School of Engineering and Computer Science

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Software-Driven Adaptive Energy Management for IoT-Enabled Smart Buildings

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Problem Statement

- **IoT growth** is driving higher energy demands in smart environments like buildings and cities.
- Integrating EV charging with other IoT devices (e.g., HVAC, lighting) increases the risk of **grid overload.**
- **Real-time energy management** is crucial for balancing loads and maintaining stability.

Approach

- We developed **a software-driven IoT orchestration tool** for smart buildings to optimize energy use.
- It **coordinates** energy flows across devices like EV chargers, HVAC, and lighting using advanced algorithms.

Algorithms

Algorithm	Description	Implementation
Baseline (None)	Charges EVs based on arrival, without adapting to demand changes or priorities.	No optimization; simple time-based allocation.
Model Predictive Control (MPC)	Predicts energy demand using a control horizon; allocates energy based on forecasts.	Implemented with CVXPY; solves optimization at each time step.
Adaptive MPC (AMPC)	Dynamically adjusts control and prediction horizons based on demand variability.	Built with CVXPY; adapts to fluctuations with flexible control horizons.
Particle Swarm Optimization (PSO)	Models each charging spot as a 'particle' and iteratively finds optimal energy allocation.	Implemented with PySwarm; adjusts particle positions based on best solutions.
Fuzzy Logic (FL)	Uses fuzzy sets and rules to handle varying EV demand and data inputs.	Built with skfuzzy; defines membership functions for balanced energy allocation.

