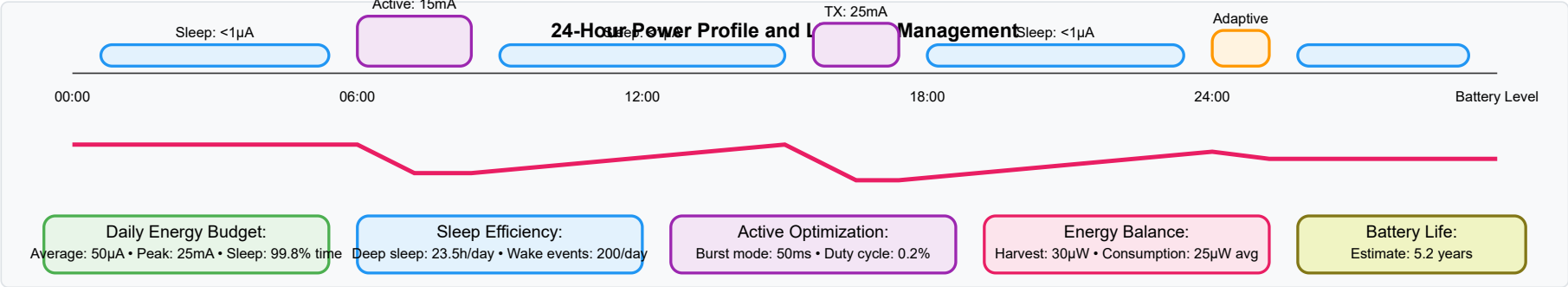
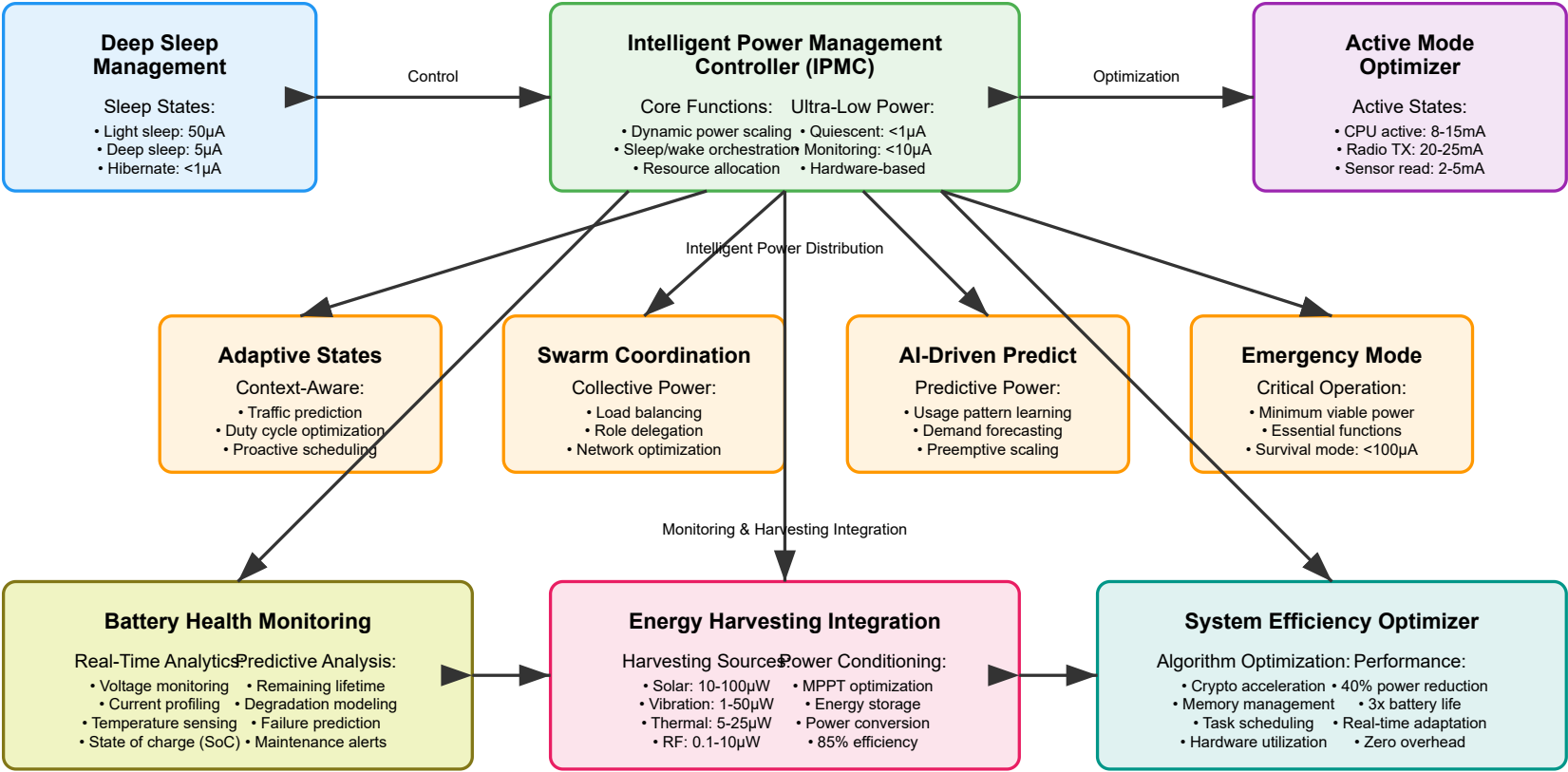


