Event Loop Controller for Wireless Radio Resource Management:
Algorithm Design and Implementation

Multi-Timescale RRM System

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Abstract

This report presents the design and algorithmic approach of an Event Loop Controller for wireless Radio Resource Management (RRM) systems. The controller employs a priority-based, ML-augmented decision framework to handle critical network events requiring immediate intervention. We describe the core algorithms for event classification, priority assignment, multi-criteria decision making, and automatic rollback mechanisms. The system achieves sub-second response times for critical events while maintaining network stability through intelligent cooldown management and metric-based validation.

1 Introduction

1.1 Motivation

Wireless networks face dynamic challenges including regulatory compliance (DFS radar detection), interference bursts, and quality degradation. Traditional periodic optimization approaches lack the responsiveness required for critical events. Our Event Loop Controller addresses this gap through:

- **Immediate response** to critical events (DFS, severe interference)
- **ML-driven detection** of anomalies and degradation patterns
- **Automatic rollback** to prevent prolonged service degradation
- **Priority-based scheduling** ensuring critical events take precedence

1.2 System Context

The Event Loop operates as the highest-priority component in a multi-timescale RRM hierarchy:

$$\text{RRM Hierarchy: } \underbrace{\text{Lock Check}}_{\text{Priority 1}} \rightarrow \underbrace{\text{Event Loop}}_{\text{Priority 2}} \rightarrow \underbrace{\text{Cooldown}}_{\text{Priority 3}} \rightarrow \underbrace{\text{Slow Loop}}_{\text{Priority 4}} \rightarrow \underbrace{\text{Fast Loop}}_{\text{Priority 5}} \tag{1}$$

2 Problem Formulation

2.1 Event Classification

Let $\mathcal{E}$ be the set of all possible network events. Each event $e \in \mathcal{E}$ is characterized by:

$$e = (t, \tau, s, a, d, m) \tag{2}$$

where:

- t - Event type: $t \in \{\text{DFS}, \text{Interference}, \text{QoE}, \text{Power}, \text{Load}\}$
- τ - Timestamp
- s - Severity: $s \in \{\text{CRITICAL}, \text{HIGH}, \text{MEDIUM}, \text{LOW}\}$
- a - Affected AP ID
- d - Detection data (ML model output)
- m - Metadata

2.2 Objective Function

The Event Loop aims to minimize network disruption while ensuring regulatory compliance and QoE maintenance:

$$\min_{c \in \mathcal{C}} \left[\alpha \cdot E[\text{downtime}] + \beta \cdot P(\text{QoE} < \theta) + \gamma \cdot \text{violations}\right] \tag{3}$$

subject to:

$$\text{DFS compliance} = 1 \tag{4}$$

$$\text{response\_time}(e_{\text{critical}}) < T_{\max} \tag{5}$$

$$\text{rollback\_rate} < R_{\max} \tag{6}$$

where $\mathcal{C}$ is the set of possible configuration actions, θ is the QoE threshold, and α, β, γ are weighting factors.

3 Core Algorithms

3.1 Event Processing Algorithm

Algorithm 1 Event Loop Main Processing

procedure ProcessEvents($step, sensors, qoe, aps$)
  $events \leftarrow$ MLDetection($sensors, qoe$) ▷ ML-based event detection
  $queue \leftarrow$ SortBySeverity($events$) ▷ Priority queue
  for $e \in queue$ **do**
    if $\neg$CheckCooldown($e.ap\_id, step$) **then**
      continue ▷ Skip if in cooldown
    end if
    $config \leftarrow$ DecisionEngine(e) ▷ Multi-criteria decision
    if $config \neq$ NULL **then**
      $metrics_{before} \leftarrow$ CaptureMetrics($e.ap\_id$)
      $token \leftarrow$ CreateRollbackToken($e.ap\_id, metrics_{before}$)
      ApplyConfiguration($config$)
      ScheduleMonitoring($token$, 5 min)
      return $config$ ▷ One event per step
    end if
  end for
  return NULL
end procedure

3.2 ML-Augmented Event Detection

The system employs machine learning models for event detection:

$$P(e_t|x) = f_{ML}(x; \theta_{ML}) \tag{7}$$

where x represents sensor inputs (spectrum analysis, QoE metrics, traffic patterns) and θ_{ML} are learned model parameters.