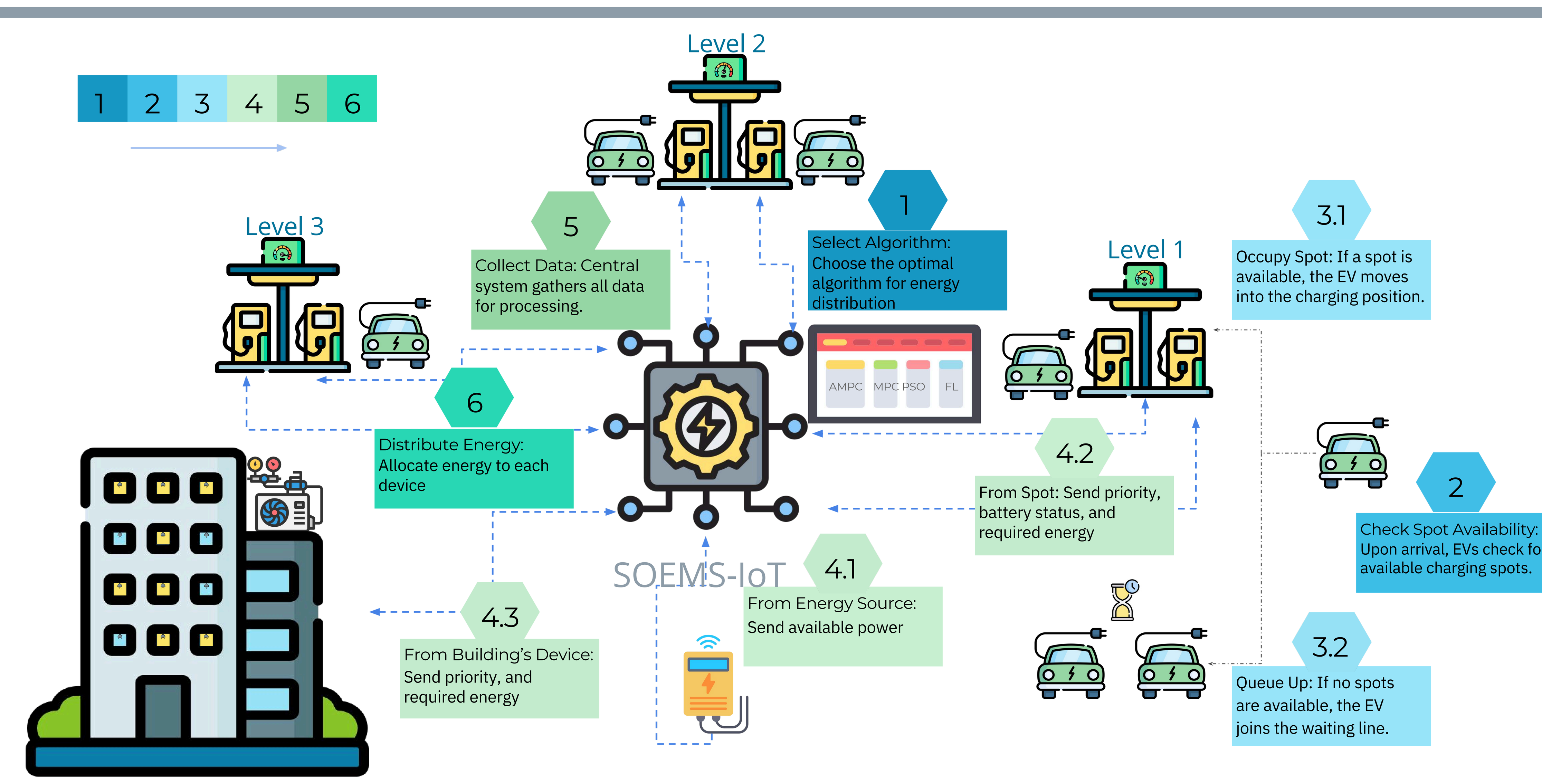
Architecture Overview

Overview:

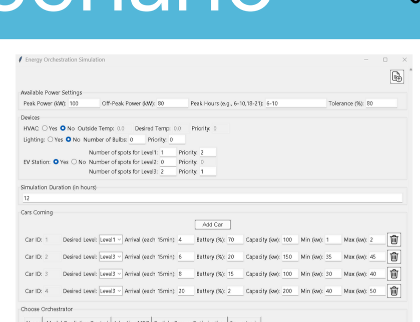
SOEMS-IoT (Software-Optimized Energy Management System for IoT) controls energy flow across IoT devices, including EV chargers and building devices.

Key Components:

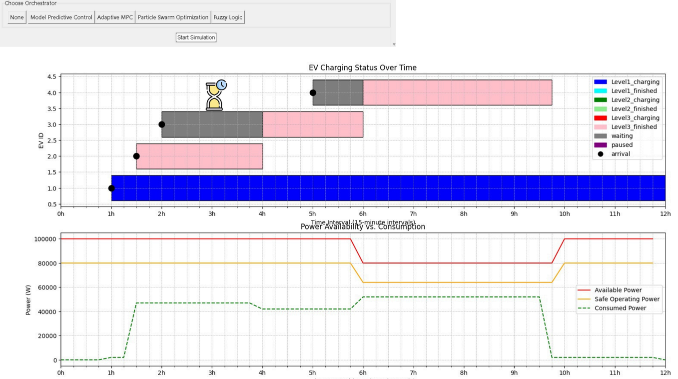
- **SOEMS-IoT:** Coordinates real-time energy distribution.
- **Data Collection:** Tracks usage and EV charging status (such as battery levels, charging rates and spot availability) for adjustments.
- **Control Algorithms**: MPC, AMPC, PSO, FL optimize energy distribution dynamically.
- **Orchestration Controller:** Applies optimization to balance supply and demand.

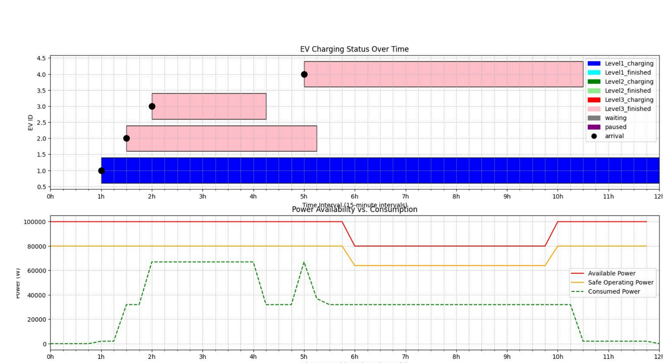


Use Case Scenario



- Simulation runs from midnight to midday.
- EV charging station has one Level 1 spot (1-2 kWh) and two Level 3 spots (30-50 kWh).
- Peak power availability is reduced from 100 kW to 80 kW between 6:00 AM and 10:00 AM.





