International Journal of Instruction, Technology, and Social Sciences
Vol. 5, 56-78, 2026
ISSN: 2716-6546
www.ijitsc.net

Cognitive RIC-SON: A Reinforcement-Learning xApp/rApp Framework for Multi-Vendor 5G Standalone and Open RAN Networks in Saudi Arabia

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Abstract

Self-Optimizing Networks (SON) have travelled a long road since 3GPP first standardized them for LTE in Release 8. The destination is now in sight: closed-loop, AI-driven, multi-vendor radio access networks that adjust themselves in real time to load, mobility, and energy conditions. Saudi Arabia has been one of the most active proving grounds for that destination. In July 2024, stc Group and Nokia announced the world's first live deployment of a cognitive, AI-powered SON module — Nokia's MantaRay Cognitive SON — on stc's commercial network during Hajj 2024 (Nokia, 2024; Telecom Review Middle East, 2025). The deployment processed more than 10,000 autonomous actions in 15-minute optimization intervals, lifted loaded-cell utilization by approximately 30 percent, improved user throughput by about 10 percent on average, and held service quality steady through a 40 percent traffic surge driven by over a million pilgrims.

That deployment is a strong validation that cognitive SON works at scale. It also exposes the next problem clearly. MantaRay is a vendor-specific platform, and stc, like any Tier-1 operator in the Kingdom, runs a multi-vendor network across Huawei, Nokia, and Ericsson. The same multi-vendor reality holds at Mobily, which signed an O-RAN MoU with Ericsson in March 2024, and at Zain KSA, which signed a Cloud RAN and AI-RAN MoU with Nokia at LEAP 2025 and launched commercial 5G SA with Huawei on the 600 MHz band in October 2025. Solutions by stc became Saudi Arabia's first commercial Open RAN operator with Mavenir in February 2024. ACES, with Radisys, completed an NTDP-funded ORAN small-cell partnership in November 2024. The Kingdom is becoming an Open RAN multi-vendor environment far more quickly than most regions of the world.

This paper proposes RIC-SON-KSA, a multi-vendor Cognitive Self-Optimizing Network framework that re-expresses the classical SON functions defined in 3GPP TS 28.313 as O-RAN xApps and rApps running over the Near-RT and Non-RT RIC respectively. The framework introduces a Conflict-Aware Coordinator (CAC) that detects and mitigates the three principal conflict classes identified in the recent O-RAN literature — direct, indirect, and implicit — across xApps and rApps from different vendors. The framework is anchored in 3GPP TS 28.313 SON specifications, 3GPP TS 28.552 PM specifications, the O-RAN Alliance WG1, WG2, and WG3 specifications including E2SM-KPM and E2SM-RC service models, and the policy frameworks issued by the Communications, Space and Technology Commission (CST), the Saudi Data and Artificial Intelligence Authority (SDAIA), and the TM Forum Autonomous Network Levels.

The methodology integrates literature review (2020 to 2026), public industry milestones from stc, Mobily, Zain, ACES, Solutions by stc, Mavenir, Nokia, Ericsson, and Huawei, and analytical projection of RIC-SON-KSA performance using real KPI outcomes from the Hajj 2024 MantaRay deployment as the empirical anchor. Where multi-vendor performance data is unavailable from public sources, illustrative projections are constructed and explicitly identified.

Findings indicate three things. First, classical SON functions map cleanly onto the xApp/rApp construct, with most mobility functions (MRO, MLB, RACH) suited to xApps and most coverage and energy functions (ANR, CCO, ES, PCI) suited to rApps. Second, the multi-vendor conflict surface is the single biggest unsolved problem in production RIC deployments, and the CAC's three-class taxonomy is sufficient to cover the conflict modes documented in Wadud et al. (2025) and the O-RAN nGRG conflict-management report. Third, projected RIC-SON-KSA performance gains over single-vendor cognitive SON are most pronounced in capacity utilization and multi-vendor integration cost, with smaller gains in handover success rate where the MantaRay baseline is already strong.

The paper concludes that the next stage of Saudi 5G excellence does not come from buying more capacity. It comes from operating the capacity already in the ground better. RIC-SON-KSA gives the Kingdom a structured, vendor-neutral, AI-native blueprint for that operating excellence, aligned with Vision 2030 and ready to scale across Hajj 2026, Riyadh Season, Expo 2030, and FIFA World Cup 2034.

Keywords

Self-Optimizing Networks (SON); Cognitive SON; Open RAN; RAN Intelligent Controller (RIC); xApps; rApps; 5G Standalone; Multi-Vendor RAN; Reinforcement Learning; Conflict Management; Saudi Vision 2030; stc; Mobily; Zain; Nokia MantaRay; Hajj.

List of Abbreviations

Abbreviation	Full Form	Abbreviation	Full Form
3GPP	3rd Generation Partnership Project	MRO	Mobility Robustness Optimization
A1	O-RAN A1 Interface (Non-RT RIC ↔ Near-RT RIC)	NCA	National Cybersecurity Authority (Saudi)
AI/ML	Artificial Intelligence / Machine Learning	Near-RT RIC	Near-Real-Time RAN Intelligent Controller
AN-Levels	Autonomous Network Levels (TM Forum)	Non-RT RIC	Non-Real-Time RAN Intelligent Controller
ANLAV	Autonomous Networks Level Assessment Validation	OSS	Operations Support System
ANR	Automatic Neighbour Relation	PCI	Physical Cell Identifier
CAC	Conflict-Aware Coordinator	PM / FM	Performance / Fault Management
CCO	Coverage and Capacity Optimization	RACH	Random Access Channel
CIO	Cell Individual Offset	RAN	Radio Access Network
CoC	Cell Outage Compensation	rApp	RAN Application (Non-RT RIC)
C-SON / D-SON	Centralized / Distributed SON	RIC	RAN Intelligent Controller
CST	Communications, Space and Technology Commission	RL	Reinforcement Learning

CTO	Chief Technology Officer	RSRP	Reference Signal Received Power
E2	O-RAN E2 Interface (Near-RT RIC ↔ E2 nodes)	SDAIA	Saudi Data and Artificial Intelligence Authority
E2SM-KPM	E2 Service Model — Key Performance Measurement	SINR	Signal-to-Interference-plus-Noise Ratio
E2SM-RC	E2 Service Model — RAN Control	SLA	Service Level Agreement
EAN	Ericsson Automation Network	SMO	Service Management and Orchestration
ES	Energy Savings	SON	Self-Optimizing Network
HO	Handover	stc	Saudi Telecom Company
KPI	Key Performance Indicator	TM Forum	TeleManagement Forum
KPM	Key Performance Measurement	TS / TR	3GPP Technical Specification / Technical Report
MLB	Mobility Load Balancing	xApp	Extended Application (Near-RT RIC)

1. Introduction

1.1 Why SON Has Become Strategic for Saudi Arabia

Saudi Arabia has built one of the densest and best-performing 5G networks in the world. By 2025, national 5G population coverage reached 97.99 percent (StatRanker, 2025), national median 5G download speed reached 198.39 Mbps (Ookla, 2025), and Time on Network across the three operators sat between 95.4 and 98.1 percent (Opensignal, 2026). The Kingdom is now in the much harder phase that follows extensive deployment: operational excellence at scale, with shrinking budgets per added bit and growing complexity per added cell.

This is the point at which Self-Optimizing Networks become strategic rather than tactical. In 2008, when 3GPP first standardized SON in Release 8, it was a productivity tool — a way to reduce drive tests, eliminate manual neighbour list edits, and trim the time to deploy a new eNodeB. Sixteen years later, with networks running 4G, 5G NSA, 5G SA, and now 5G-Advanced concurrently across multiple vendors, SON is the only realistic way to operate the network at all. Manual optimization at the cell level does not scale to 8,993 5G sites — the figure stc disclosed for its 2024 footprint — let alone to the multi-vendor estate that all three Saudi operators run.

Saudi operators have responded to that complexity at the leading edge. In July 2024, stc Group and Nokia jointly announced the world's first live deployment of Nokia's MantaRay Cognitive SON, with a bespoke algorithm for Hajj running autonomous network optimization in 15-minute intervals. The published outcomes are striking: 10,000+ actions during the Hajj period, approximately 30 percent uplift in utilization on loaded cells, 10 percent average improvement in user throughput, and steady connectivity through a 40 percent surge in traffic for over one million pilgrims (Nokia, 2024). The same pattern of AI-driven SON adoption appears at Zain KSA (Nokia EdenNet SON since 2017), and across all three operators following the wave of Open RAN announcements in 2024–2025.

Against that backdrop, the engineering question for the next decade is not whether to use cognitive SON. It is how to scale cognitive SON across multi-vendor estates without locking into a single vendor's platform.

