agreeable solution. Without an effective network design and project plan—as well as sufficient implementation time—significant challenges will exist during deployment.

This trial can be termed successful, especially with respect to the TIP agenda of "Connecting the Unconnected." The Parallel Wireless OpenRAN solution meets acceptable performance levels for rural environments. Further roadmapped feature and product updates are in progress for urban testing and deployments.

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# Future Parallel Wireless Product Vision

Parallel Wireless' complete OpenRAN solution features an ecosystem of virtualized functionality; it replaces dedicated hardware appliances with VNFs running on Intel® Xeon® processor-based servers (they offer the performance for mission-critical and data-demanding workloads). With a range of price/performance levels, Xeon-based servers provide MNOs with cost-effective flexibility to deploy OpenRAN software both in the network core and at its edge.

Intel FlexRAN permits Parallel Wireless support to be integrated on Intel SoC and split OpenRAN architectures (see OpenRAN USE-CASES image below).

All options can be deployed based on a customer use case. The integrated option is more applicable in rural areas having a smaller user count, and where an all-in-one approach (digital and RF processing occurring inside the base station) is preferred. This is what was originally deployed in Turkey.

A split architecture is applicable for capacity or coverage deployments in urban and suburban scenarios. Here, digital processing occurs on the server, enabling more throughput and user counts for all G. (We're using split 6 to add servers/vBBUs to some original sites to add more capacity.)

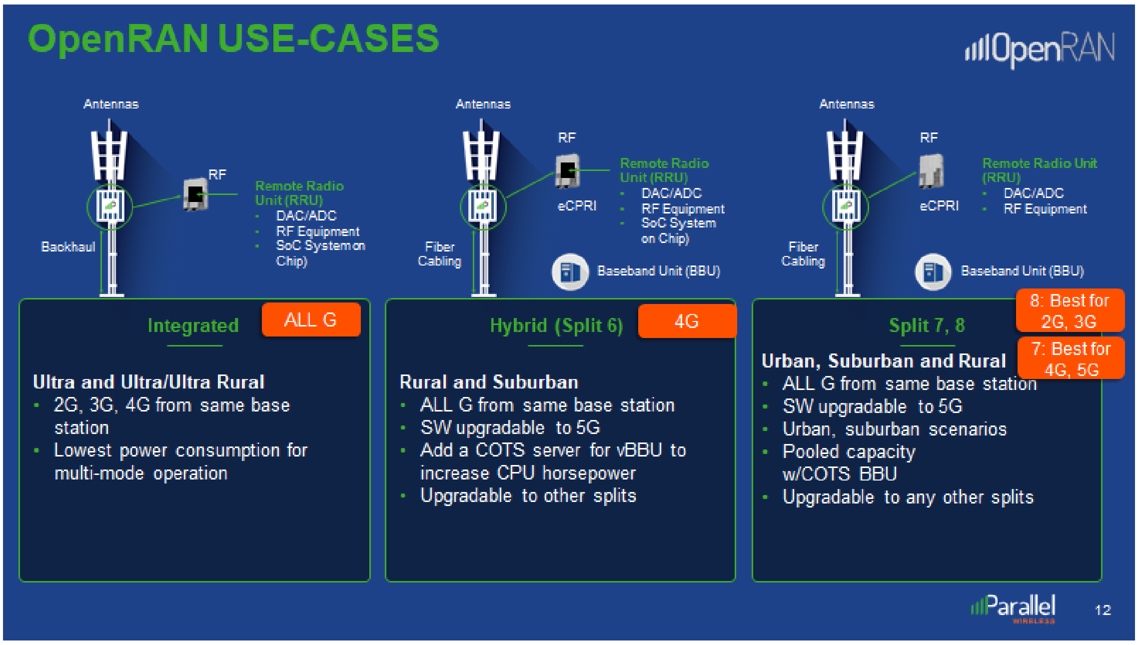


*Figure 16 – Supported types of OpenRAN use cases*

Parallel Wireless OpenRAN can support all 3GPP-compliant RAN splits. For 5G, 3GPP is considered the split concept (DU and CU) from the onset. The gNB may consist of a centralized unit (CU) and one or more distributed units (DUs) connected to the CU via Fs-C and Fs-U interfaces for CP and UP, respectively. The split architecture will enable a 5G network to use a different protocol stack distribution between CU and DUs, depending on fronthaul availability and network design criteria.

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Centralized baseband deployment is initially proposed to permit load-balancing between disparate base stations. In most cases DU will be collocated with RRH to conduct all computationally intense processing tasks (e.g., fast Fourier transform/inverse fast Fourier transform (FFT/IFFT)). These are not load dependent and exhibit no sharing gains. CU can be separate or collocated with the aggregator depending on fronthaul availability.