Without Orchestration (None):

EVs start charging based on arrival, leading to delays during peak demand.

Example: EV 3 arrives at 2:00 AM but waits until 4:00 AM to charge due to a lack of dynamic power redistribution.

EV 4 arrives at 5:00 AM but waits until 6:00 AM despite an available charging spot, due to lack of power availability.

With Model Predictive Control (MPC):

MPC dynamically adjusts power distribution as EVs arrive, minimizing delays.

Example: EV 3 arrives at 2:00 AM and starts charging immediately by reallocating power from other vehicles.

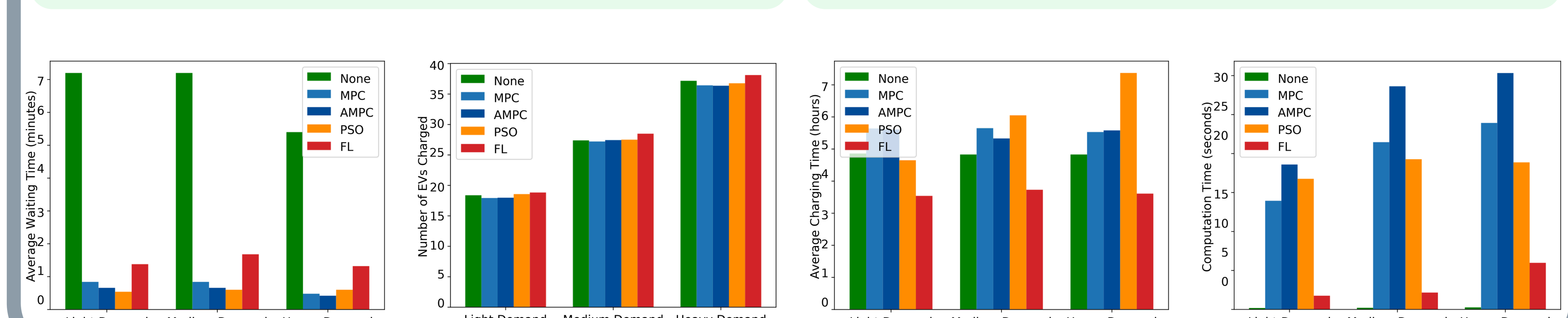
EV 4 arrives at 5:00 AM and starts charging right away, as MPC optimizes the distribution of available power.

Experiment Results

We evaluated the performance of different algorithms across three demand scenarios —Light, Medium, and Heavy.

Key metrics include average waiting time, charging time, number of EVs charged, and computation time.

- **Waiting Time:** PSO minimized waiting time under light and medium demand, while AMPC excelled in heavy demand, **reducing waiting time by 30%.**
- **Number of EVs Charged:** All algorithms performed **similarly** in terms of the number of EVs charged, but FL charges the most across all demand scenarios, especially under heavy demand.
- **Charging Time:** MPC and AMPC show stable average **charging times**, but are generally **longer** than FL and shorter than PSO in higher demand.
- **Computation Time:** FL demonstrated the lowest computation time, executing up to **80-92% faster** than other methods.



Conclusion

- Utilized a custom-built simulator to evaluate control algorithms for optimizing energy distribution under different demand scenarios.
- AMPC showed **superior performance** in high-demand scenarios, reducing waiting time while maintaining charging efficiency.
- PSO **minimized** waiting time but struggled with longer charging time during heavy demand.
- FL offered the **shortest** charging time and **lowest** computational costs, ideal for quick charging scenarios.
- Both MPC and AMPC **balanced** charging performance, but increased computational demands.