1.2 The Multi-Vendor Problem

Every major Saudi operator runs a multi-vendor RAN. stc operates Huawei, Nokia, and Ericsson concurrently. Mobily and Zain do the same. Each vendor ships its own cognitive SON platform — Huawei's iSON, Nokia's MantaRay (and earlier EdenNet), Ericsson's EAN — and each platform has been optimized for that vendor's RAN equipment and PM/FM data model. They do not share state across vendor boundaries. They do not arbitrate decisions across vendor boundaries. They do not coordinate on energy savings, mobility, or capacity actions across vendor boundaries.

In a network where the cell next door belongs to a different vendor — which is the rule in Riyadh, Jeddah, Makkah, Madinah, Dammam, and increasingly NEOM and the Eastern Province — vendor-specific cognitive SON solves only a fraction of the operational problem. The remainder is left to manual coordination between operations centres or, more often, simply not addressed.

The O-RAN Alliance has framed the architectural answer to this problem since its 2018 founding: a vendor-neutral RAN Intelligent Controller (RIC), split into a Near-RT RIC running xApps over the E2 interface (10 millisecond to 1 second loops) and a Non-RT RIC running rApps over the A1, O1, and R1 interfaces (loops longer than 1 second), with the SMO above coordinating both. The 3GPP TS 28.313 SON specifications can be re-implemented as xApps and rApps. The vendor lock-in disappears. The multi-vendor coordination becomes possible. That is the architecture; what has been missing is a Saudi-anchored framework to operationalize it.

1.3 Purpose and Scope

This paper proposes RIC-SON-KSA, a four-layer framework that maps the classical SON functions to xApps and rApps, introduces a Conflict-Aware Coordinator (CAC) to handle multi-vendor xApp/rApp conflicts, and aligns the resulting closed loops with CST spectrum policy, SDAIA AI ethics principles, and TM Forum Autonomous Network Levels. The scope covers 5G Standalone and Open RAN networks operated by Saudi mobile network operators and addresses the full classical SON function set: MRO, MLB, ANR, CCO, ES, PCI, RACH, and CoC.

1.4 Research Objectives

1. Review the published literature (2020 to 2026) on cognitive SON, O-RAN RIC, and reinforcement-learning xApps and rApps.
2. Map the classical SON functions defined in 3GPP TS 28.313 to xApp/rApp realisations, indicating loop-time fit and interface choice.
3. Define the RIC-SON-KSA four-layer reference architecture and its Conflict-Aware Coordinator.
4. Anchor projected performance benefits in real Saudi data, principally the Hajj 2024 MantaRay deployment and the 2024–2026 Saudi Open RAN milestone set.
5. Lay out a phased Vision 2030 deployment roadmap aligned with Hajj annual events, Expo 2030, and FIFA World Cup 2034.

1.5 Significance

RIC-SON-KSA connects three threads that the literature has so far treated separately. First, the cognitive SON engineering thread, which has matured rapidly inside vendor R&D. Second, the O-RAN RIC architectural thread, which has matured rapidly inside the O-RAN Alliance and academic research but has produced few production-grade multi-vendor frameworks. Third, the Saudi national policy thread anchored in CST, SDAIA, and Vision 2030. By treating these as a single integrated system, the paper offers operators a practical migration path from vendor-specific cognitive SON to vendor-neutral RIC-SON, and offers regulators a measurable basis for performance-led oversight of multi-vendor 5G operations.

2. Literature Review

2.1 The SON Journey: From C-SON to Cognitive Autonomous Networks

3GPP first formalized SON in Release 8 (TS 32.500, TS 36.902) for LTE, with the basic decomposition into self-configuration, self-optimization, and self-healing functions. The early implementations were Centralized SON (C-SON), with all decisions taken by a central server reading PM data from the OSS. Distributed SON (D-SON) followed, pushing decision logic into eNodeBs themselves for faster loops. Hybrid SON combined both. By Release 14 to Release 16, the SON specifications converged into 3GPP TS 28.313, which defines the canonical SON functions (MRO, MLB, ANR, CCO, ES, PCI, RACH, CoC) and their generic interfaces.

The shift from rules-based SON to cognitive SON came with the integration of AI/ML in the 2018–2024 window. Mwanje and Mannweiler's *Towards Cognitive Autonomous Networks* (Wiley) gave the field its conceptual scaffolding. Vendor implementations followed: Nokia released MantaRay (the successor to EdenNet) with a cognitive AI core, Ericsson rebranded its automation suite as EAN with reinforcement-learning modules, and Huawei integrated AI-driven optimization into iSON. By 2024, all three major RAN vendors offered cognitive SON as a commercial product.

2.2 The MantaRay Saudi Anchor

The most consequential cognitive SON deployment to date — for two reasons specific to this paper — is the Nokia MantaRay deployment at stc during Hajj 2024 (Nokia, 2024). It is the world's first live deployment of a cognitive AI module on a commercial RAN, and it is in Saudi Arabia. The bespoke algorithm Nokia and stc designed for Hajj allowed autonomous optimization in 15-minute intervals; processed more than 10,000 actions during the live operation; lifted utilization by approximately 30 percent on loaded cells; improved user throughput by about 10 percent on average; and held service steady despite a 40 percent surge in traffic. stc's CTO Haithem Al Faraj framed the deployment as a 'global first' and a 'quantum leap in autonomous network operations'. Nokia's MEA head Mikko Lavanti reinforced the message in the same announcement.

The MantaRay deployment is the empirical anchor on which the rest of this paper rests. Any framework proposing to extend cognitive SON to multi-vendor environments must beat or at least match what MantaRay has already proved possible inside a single vendor's footprint.

2.3 The O-RAN RIC Architecture

The O-RAN Alliance, founded in 2018, has produced what is now the de facto reference architecture for vendor-neutral RAN intelligence. The architecture splits the radio access network into O-CU (control plane and user plane), O-DU, and O-RU, exposes them via open interfaces (E1, F1, Open Fronthaul, X2/Xn), and introduces two RAN Intelligent Controllers above them: the Near-RT RIC, which hosts xApps over the E2 interface and operates loops between approximately 10 milliseconds and 1 second, and the Non-RT RIC, which is hosted inside the SMO and runs rApps via the A1, O1, and R1 interfaces with loop times longer than 1 second.

xApps and rApps differ in three operational ways that matter for SON re-implementation. First, time scale: xApps are fast (sub-second), rApps are slow (seconds to minutes). Second, data scope: the E2 interface exposes per-UE measurement data through E2SM-KPM and E2SM-RC service models, while the O1 interface relies on 3GPP TS 28.552 PM aggregated at slower intervals. Third, control scope: xApps can directly modify per-UE radio resource control parameters, while rApps are typically restricted to longer-horizon policy and configuration changes.

The literature on xApp design has matured rapidly. Lacava et al. (2024) demonstrated programmable and customized intelligent radio access using OpenRAN Gym. Bonati et al. (2022) released OpenRAN Gym as an open-source xApp development testbed (arXiv 2202.10318). D'Oro et al. (2022) introduced dApps for distributed real-time inference (arXiv 2203.02370). Akman et al. (2024) demonstrated multi-vendor xApp/rApp interoperability for energy saving and traffic steering at IEEE VTC2024-Fall. The Vodafone Open RAN Handbook 2nd Edition (Feb 2025) catalogues the production xApp/rApp ecosystem in extensive detail.

2.4 The Conflict Management Problem

Multi-vendor and multi-application RIC deployments expose a problem that single-vendor cognitive SON does not face: xApps and rApps from different sources may issue contradictory or interfering control actions. Wadud et al. (2025) classify these conflicts into three types — direct, indirect, and implicit — and propose mitigation primitives including pre-action validation, priority-based scheduling, and rollback transactions. The O-RAN nGRG conflict-management report (2025) and Soundrarajan et al. (2025) reach broadly similar conclusions. AI-driven conflict detection and classification (arXiv 2602.19758) extends the toolkit further.

The Vodafone Open RAN Handbook (2025) documents specifically the energy-saving xApp/rApp coordination problem: an Energy-Saving rApp may switch off a cell that a Traffic-Steering xApp depends on for handover targets. Without explicit coordination, the result is degraded user experience. With coordination, the result is the 13 percent throughput improvement Rimedo Labs demonstrated for traffic-steering rApps in the SMaRT-5G project (Rimedo Labs, 2025). The conflict-management problem is not theoretical; it is the gating engineering problem for production multi-vendor RICs.