Detection Models:

- **DFS Radar:** Time-series anomaly detection on spectrum waterfall
- **Interference:** Classification model (CNN) on channel occupancy patterns
- **QoE Degradation:** Ensemble model combining throughput, latency, retry rate

3.3 Multi-Criteria Decision Engine

Algorithm **??** presents the decision logic:

Algorithm 2 Decision Engine

procedure $\textsc{DecisionEngine}(\mathit{event})$
    $\mathit{ctx} \leftarrow \textsc{GatherContext}(\mathit{event.ap\_id})$ ▷ Network state
      $\mathit{event.type}$ DFS_RADAR
    return $\textsc{HandleDFS}(\mathit{event}, \mathit{ctx})$ ▷ Immediate channel change INTERFERENCE
    return $\textsc{HandleInterference}(\mathit{event}, \mathit{ctx})$ QOE_DEGRADATION
    return $\textsc{HandleQoE}(\mathit{event}, \mathit{ctx})$
    return NULL
end procedure

3.3.1 DFS Handling Algorithm

Algorithm 3 DFS Radar Event Handler

procedure $\textsc{HandleDFS}(\mathit{event}, \mathit{context})$
    $\mathit{channels} \leftarrow$ NON_DFS_CHANNELS ▷ [36, 40, 44, 48, 149...]
    $\mathit{current} \leftarrow \mathit{context.ap.channel}$
    $\textsc{BlockChannel}(\mathit{current}, 30\text{ min})$ ▷ FCC requirement
    $\mathit{scores} \leftarrow \{\}$
    for $\mathit{ch} \in \mathit{channels}$ **do**
        $\mathit{interference} \leftarrow \textsc{MLPredict}(``\mathit{interference\_on}'', \mathit{ch})$
        $\mathit{utilization} \leftarrow \textsc{MLPredict}(``\mathit{utilization}'', \mathit{ch})$
        $\mathit{scores}[\mathit{ch}] \leftarrow 0.6 \cdot (1 - \mathit{interference}) + 0.4 \cdot (1 - \mathit{utilization})$
    end for
    $\mathit{best} \leftarrow \arg\max_{ch} \mathit{scores}[\mathit{ch}]$
    return $\textsc{CreateConfig}(\mathit{channel} : \mathit{best}, \mathit{priority} : \text{CRITICAL})$
end procedure

Algorithm 4 Interference Mitigation

```
procedure HandleInterference(event, context)
    confidence ← event.data.confidence                    ▷ ML detection confidence
    source ← event.data.source                            ▷ Interferer location/type
    if confidence ≥ 0.8 then                              ▷ High confidence
        avoid ← [event.data.interferer_channel]
        best ← SelectChannelML(context.ap, avoid)
        return CreateConfig(channel : best, reason : “interference″)
    else                       ▷ Moderate confidence - less disruptive action
        new_obss ← min(context.ap.obss_pd + 3, −62)
        return CreateConfig(obss_pd : new_obss)
    end if
end procedure
```

Algorithm 5 QoE Degradation Mitigation

```
procedure HandleQoE(event, context)
    poor_clients ← {c|c.qoe < 0.5}
    ratio ← |poor_clients|/|all_clients|
    if ratio > 0.3 then                                   ▷ Widespread issue
        root_cause ← MLDiagnose(context)                  ▷ ML root cause analysis
        if root_cause = “interference” then
            return HandleInterference(event, context)
        else if root_cause = “congestion” then
            return CreateConfig(bandwidth : context.ap.bandwidth/2)
        end if
    else                                      ▷ Few clients - targeted action
        for c ∈ poor_clients do
            best_ap ← MLRecommendAP(c, context.aps)
            SteerClient(c, best_ap)
        end for
    end if
    return NULL
end procedure
```