We believe a dynamic, functional split between a CU and DUs will be the approach for 5G systems and beyond. While CUs will maintain BBU-like functionalities, DUs will be more than RRH in terms of processing capacities.

In case of requirements for more delay-sensitive 5G service (including but not limited to beamforming and configuration) and based on appropriate fronthaul availability, the MAC-PHY split will be the preferred solution. Parallel Wireless believes the future of 5G is not about specific split, but more about flexibility and the ability to create splits based on disparate morphologies and deployment scenarios. Parallel Wireless' 5G RAN visualization will address all these requirements through its OpenRAN software suite as an anchoring point.

We believe lower-level splits (7.x) will be the best approach going forward for deploying future mobile networks in different environments and morphologies. While its requirements for fronthaul are not as restricted as split 8, by using the vBBU its solution can support traffic in a dense urban area while maintaining a less-than-perfect backhaul to connect this local vBBU to the OpenRAN software suite.

Parallel Wireless recommends option 7.2 split of 3GPP when high throughput and low latency fronthaul is available between vBBU and the RRH. This is a very efficient and practical PHY split, considering IFFT/FFT are not load dependent and add no sharing gain by accommodating it in the CU. RRH, vBBU and OpenRAN software suite products are naturally equipped to support split 7.2

For rural areas where there is no reliable and high capacity fronthaul availability, the local vBBU connection to RRH will use a close-to-perfect fronthaul since they are in proximity and use less-than-perfect backhauls (e.g., satellite links) to connect the vBBU (virtualized BBU/vBBU) to the OpenRAN software suite (it serving as a vCU, orchestrator, and aggregator).

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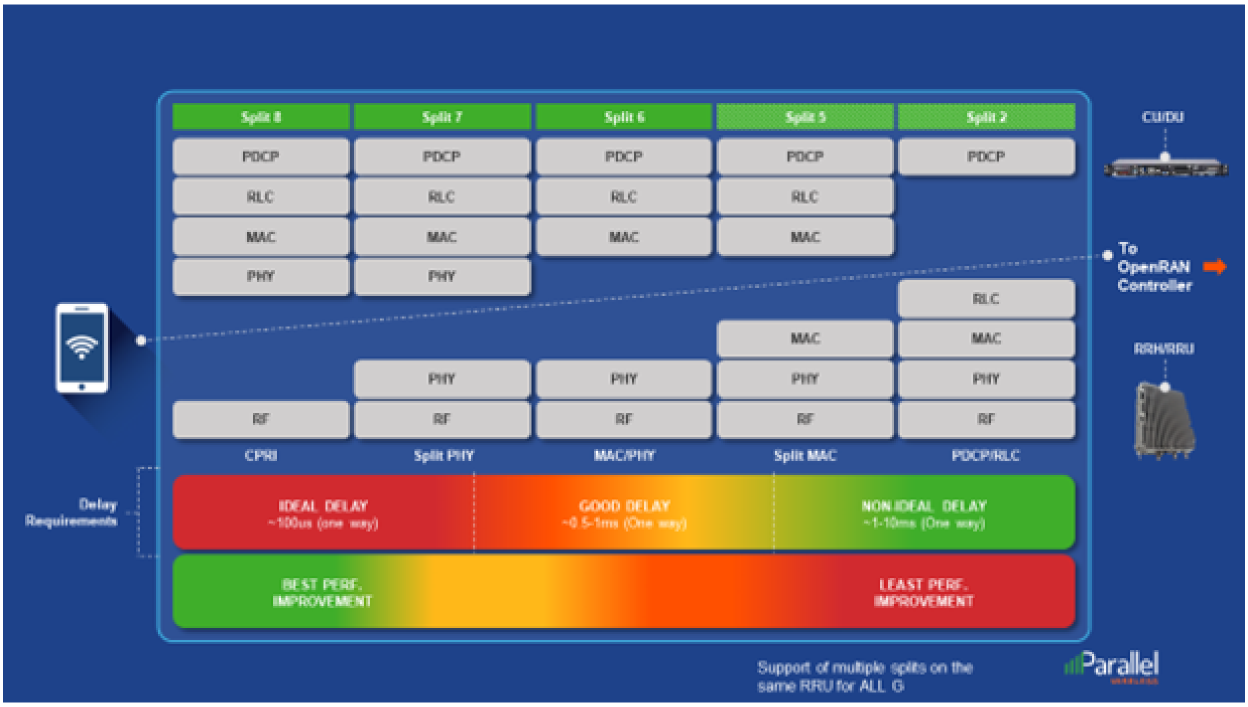


*Figure 17 – RAN Split options overview*