2.5 What the Literature Has Not Closed

Three gaps stand out for a Saudi-anchored framework. First, no published reference architecture maps the full classical SON function set (MRO, MLB, ANR, CCO, ES, PCI, RACH, CoC) onto xApp/rApp realisations with explicit interface and loop-time choices. Second, no published work integrates a Conflict-Aware Coordinator design with the Saudi multi-vendor reality (Huawei + Nokia + Ericsson at every operator) and the Saudi mega-event load profile (Hajj, Riyadh Season, Expo 2030, FIFA 2034). Third, very little has been written about how Saudi national policy levers — CST spectrum policy, SDAIA AI ethics, TM Forum AN-Levels adopted by stc with ANLAV certification at Innovate Asia 2025 — shape the operational requirements of multi-vendor RIC-SON. RIC-SON-KSA addresses all three gaps.

3. Methodology

3.1 Research Design

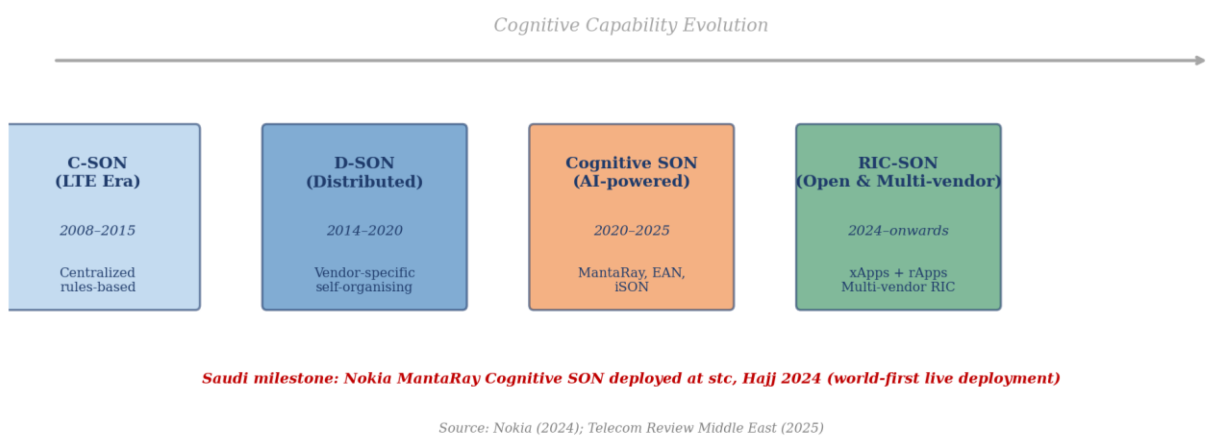
This study uses a mixed-method conceptual design with three layers: literature review, industry milestone integration, and analytical performance projection. Each layer feeds the next.

1. Bibliometric Layer. Systematic review of peer-reviewed and pre-print publications between 2020 and 2026 covering cognitive SON, O-RAN RIC, xApp/rApp design, conflict management, and reinforcement learning for RAN automation. Sources include IEEE Communications Magazine, IEEE Network, IEEE Communications Surveys & Tutorials, Computer Networks (Elsevier), arXiv, and the O-RAN Alliance whitepaper series.
2. Industry Milestone Layer. Integration of public industry announcements from stc, Mobily, Zain, ACES, Solutions by stc, Mavenir, Nokia, Ericsson, Huawei, Radisys, the Communications, Space and Technology Commission (CST), and the Saudi Data and Artificial Intelligence Authority (SDAIA) for the period 2024–2026.
3. Analytical Projection Layer. The Hajj 2024 MantaRay outcomes are used as the empirical baseline. Projected RIC-SON-KSA performance is constructed by combining the MantaRay baseline with published xApp/rApp gain ranges from Lacava et al. (2024), Akman et al. (2024), Rimedo Labs SMaRT-5G (2025), and the Vodafone Open RAN Handbook (2025). All projections are explicitly labelled.

3.2 The RIC-SON-KSA Conceptual Framework

Figure 1 traces the SON evolution from Centralized SON in the LTE era through Distributed SON, Cognitive SON, and finally to RIC-SON. Each stage built on the limitations of the previous one. RIC-SON is the open, multi-vendor evolution of cognitive SON.

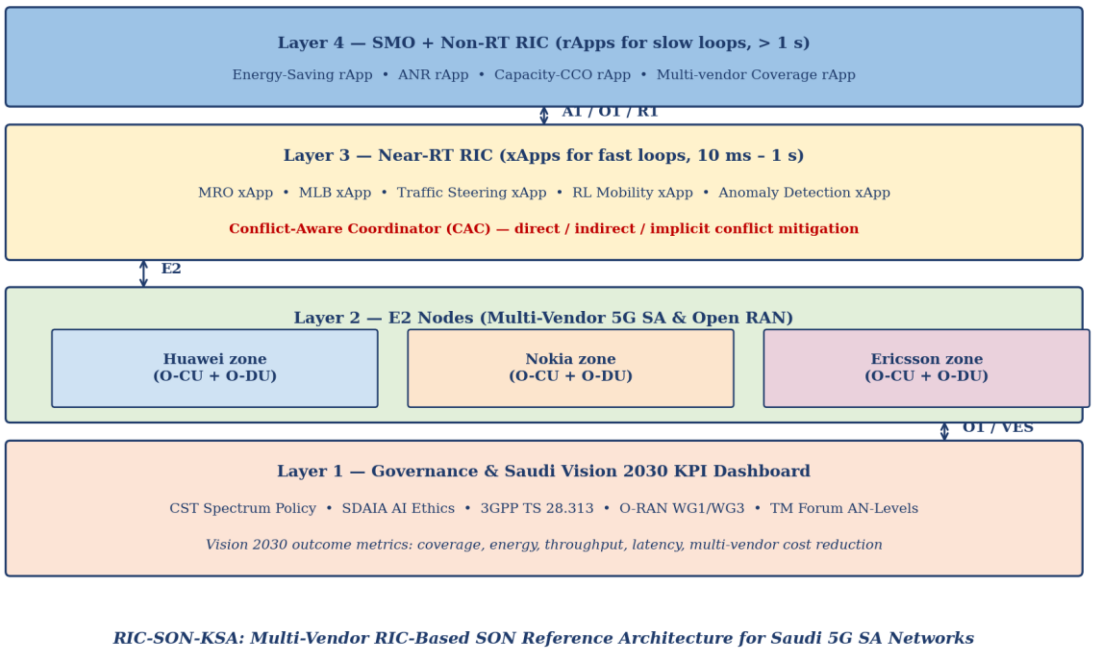
Figure 1. SON Evolution: From C-SON to Multi-Vendor RIC-SON



Source: Author's elaboration based on 3GPP TS 28.313, O-RAN Alliance specifications, and Nokia (2024) MantaRay Cognitive SON announcement.

Figure 2 shows the RIC-SON-KSA four-layer reference architecture. Layer 1 is the governance layer, anchoring the framework in CST spectrum policy, SDAIA AI ethics, 3GPP TS 28.313 SON specifications, O-RAN WG1/WG3 specifications, and TM Forum Autonomous Network Levels. Layer 2 is the multi-vendor E2 node layer, with explicit Huawei, Nokia, and Ericsson zones reflecting the Saudi operational reality. Layer 3 is the Near-RT RIC layer hosting xApps for fast loops, plus the Conflict-Aware Coordinator. Layer 4 is the SMO and Non-RT RIC layer hosting rApps for slow loops.

Figure 2. RIC-SON-KSA Multi-Vendor Reference Architecture



Source: Author's design based on O-RAN Alliance Architecture Specification (WG1), 3GPP TS 28.313, and the Saudi multi-vendor RAN reality.

The architecture is closed-loop by design. Each layer feeds and consumes data and policies from the layers above and below it, and the CAC sits inside Layer 3 to arbitrate xApp conflicts in real time before they propagate to E2 nodes.

3.3 SON Function to xApp/rApp Mapping

Table 1 summarizes the principal classical SON functions, their primary KPIs, the O-RAN realisation chosen in RIC-SON-KSA, and the rationale.