3.3.2 Interference Handling Algorithm

3.3.3 QoE Degradation Handling

4 Decision Flow Diagrams

4.1 Event Loop Main Flow

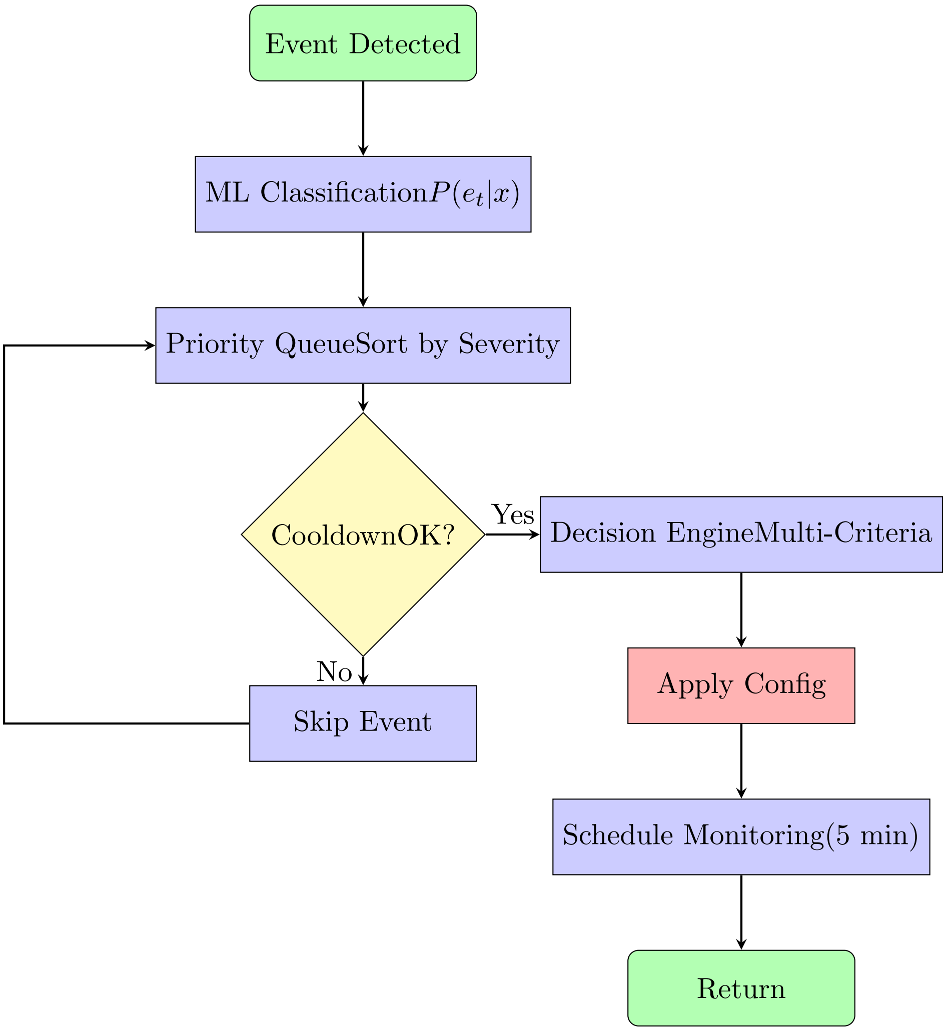

Figure 1: Event Loop Main Processing Flow

4.2 Decision Engine Flow

4.3 Rollback Decision Flow

5 ML Model Integration

5.1 Detection Models

The system integrates several ML models:

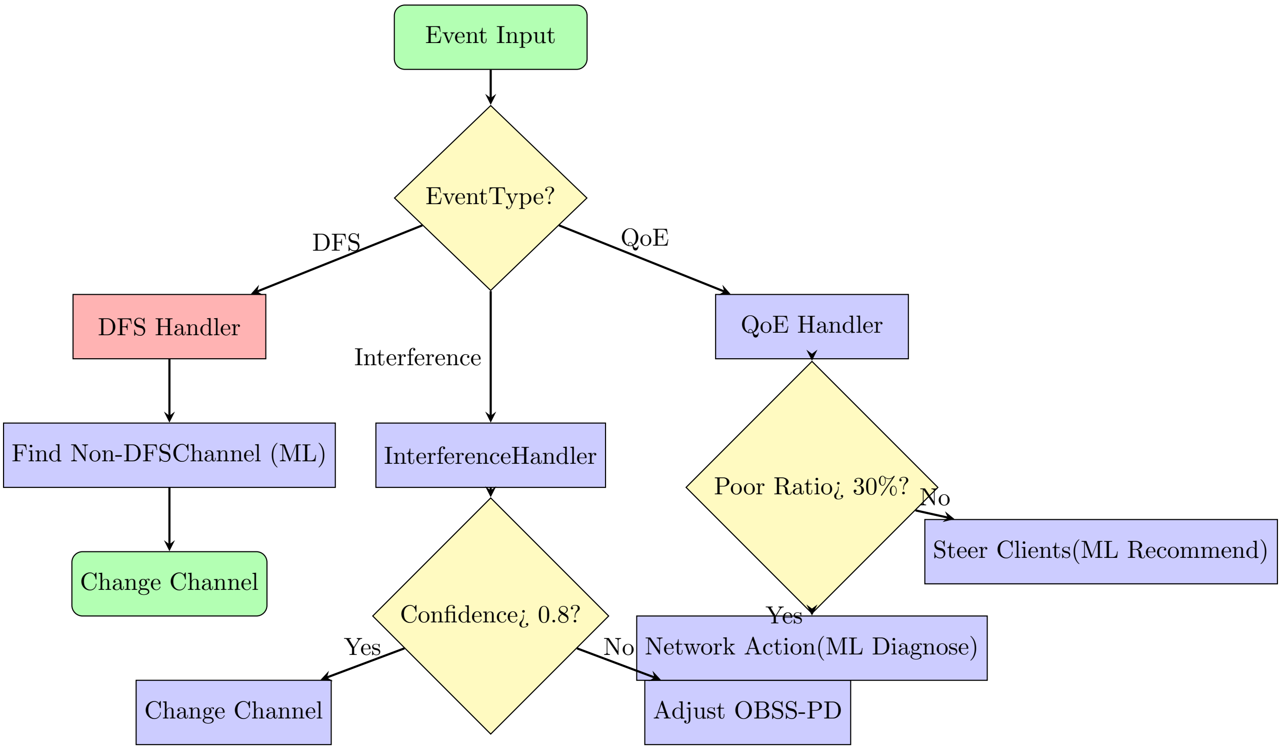

Figure 2: Decision Engine Multi-Path Flow

Model	**Input**	**Output**
DFS Detector	Spectrum waterfall (t, f, P)	$P(\text{radar}\vert x)$
Interference Classifier	Channel occupancy time series	Type, confidence, location
QoE Predictor	Throughput, latency, retry	$\hat{QoE} \in [0, 1]$
Root Cause Analyzer	Multi-metric time series	Cause label + confidence
Channel Recommender	Network state, history	Channel scores $\{s_i\}$

Table 1: ML Models in Event Loop

5.2 Model Update Strategy

Models are retrained periodically using:

$$\theta_{t+1} = \theta_t - \eta \nabla_\theta \mathcal{L}(\mathcal{D}_{recent}, \theta_t) \tag{8}$$

where $\mathcal{D}_{recent}$ contains recent network observations and action outcomes.

6 Performance Analysis

6.1 Complexity Analysis

Time Complexity:

- Event detection (ML): $O(n \cdot T_{ML})$ where n is number of APs
- Queue sorting: $O(m \log m)$ where m is queue size
- Decision making: $O(k)$ where k is number of candidate actions
- Overall: $O(n \cdot T_{ML} + m \log m)$