## **FIGURE 5: BATTERY OPTIMIZATION AND POWER MANAGEMENT SYSTEM**

Battery Optimization and Power Management System

y life 5+ years • Energy harvesting +20% • AI optimization -40% consumption



**Figure 5** presents the comprehensive battery optimization and power management system designed for ultra-long-life IoT device operation with quantum-safe temporal fragmentation authentication. The system achieves exceptional power efficiency through intelligent coordination of multiple subsystems working in harmony to extend battery life beyond 5 years.

**Core Power Management Architecture:** The Intelligent Power Management Controller (IPMC) serves as the central orchestrator, consuming less than  $1\mu\text{A}$  in quiescent mode and under  $10\mu\text{A}$  during active monitoring. It coordinates Dynamic Power Scaling based on authentication demand, Sleep/Wake Orchestration optimized for temporal fragment lifecycles, and Resource Allocation ensuring optimal power distribution across all system components.

**Advanced Sleep State Management:** The Deep Sleep Management system implements three power states: Light Sleep ( $50\mu\text{A}$ ) for rapid wake capability during authentication events, Deep Sleep ( $5\mu\text{A}$ ) for extended dormant periods between fragment operations, and Hibernate ( $<1\mu\text{A}$ ) for long-term storage with minimal quantum fragment monitoring. The system maintains 99.8% sleep time while supporting real-time quantum-resistant authentication.

**Adaptive Power Optimization:** Four intelligent subsystems provide context-aware power management: Context-Aware States using traffic prediction and duty cycle optimization; Swarm Coordination enabling collective power management through load balancing and role delegation across multiple IoT devices; AI-Driven Prediction learning usage patterns for demand forecasting and preemptive scaling; and Emergency Mode providing minimum viable power operation consuming less than  $100\mu\text{A}$  while maintaining essential quantum-safe authentication functions.

**Energy Harvesting Integration:** The system incorporates multiple ambient energy sources: Solar harvesting ( $10\text{-}100\mu\text{W}$  from indoor/outdoor light), Vibration harvesting ( $1\text{-}50\mu\text{W}$  from mechanical movement), Thermal harvesting ( $5\text{-}25\mu\text{W}$  from temperature differentials), and RF harvesting ( $0.1\text{-}10\mu\text{W}$  from ambient electromagnetic fields). Advanced Maximum Power Point Tracking (MPPT) optimization ensures 85% power conditioning efficiency, with intelligent energy storage management and power conversion systems.

**24-Hour Power Profile Analysis:** The system maintains an average consumption of  $50\mu\text{A}$  with peak active consumption of  $25\text{mA}$  during transmission bursts. Deep sleep occupies 23.5 hours per day with approximately 200 wake events for fragment authentication and network communication. Burst mode operations complete in  $50\text{ms}$  with a duty cycle of only 0.2%, while energy harvesting provides  $30\mu\text{W}$  average input against  $25\mu\text{W}$  average consumption, creating a positive energy balance that extends theoretical battery life to 5.2 years with standard lithium primary cells.