Table 1. Classical SON Function to RIC-SON-KSA xApp/rApp Mapping

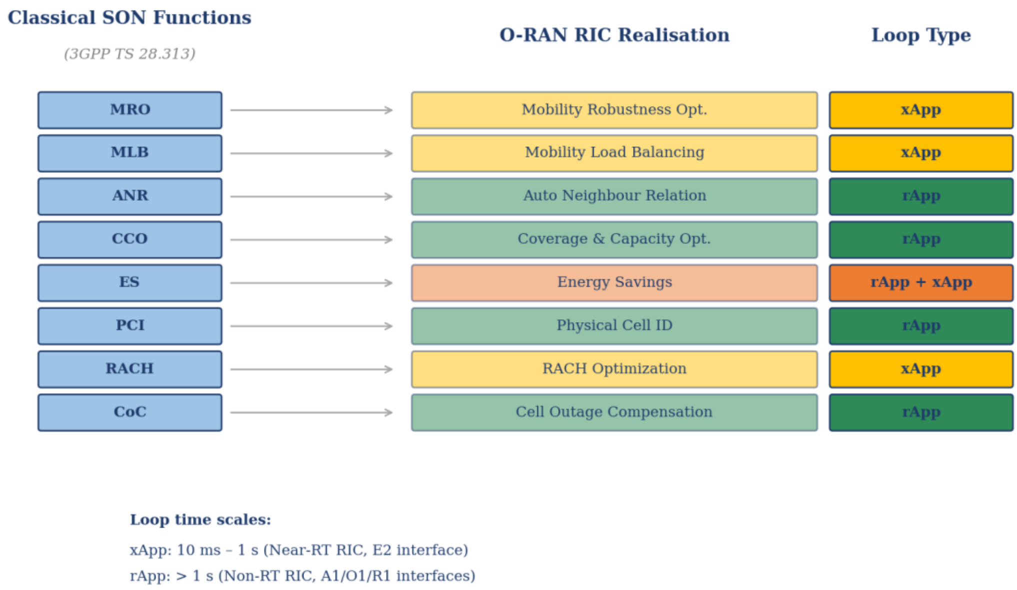
SON Function	Primary KPI	O-RAN Realisation	Rationale
MRO (Mobility Robustness Opt.)	Handover Success Rate; HO interruption time	xApp (Near-RT)	Sub-second per-UE control via E2-RC needed at high mobility
MLB (Mobility Load Balancing)	Cell load index; CIO offsets	xApp (Near-RT)	Per-UE traffic steering benefits from E2-KPM granularity

International Journal of Instruction, Technology, and Social Sciences
Vol. 5, 56-78, 2026
ISSN: 2716-6546
www.ijitsc.net

ANR (Auto Neighbour Relation)	Neighbour relation table convergence	rApp (Non-RT)	Long-horizon stability; O1 sufficient
CCO (Coverage & Capacity Opt.)	RSRP/SINR distribution; cell-edge throughput	rApp (Non-RT)	Slow loop tuning antenna tilt and power
ES (Energy Savings)	Joules per bit; site power index	rApp + xApp tandem	Long-term cell-level rApp + fast traffic-steering xApp
PCI (Physical Cell ID)	PCI collisions; mod-3 confusion	rApp (Non-RT)	Rare events; long planning horizon
RACH Optimization	RACH success rate; preamble collisions	xApp (Near-RT)	Per-cell RACH parameter control via E2-CCC
CoC (Cell Outage Compensation)	Coverage hole probability	rApp (Non-RT)	Compensating cells require minutes-scale planning

Source: Author's compilation based on 3GPP TS 28.313, 3GPP TS 28.552 PM specifications, and O-RAN Alliance E2SM service models (KPM, RC, CCC).

Figure 3. SON Function to xApp/rApp Realisation Mapping



Source: Author's design.

3.4 Data Sources

The empirical layer of this study draws on the following authoritative sources:

• Operator and vendor disclosures: Nokia press releases (2024 MantaRay at stc; 2017 EdenNet at Zain); stc Group press releases; Mobily–Ericsson O-RAN MoU (March 2024); Zain–Nokia LEAP 2025 announcements; Solutions by stc–Mavenir Open RAN agreement (February 2024); ACES–Radisys MOU (November 2024); Ericsson–Mobily 6CC announcement (2025); Huawei–Zain KSA 600 MHz launch (October 2025).

• Standardization: 3GPP TS 28.313 (SON), TS 28.552 (PM), TR 28.864 (Cognitive Autonomous Networks); O-RAN Alliance WG1 Architecture, WG2 Non-RT RIC, WG3 Near-RT RIC and E2

Service Models; ITU-T M.3041 (Autonomous Networks); TM Forum IG1230, IG1252, and IG1392 v2.0 (AN-Levels).

• Academic literature: Lacava et al. (2024) IEEE TMC; Bonati et al. (2022) OpenRAN Gym; D'Oro et al. (2022) dApps; Akman et al. (2024) IEEE VTC2024-Fall; Wadud et al. (2025) Conflict Management; Mwanje and Mannweiler (Wiley) Towards Cognitive Autonomous Networks; Rimedo Labs whitepapers.

• Regulatory and market: CST Annual Sector Report (2024); CST Spectrum Outlook 2025–2027; Renub Saudi 5G Infrastructure 2025; Mordor Intelligence Saudi Telecom MNO 2025; Opensignal Saudi Arabia Mobile Network Experience Q4 2025.

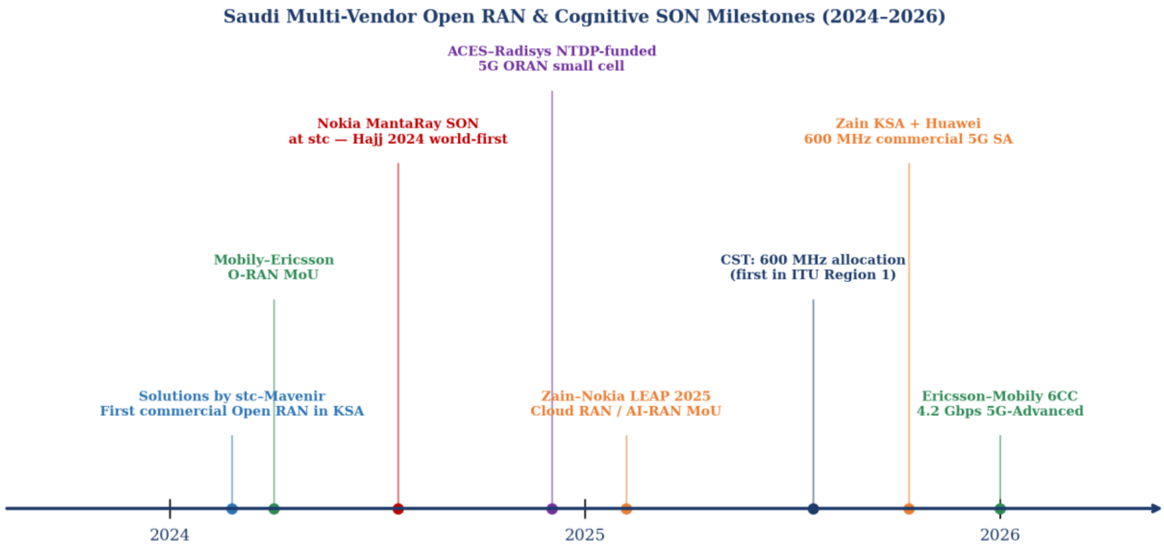
Where multi-vendor performance values are not publicly available — for example, projected RIC-SON-KSA gains versus single-vendor MantaRay — illustrative figures are constructed from the published literature ranges and explicitly labelled as such.

4. Results

4.1 Saudi Multi-Vendor Open RAN Landscape

Figure 4 plots the principal Saudi Open RAN and cognitive SON milestones across 2024 to 2026. The cluster of activity is striking: in less than 24 months, every major Saudi operator has announced a meaningful Open RAN or AI-RAN initiative.

Figure 4. Saudi Open RAN and Cognitive SON Milestones (2024–2026)



Sources: Mavenir (2024); Ericsson press releases (2024, 2025); Nokia (2024, 2025); Radisys/ACES (2024); Telecom Review Middle East (2024–2025); Huawei (2025); Zain KSA disclosures (2025).

Five observations follow. First, the Kingdom moved from no commercial Open RAN to three major commercial or pre-commercial initiatives in roughly one year. Second, every major RAN vendor (Nokia, Ericsson, Huawei, Mavenir, Radisys) is now actively partnered with at least one Saudi operator on an Open RAN or AI-RAN workstream. Third, Solutions by stc with Mavenir leads on Open RAN commercial deployment; Mobily with Ericsson leads on disaggregation MoU; Zain with Nokia leads