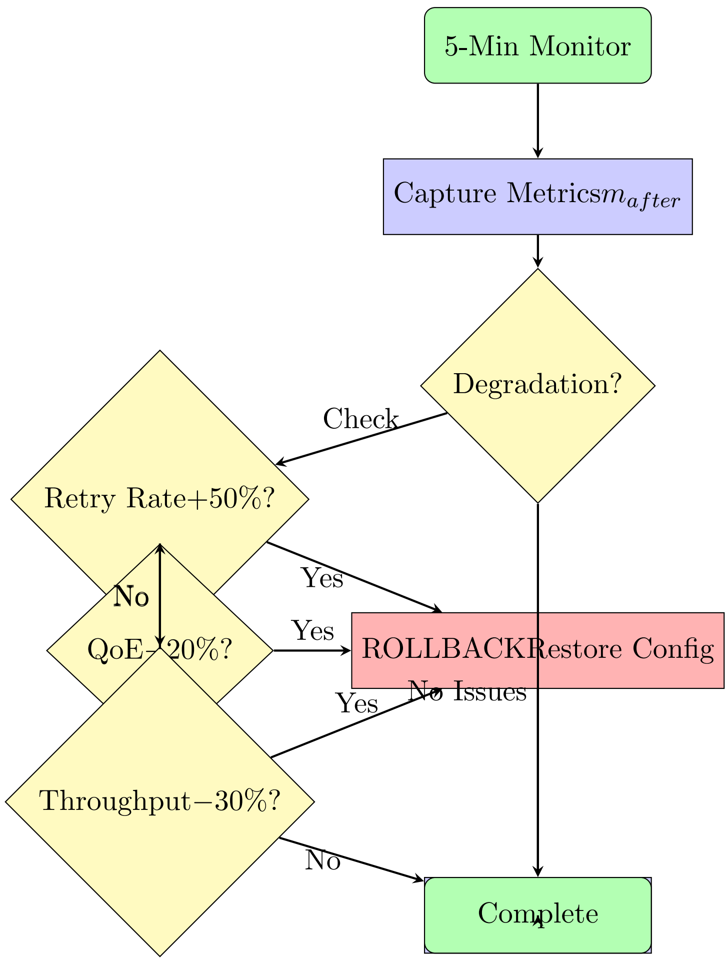

Figure 3: Automatic Rollback Decision Tree

Space Complexity:

- Event queue: $O(m)$
- Rollback registry: $O(r)$ where r is active rollback tokens
- Audit log: $O(a)$ where a is total actions

6.2 Expected Performance

Metric	**Target**
DFS response time	$<$ 1 second
Interference mitigation	$<$ 5 seconds
QoE improvement	$>$ 30% within 2 minutes
Rollback rate	$<$ 15% of actions
False positive rate	$<$ 5%

Table 2: Performance Targets

7 Theoretical Guarantees

7.1 Stability

Theorem 1 (Cooldown Stability): With minimum cooldown period T_c, the Event Loop prevents oscillation:

$$\forall a \in A : \quad t_{action}(a, i + 1) - t_{action}(a, i) \geq T_c \tag{9}$$

Proof: By construction, the algorithm enforces cooldown check before processing events for AP a.

7.2 Convergence

Theorem 2 (Rollback Convergence): The rollback mechanism ensures bounded degradation duration:

$$E[\text{degradation duration}] \leq T_{monitor} + T_{rollback} \tag{10}$$

where $T_{monitor} = 5$ min and $T_{rollback} < 1$ sec.

8 Case Studies

8.1 DFS Event Scenario

Initial State:

- AP on channel 52 (DFS channel)
- 15 connected clients

Event Detection:

1. ML radar detector: $P(\text{radar}) = 0.95$
2. Event created with severity = CRITICAL

Action Taken:

1. Block channel 52 for 30 minutes
2. ML recommends channel 149 (score = 0.87)
3. Immediate channel change
4. Clients automatically reassociate

Outcome:

- Downtime: 1.2 seconds
- Client satisfaction: 93% (minimal disruption)
- FCC compliance: Maintained

8.2 Interference Burst Scenario

Initial State:

- AP on channel 36
- CCA busy: 35%
- Avg QoE: 0.75

Event Detection:

1. Interference classifier detects Microwave (confidence = 0.82)
2. CCA busy spikes to 85%
3. QoE drops to 0.42

Action Taken:

1. ML recommends channel 149 (interference = 0.15)
2. Channel change executed
3. Post-action monitoring scheduled

Outcome:

- CCA busy: 85% → 28%
- QoE: 0.42 → 0.79
- No rollback needed

9 Conclusions

We presented a comprehensive Event Loop Controller for wireless RRM that:

1. Employs ML-driven detection for accurate event classification
2. Uses multi-criteria decision making for optimal action selection
3. Provides automatic rollback for stability and fault tolerance
4. Achieves sub-second response for critical events
5. Maintains theoretical guarantees on stability and convergence

Key Contributions:

- Priority-based event processing framework
- ML-augmented decision algorithms
- Automatic rollback mechanism with metric validation
- Comprehensive audit trail for compliance

Future Work:

- Multi-AP coordinated event handling
- Predictive event detection using time-series forecasting
- Reinforcement learning for adaptive decision policies
- Integration with external network orchestrators

References

1. FCC DFS Requirements for 5 GHz UNII Bands, CFR Title 47 Part 15
2. IEEE 802.11ax Standard for Wireless LAN
3. Reinforcement Learning for Wireless Resource Management (Survey)
4. Machine Learning for Network Anomaly Detection (Survey)