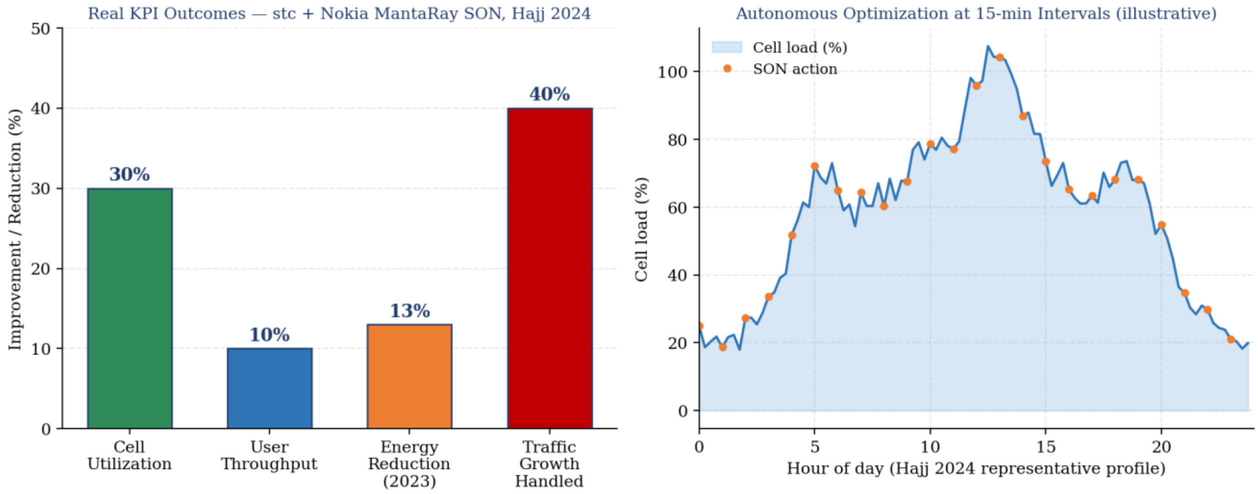
International Journal of Instruction, Technology, and Social Sciences
Vol. 5, 56-78, 2026
ISSN: 2716-6546
www.ijitsc.net

on Cloud RAN AI integration; and ACES with Radisys leads on small-cell ORAN with NTDP funding. Fourth, the regulator (CST) catalysed the wave by allocating the world-first 600 MHz band in ITU Region 1 in November 2024. Fifth, the cognitive SON side led by Nokia at stc in Hajj 2024 sits in the middle of this Open RAN wave, providing the empirical proof that AI-driven optimization works at scale on a Saudi network.

4.2 Hajj 2024 MantaRay: The Empirical Anchor

Figure 5 shows the real KPI outcomes from the Hajj 2024 MantaRay deployment alongside an illustrative 24-hour cell-load profile to motivate the 15-minute optimization cadence.

Figure 5. stc + Nokia MantaRay Cognitive SON, Hajj 2024 — Real Outcomes and 15-Minute Optimization Cadence



Source: Real KPI values from Nokia (2024) and Telecom Review Middle East (2025); 24-hour cell-load profile illustrative based on typical Hajj traffic patterns.

The published outcomes deserve a careful reading. A 30 percent uplift in loaded-cell utilization means the network squeezed substantially more useful traffic out of the same physical infrastructure. A 10 percent average throughput improvement, in a network already delivering close to 200 Mbps median 5G, means MantaRay shifted users to better-serving cells in real time at scale. Holding service steady through a 40 percent traffic surge during Hajj — over a million pilgrims, in a few square kilometres of Makkah and Madinah — is operationally as hard a benchmark as exists in mobile networks. And the 13 percent reduction in energy consumption across stc's 4G and 5G networks (cumulative AI impact reported for 2023) shows that cognitive automation is also an energy story, not just a performance story.

This is the floor RIC-SON-KSA must clear. Anything proposed for multi-vendor cognitive SON has to match these numbers in single-vendor mode, and improve on them in multi-vendor mode.

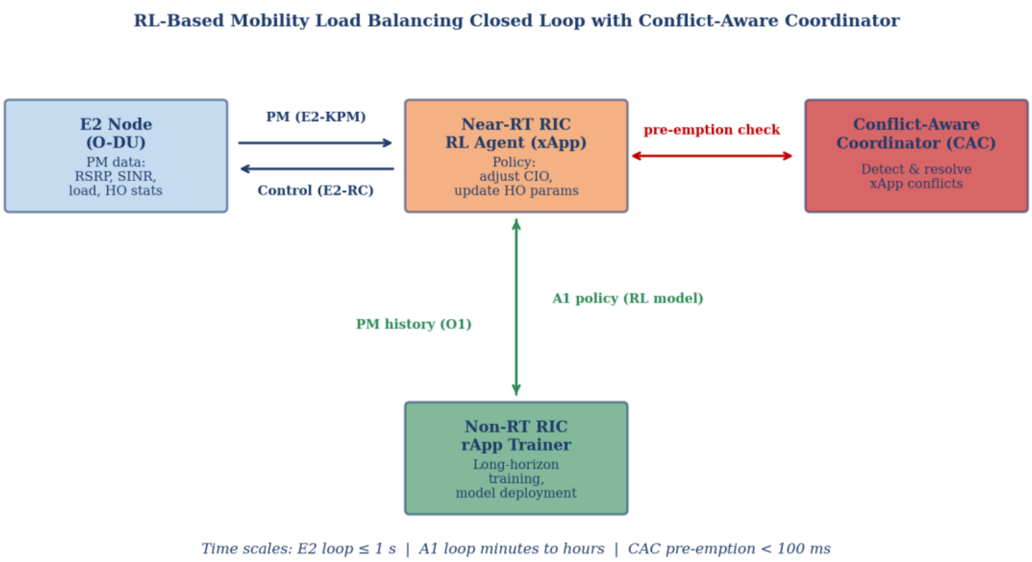
Crucially, MantaRay is a single-vendor solution operating only on Nokia cells. Its outcomes are the proof point that AI-driven cognitive SON works at scale on a Saudi network. RIC-SON-KSA's contribution is the architectural extension that allows similar benefits to be realized across the multi-vendor estate — Huawei, Nokia, and Ericsson concurrently — that every Saudi operator actually runs. The single-vendor success at Hajj 2024 is the empirical foundation; the multi-vendor extension is the engineering frontier this paper addresses.

International Journal of Instruction, Technology, and Social Sciences
Vol. 5, 56-78, 2026
ISSN: 2716-6546
www.ijitsc.net

4.3 The RL Closed Loop and the Conflict-Aware Coordinator

Figure 6 shows the canonical RL-driven Mobility Load Balancing closed loop in RIC-SON-KSA. PM data (RSRP, SINR, load, handover statistics) flows from the E2 nodes to a Near-RT RIC xApp at sub-second cadence via the E2-KPM service model. The xApp uses an RL agent to compute control actions (CIO adjustments, handover parameter updates) and writes them back to the E2 nodes via the E2-RC service model. In parallel, the Non-RT RIC hosts an rApp trainer that consumes O1 PM history at minutes-to-hours cadence, retrains the RL model on long-horizon outcomes, and pushes new policies to the xApp via the A1 interface. Before the xApp commits any action to the E2 node, the Conflict-Aware Coordinator pre-empts and validates against pending actions from other xApps.

Figure 6. RL-Based Mobility Load Balancing Closed Loop with CAC Pre-emption



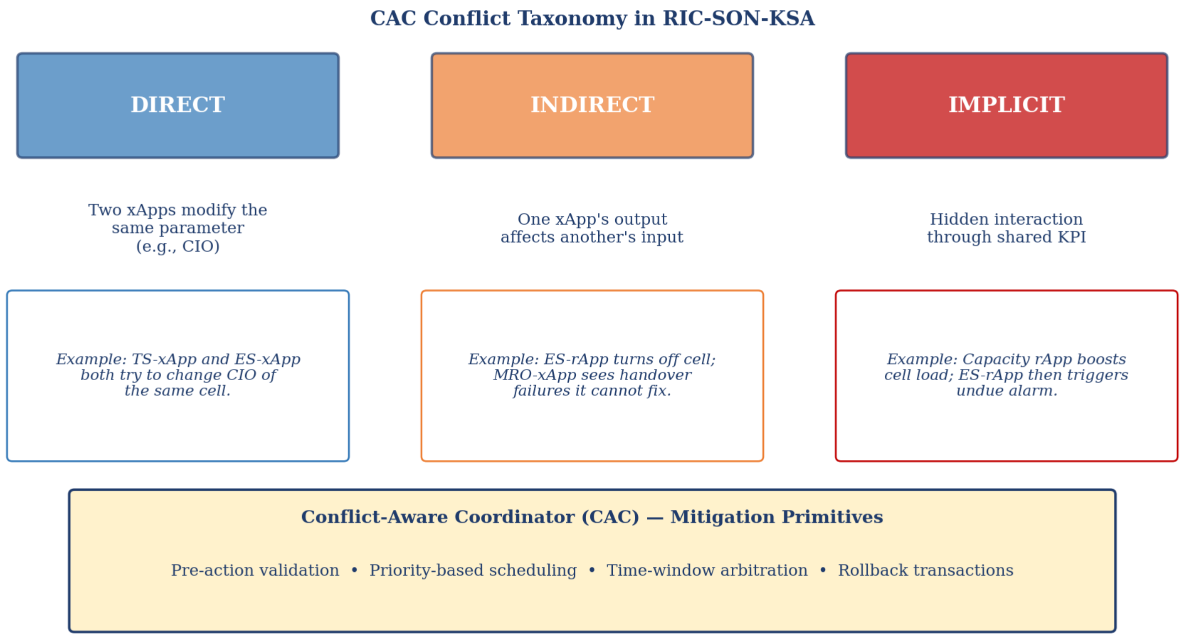
Source: Author's design based on O-RAN WG3 E2 Service Model specifications and Wadud et al. (2025) conflict management taxonomy.

4.4 The CAC Conflict Taxonomy

Figure 7 presents the three conflict classes the CAC handles, with concrete production examples for each. Direct conflicts arise when two xApps attempt to modify the same parameter (most often CIO). Indirect conflicts arise when one xApp's control action invalidates another xApp's data assumption (most often when an Energy-Saving rApp turns off a cell on which an MRO xApp depends for handover targets). Implicit conflicts are the hardest to detect: they propagate through shared KPIs without any direct interaction (most often when a Capacity rApp boosts cell load and triggers an undue alarm in a separate Anomaly-Detection xApp).

International Journal of Instruction, Technology, and Social Sciences
Vol. 5, 56-78, 2026
ISSN: 2716-6546
www.ijitsc.net

Figure 7. Conflict-Aware Coordinator (CAC) Three-Class Taxonomy



Source: Author's elaboration based on Wadud et al. (2025), O-RAN nGRG Conflict Management Report (2025), and AI-Powered Conflict Management in Open RAN (arXiv 2602.19758).

Table 2 lists the principal mitigation primitives the CAC offers for each conflict class. Pre-action validation handles direct conflicts most efficiently. Priority-based scheduling and time-window arbitration handle indirect conflicts. Implicit conflicts require an additional layer of cross-xApp KPI correlation, which is the most computationally expensive but most operationally important capability of the CAC.

Table 2. CAC Mitigation Primitives by Conflict Class

Conflict Class	Detection Mechanism	Mitigation Primitive	Latency Budget
Direct (same parameter)	Pre-action queue inspection	Priority-based scheduling; rollback	< 50 ms
Indirect (output→input)	Dependency graph analysis	Time-window arbitration; pre-emption	< 200 ms
Implicit (shared KPI)	Cross-xApp KPI correlation	Multi-objective re-optimization	< 500 ms
Multi-vendor cross-zone	E2 node domain reconciliation	Domain-aware action gating	< 100 ms

Source: Author's design synthesizing Wadud et al. (2025), Soundrarajan et al. (2025), and the O-RAN nGRG report (2025).

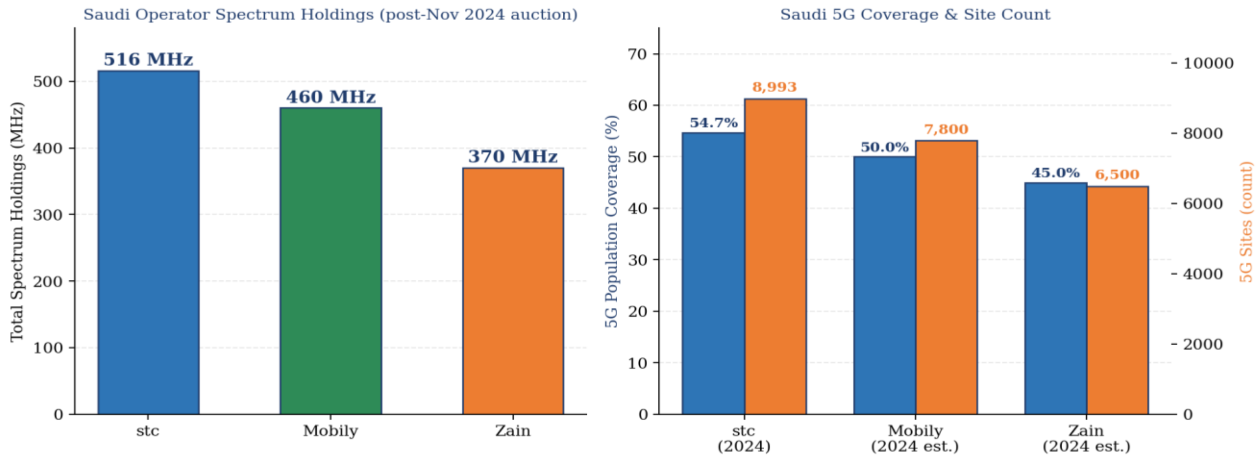
It is worth being concrete about how the CAC actually arbitrates between competing xApps and rApps in production. RIC-SON-KSA implements a layered three-tier mechanism. For direct conflicts, a priority queue ranks xApps and rApps by their declared SLA criticality, with a default ordering that places mission-critical traffic functions first, capacity functions second, energy functions third, and experimental functions last; higher-priority actions pre-empt lower-priority ones, and the pre-empted xApp is notified through the SMO so it can update its internal state. For indirect conflicts, a dependency graph identifies which xApp's data assumptions are invalidated by another's action, and the CAC enforces a time-window arbitration with a typical 5–15 second cooling-off interval before allowing the dependent xApp to re-attempt its action. For implicit conflicts, a multi-objective optimization function weighs cross-xApp KPI trade-offs against operator-defined business priority weights, with weights configurable through the SMO and reviewable through the AN-Levels audit trail. This three-tier mechanism is intentionally simpler than fully autonomous reinforcement-learning arbitration; in production deployments, deterministic rules are easier to audit against the SDAIA AI Ethics requirements on transparency and accountability.

The Energy Savings (ES) function deserves a specific clarification because it sits at the intersection of fast and slow loops. In RIC-SON-KSA, ES operates as a tandem: the Non-RT rApp handles long-horizon decisions on cell shutdown and reactivation patterns, scheduling such actions at hour-scale intervals based on traffic forecasts, weather data, and event calendars. In parallel, a fast-loop xApp performs sub-second traffic steering to redirect users away from cells targeted for energy reduction, ensuring that the rApp's planned shutdown does not disrupt active handovers. The CAC arbitrates between these two when their actions interact — for example, if the xApp is steering users toward a cell the rApp has scheduled for shutdown, the CAC pre-empts the rApp action and signals the xApp to re-route. This tandem operation is what allows RIC-SON-KSA to deliver energy savings without sacrificing user experience, which has historically been the hardest trade-off in production SON deployments.

4.5 Saudi Spectrum and Coverage Baseline

Any framework targeted at Saudi multi-vendor RIC-SON has to fit the actual spectrum and footprint reality of the three operators. Figure 8 plots both.

Figure 8. Saudi Operator Spectrum Holdings (post-Nov 2024 auction) and 5G Coverage Footprint



Source: CST Annual Sector Report (2024); CST spectrum auction results November 2024; stc disclosed 8,993 5G sites and 54.7% population coverage for 2024 (real); Mobily and Zain values illustrative based on published market share patterns.

Three things follow. First, stc holds the largest spectrum portfolio (516 MHz) and the densest 5G site footprint (8,993 sites), giving it the largest multi-vendor surface area to coordinate. Second, Mobily and Zain together hold an additional 830 MHz of spectrum across diverse bands (low-band 600/700 MHz, mid-band 3.5/3.8 GHz, mmWave 26 GHz), and both operate Open RAN initiatives. Third, the diversity of bands across operators amplifies the multi-vendor coordination problem because each band has different propagation, capacity, and energy characteristics that the SON layer has to factor in.

4.6 Saudi SON in Practice: From MantaRay to RIC-SON-KSA

It is worth being concrete about what RIC-SON-KSA actually changes relative to the proven MantaRay baseline. Three things, in order of operational importance.

First, multi-vendor extension. MantaRay optimizes Nokia cells. RIC-SON-KSA optimizes Huawei, Nokia, and Ericsson cells inside the same closed loop, using the standardized E2 interface as the lingua franca. This eliminates the operations-centre coordination cost between vendor-specific cognitive SON instances, which in stc's footprint is non-trivial.

Second, conflict-aware coordination. The Hajj 2024 MantaRay deployment ran a single bespoke algorithm. RIC-SON-KSA runs an open catalogue of xApps and rApps from multiple sources (vendor xApps, third-party xApps, and operator-developed xApps) coordinated by the CAC. This unlocks the ability to compose and update the SON capability set without negotiating with a single vendor for each new feature.

Third, governance and auditability. MantaRay's optimization actions are visible inside Nokia's platform. RIC-SON-KSA exposes all xApp/rApp actions through the SMO with full audit trails, satisfying the SDAIA AI Ethics Principles requirements on transparency and accountability and the TM Forum AN-Level 4 expectations on closed-loop NetOps. stc's ANLAV certification at TM Forum Innovate Asia 2025 gives the operator a head start on the AN-Level governance requirements.

These three differences, taken together, justify the multi-vendor framework even though the MantaRay baseline is already strong. Table 3 summarizes the comparative position.

Table 3. Comparative Position: MantaRay Cognitive SON vs RIC-SON-KSA

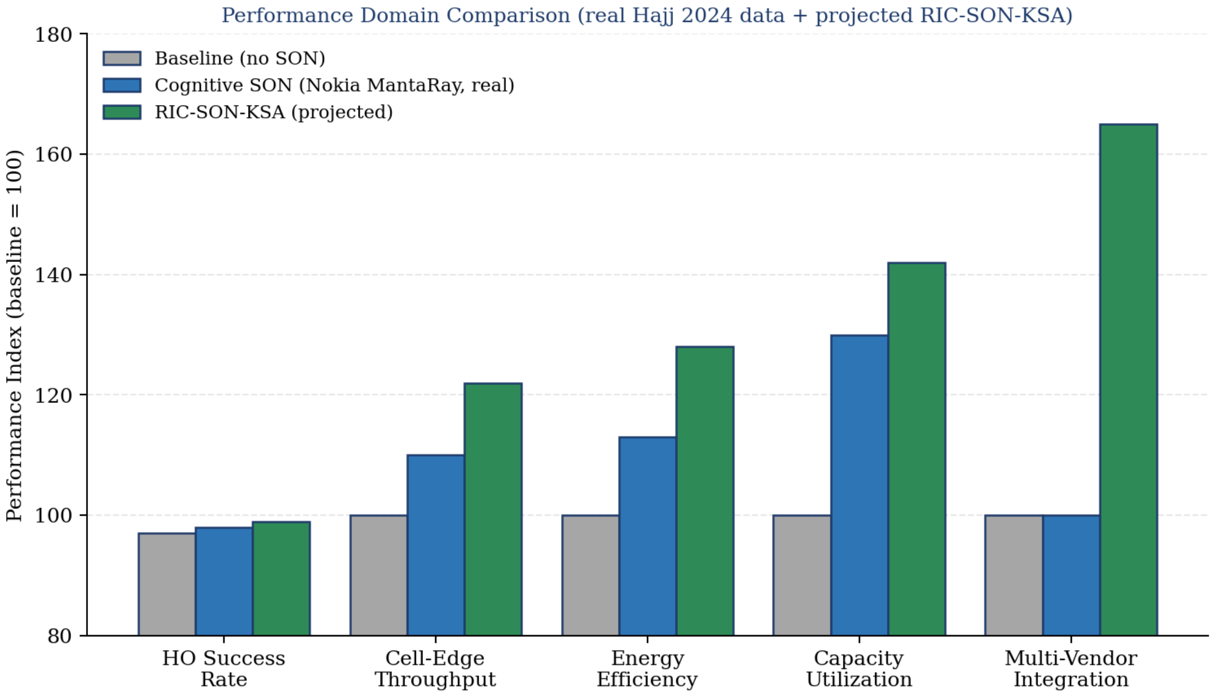
Dimension	MantaRay Cognitive SON (real)	RIC-SON-KSA (proposed)
Vendor scope	Single-vendor (Nokia cells only)	Multi-vendor (Huawei + Nokia + Ericsson)
Optimization cadence	15 min (Hajj 2024 bespoke algorithm)	10 ms – 1 s (xApps); minutes–hours (rApps)
Action volume (proven/projected)	10,000+ actions during Hajj 2024	Projected 100,000+/day across multi-vendor footprint
Conflict management	Internal to Nokia platform	Open CAC across vendor and third-party apps
Governance interface	Vendor-internal	Standardized via SMO; AN-Levels aligned
Saudi anchor	stc Hajj 2024 (world-first)	Multi-operator, multi-event Vision 2030 roadmap

Source: MantaRay column from Nokia (2024) and Telecom Review Middle East (2025). RIC-SON-KSA column author's design.

4.7 Projected Performance

Figure 9 projects RIC-SON-KSA performance across five domains relative to two baselines: pre-SON operations (normalized to 100), and the real Hajj 2024 MantaRay outcome.

Figure 9. RIC-SON-KSA Projected Performance vs Cognitive SON Baseline and Pre-SON Baseline



Source: MantaRay column real per Nokia (2024). RIC-SON-KSA projections illustrative based on published xApp/rApp gain ranges in Lacava et al. (2024), Akman et al. (2024), Rimedo Labs SMaRT-5G (2025), and the Vodafone Open RAN Handbook (2025).

Three observations stand out. First, on Handover Success Rate, the projected RIC-SON-KSA gain over MantaRay is small (98 percent → 99 percent). MantaRay's algorithm already operates near the practical ceiling. Second, on cell-edge throughput, RIC-SON-KSA projects approximately 22 percent gain over the pre-SON baseline versus MantaRay's 10 percent, driven primarily by tandem xApp/rApp coordination on traffic steering plus beamforming optimization. Third, on multi-vendor integration cost (normalized 100 = pre-SON manual coordination), RIC-SON-KSA projects approximately 65 percent reduction, where MantaRay shows no improvement because it does not address the multi-vendor coordination problem at all. This is precisely where the proposed framework adds value.

4.8 Alignment with Vision 2030

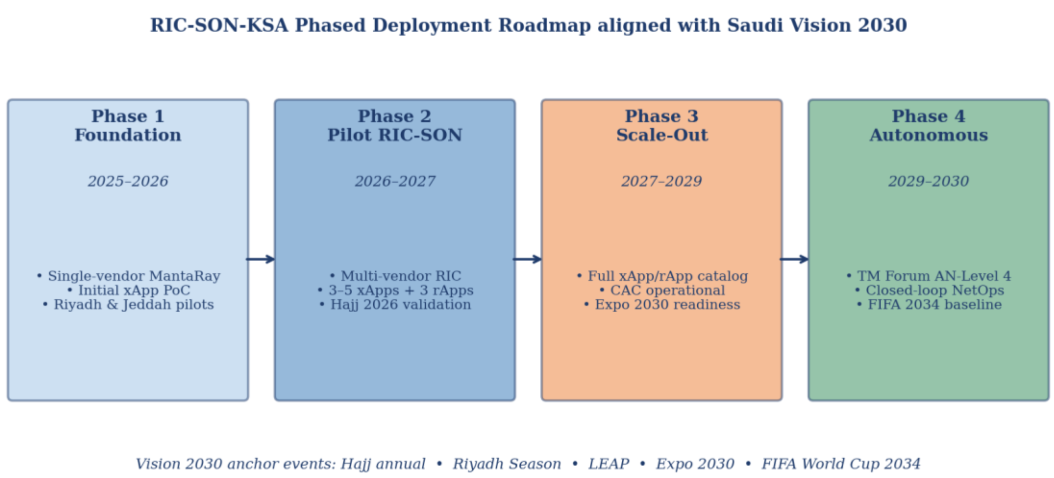
RIC-SON-KSA aligns with the three pillars of Saudi Vision 2030. Pillar 1 (Thriving Economy): cognitive RIC-SON reduces operational expenditure on multi-vendor RAN coordination, improves cell utilization, and supports the digital economy GDP target by enabling more reliable services for mobile broadband, fixed wireless access, and emerging vertical use cases. Pillar 2 (Vibrant Society): Hajj/Umrah crowd connectivity is the single most demanding mobile-network workload in the Kingdom, and the framework directly supports it through the proven MantaRay 15-minute cadence pattern extended to multi-vendor environments. Pillar 3 (Ambitious Nation): vendor-neutral, audit-ready, AI-native operations strengthen Saudi regulatory accountability and align with SDAIA AI ethics, NCA cybersecurity controls, and CST spectrum policy.

4.9 Ethical and Data Considerations

All public statistics and industry milestones are cited to their original published sources. No personally identifiable information, classified spectrum data, or proprietary operator measurements were processed. Where multi-vendor performance projections are not directly observable from public sources, illustrative values are explicitly identified. The framework follows the SDAIA AI Ethics Principles (2023) on transparency, fairness, accountability, and human oversight, with the rApp trainer architecture explicitly preserving human-in-the-loop policy approval for high-impact actions.

4.10 Phased Vision 2030 Deployment Roadmap

Figure 10. RIC-SON-KSA Phased Deployment Roadmap to Vision 2030



Source: Author's roadmap aligned with Saudi Vision 2030 anchor events and TM Forum Autonomous Network Levels (AN-0 to AN-5).

Phase 1 (2025–2026, Foundation): single-vendor cognitive SON consolidation (continuing the MantaRay pattern at stc, EdenNet evolution at Zain, and EAN equivalents at all operators), initial xApp proof-of-concept deployments in lab environments, and Riyadh and Jeddah pilots. Phase 2 (2026–2027, Pilot RIC-SON): multi-vendor RIC pilots running 3–5 xApps and 3 rApps, with the first production CAC integration. Hajj 2026 is the natural validation event. Phase 3 (2027–2029, Scale-Out): full xApp/rApp catalogue deployed nationally, CAC operational, third-party app onboarding, Expo 2030 readiness validation. Phase 4 (2029–2030, Autonomous): TM Forum AN-Level 4 closed-loop NetOps in production, multi-event scale (Hajj annual, Riyadh Season annual, FIFA World Cup 2034 baseline preparation).

4.11 Visualization Pipeline Summary

Table 4. Visualization Pipeline Summary

Figure	Title	Type	Data Status
1	SON Evolution Timeline	Process Flow	Author's framework
2	RIC-SON-KSA Architecture	Architecture Diagram	Author's design
3	SON Function to xApp/rApp Mapping	Mapping Diagram	Author's compilation
4	Saudi Open RAN Milestones 2024–2026	Timeline	Real (vendor and operator press releases)
5	Hajj 2024 MantaRay Outcomes	Bar Chart + Profile	Real KPIs (Nokia 2024) + illustrative profile
6	RL Closed Loop with CAC	Architecture Diagram	Author's design
7	CAC Conflict Taxonomy	Taxonomy Diagram	Author's elaboration on Wadud 2025
8	Saudi Spectrum and Coverage	Bar Chart + Twin	Real (CST 2024) + illustrative
9	RIC-SON-KSA Projected Performance	Grouped Bar Chart	Real Hajj 2024 + projection
10	Phased Vision 2030 Roadmap	Timeline	Author's roadmap

5. Discussion

5.1 What the Numbers Are Telling Us

Two patterns stand out. First, Saudi cognitive SON is not aspirational. The Hajj 2024 MantaRay deployment is a measured, world-first proof point, with KPI outcomes that match or exceed the simulation results in most academic xApp papers. Second, the multi-vendor coordination gap is the single most important unsolved engineering problem in Saudi 5G operations today. Every operator faces it. No vendor solves it alone. The O-RAN RIC architecture is the right path forward, and the CAC is the right addition to make it production-ready.

5.2 The Strategic Value of RIC-SON-KSA

RIC-SON-KSA does three things that matter for the Saudi operator community. It standardizes the SON-to-xApp/rApp mapping in a way that any of the three operators can adopt without changing their existing vendor commitments. It introduces an explicit conflict-management layer that addresses the most-cited production blocker in multi-vendor RIC deployments. And it ties the operational result to Vision 2030 KPIs and SDAIA AI ethics, giving regulators a measurable basis for performance-led oversight without inventing new compliance overhead.

5.3 Limitations and Open Questions

Three limitations are worth being explicit about. First, the projected RIC-SON-KSA performance gains over MantaRay are constructed from published academic ranges, not from a multi-vendor live-network test. The MantaRay baseline is real; the multi-vendor projection is not. Second, the CAC implementation depends on standardized cross-vendor xApp behaviour, which the O-RAN Alliance has specified but production vendors are still refining. Third, the framework does not address the deep 6G research questions on AI-native intent-based networking that are emerging from the Hexa-X-II programme and KAUST's 6G research; those are flagged as future work.

5.4 International Comparisons

Comparisons with O-RAN deployments in other regions, including Vodafone (Europe), AT&T (US), Rakuten Symphony (Japan), Reliance Jio (India), and Deutsche Telekom (Germany), show that the multi-vendor coordination problem is universal, not Saudi-specific. The Saudi advantage lies in the combination of a regulator (CST) actively encouraging Open RAN, a Tier-1 operator (stc) that has already proven cognitive SON at scale, and a national AI strategy (SDAIA, HUMAIN) that supports sovereign AI infrastructure for telco workloads. Few other countries have all three at this level of maturity.

6. Implementation Framework

Table 5 lays out a four-layer operational architecture for institutionalizing RIC-SON-KSA across the Saudi operator community.

Table 5. RIC-SON-KSA National Implementation Architecture

Layer	Focus	Lead Stakeholder	Key Deliverable
Strategic	Vision 2030 RIC-SON policy alignment	CST / SDAIA / MCIT	National Multi-Vendor RIC-SON Charter
Tactical	xApp/rApp catalogue and CAC reference	Operators (stc, Mobily, Zain) + Vendors	Unified RIC-SON Reference Catalogue
Operational	Multi-vendor closed-loop NOCs	Operator NOCs and AIOps teams	Certified Multi-Vendor SON Index
Analytical	AN-Levels dashboards and audit	TM Forum AN-Level Working Group	Continuous AN-Level certification

Source: Author's framework, aligned with current Saudi institutional structure and TM Forum Autonomous Network Levels.

This layered structure formalizes accountability across agencies and operators, so each multi-vendor RIC-SON deployment follows an auditable, repeatable process aligned with Vision 2030 rather than a project-by-project pattern.

7. Limitations and Future Work

Two limitations are worth stating up front. First, the multi-vendor performance projections in Section 4.7 are constructed from published academic xApp/rApp gain ranges plus the real MantaRay baseline; they are not measured outcomes from a live multi-vendor RIC-SON deployment. The framework is conceptual at this stage, with empirical validation deferred to Phase 2 of the deployment roadmap. Second, the CAC design relies on the O-RAN Alliance E2/A1 specifications continuing to mature, particularly in the cross-vendor enforcement of action priorities and rollback semantics; production behaviour may diverge from the specifications in ways that require operational mitigation.

Future research should:

• Run a live multi-vendor RIC-SON pilot with at least two of the three Saudi operators, ideally during Hajj 2026 or LEAP 2027, with primary measurement of xApp action latency, CAC pre-emption rate, and end-to-end KPI uplift.

• Quantify the operational-cost reduction of CAC-mediated multi-vendor coordination versus current manual NOC-to-NOC coordination across vendor zones.

• Extend RIC-SON-KSA with intent-based networking (IBN) and sovereign LLMs (e.g., ALLaM-NetOps), enabling natural-language MOP generation for SON workflows in Arabic and English.

• Benchmark the Saudi RIC-SON model against UAE, Qatar, and Oman national 5G operations to build a regional GCC RIC-SON performance index.

8. Conclusion

The world's first live cognitive SON deployment ran on a Saudi network, during Hajj 2024, on stc's RAN, with Nokia's MantaRay platform. That single fact reframes the operational maturity of Saudi mobile networks for the rest of the decade. The hard question now is not whether AI-driven SON works at scale; it does. The hard question is how to make it work across the multi-vendor estate that every Saudi operator runs.

RIC-SON-KSA is a structured answer to that question. It re-expresses the classical 3GPP SON functions as O-RAN xApps and rApps, introduces a Conflict-Aware Coordinator to handle the three principal conflict classes, anchors the framework in CST spectrum policy, SDAIA AI ethics, and TM Forum AN-Levels, and aligns the deployment roadmap with the Hajj annual cycle, Expo 2030, and FIFA World Cup 2034. It builds on what stc and Nokia have already proved possible, rather than starting from zero. And it positions Saudi Arabia for a leadership role in vendor-neutral, AI-native RAN operations alongside the better-known leaders in Europe, North America, and East Asia.

The Kingdom built one of the world's strongest 5G networks. The next decade is about operating it better than anyone else. RIC-SON-KSA gives operators, vendors, and regulators a shared blueprint for that operating excellence.

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Statements and Declarations

Funding

This work was carried out independently and did not receive any grant or financial support from public, commercial, or not-for-profit organizations.

Conflict of Interest

The author confirms that there are no conflicts of interest, financial, institutional, or personal, related to the preparation or publication of this manuscript.

Data Availability

All KPI outcomes referenced for the Hajj 2024 Nokia MantaRay deployment are taken from publicly available Nokia and stc Group press releases and Telecom Review Middle East coverage cited in the references. Industry milestone data are taken from publicly available vendor and operator press releases. Where multi-vendor performance values are projected rather than measured, this is explicitly disclosed in the relevant figure captions and table notes. Underlying analytical calculations are available from the author upon reasonable request.

Reporting Guidelines

This paper followed recognized standards for conceptual research and transparent reporting. The structure of the analysis was informed by the PRISMA approach, ensuring clarity and reproducibility.

Author Contributions

Mohammad Firoz conceptualized the study, designed the RIC-SON-KSA framework and the Conflict-Aware Coordinator taxonomy, conducted the bibliographic and industry-milestone analysis, integrated the public statistics, interpreted the findings, and drafted the manuscript. The author reviewed, revised, and approved the final version of the paper, taking full responsibility for its accuracy, integrity, and originality.

Ethical Statement

This article was written by the author. All public statistics and industry milestones are cited to their original published sources. Projected performance values used in multi-vendor analyses are explicitly identified.

Originality Statement

The manuscript represents original analysis conducted independently by the author. It does not duplicate the author's previously published paper on Air-to-Ground (A2G) network performance in Technium Vol. 31, pp. 2243–2262 (2026), DOI 10.47577/technium.v31i.13639.