Cleveland State University

Genetic Algorithm Based Charge Optimization of Lithium-Ion Batteries in Small Satellites

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Outline

- Problem Identification
- Solution approaches
- Our strategy
  - Problem representation
  - Modified Genetic algorithm
- Results
- Conclusion and Future work

Problem Identification

How to autonomously optimize the battery state of charge while meeting the diverse requirements of all the subsystems and payloads?

Solution Approaches

- Increase the solar array size or battery size
- Have a pre-decided time multiplexed operation sequence
  - Needs a highly skilled team - time, cost
  - Reduced capability to react to unforeseen events
  - Needs frequent updates from ground station

Our Strategy

Scheduling of operations of the spacecraft

- Achieve optimum charge levels in the batteries while ensuring uninterrupted operation
- Enhance battery life so that the mission life can be extended

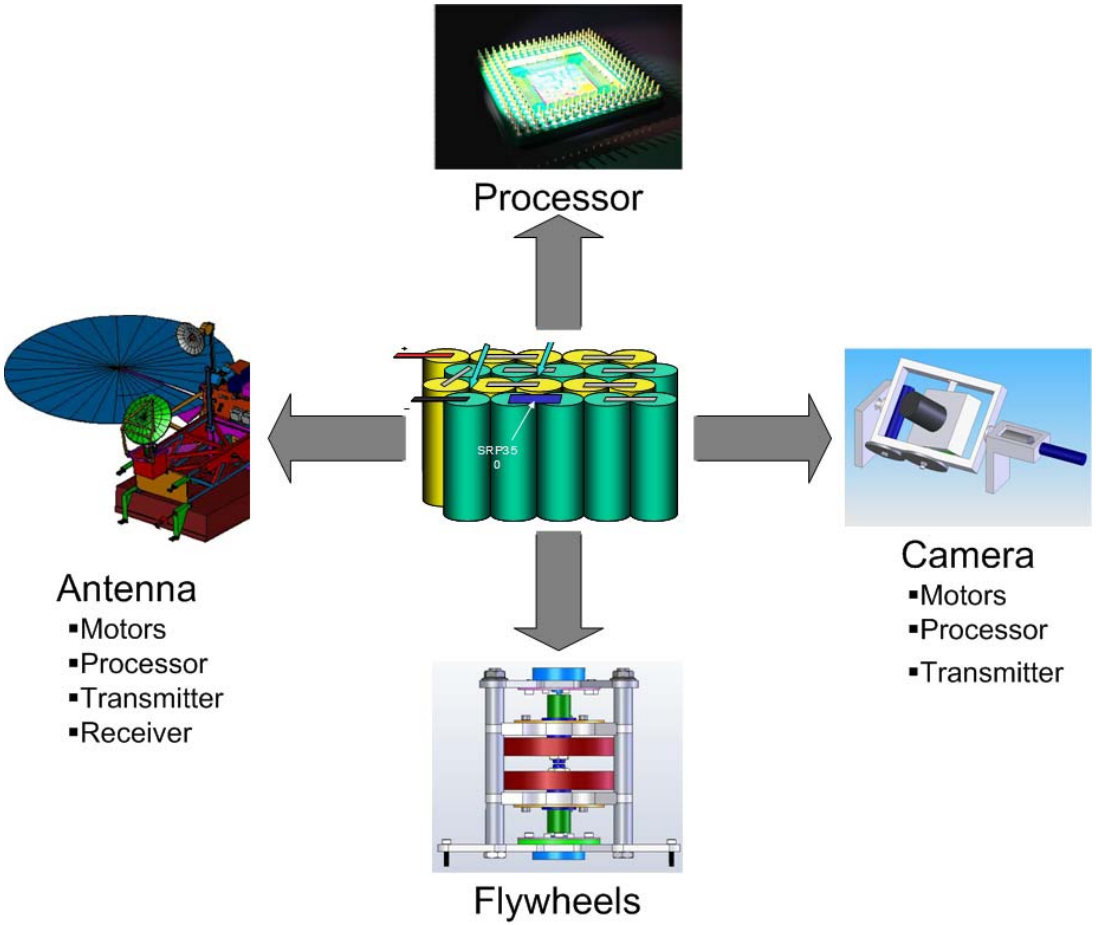
Our Strategy

Presence of an autonomous agent for scheduling operations

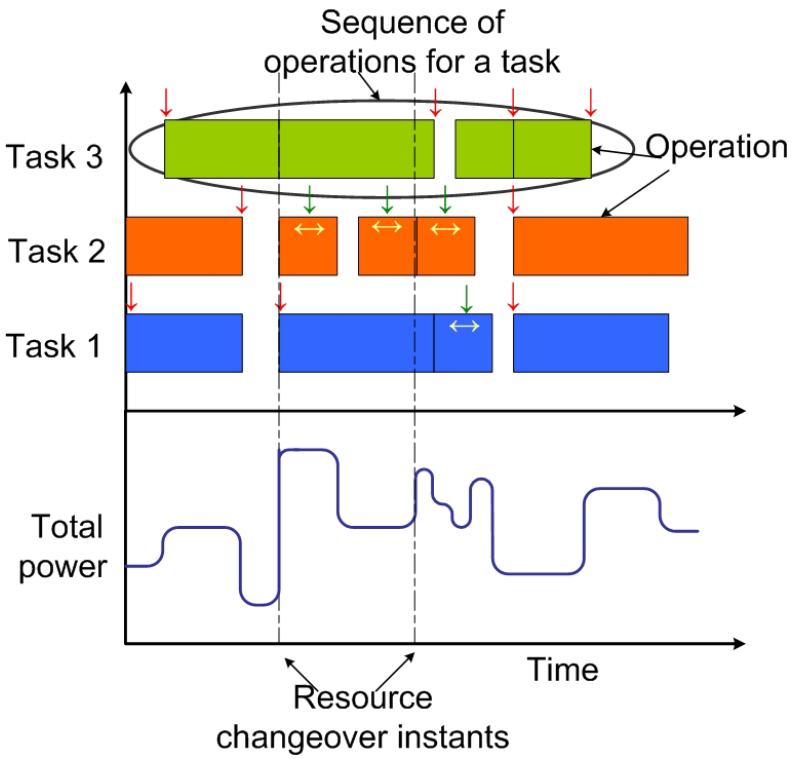
- Decides the best sequence of operations given a set of tasks
- It can be interrupted if needed or overwritten
- The sequences are generated so that the power utilization is optimum, and battery life is not compromised

Problem Representation

- The distribution system consists of load nodes
  - Nodes = power sinks
  - Nodes have power ratings
  - Nodes can be composite units
- A 'star' topology of the distribution system



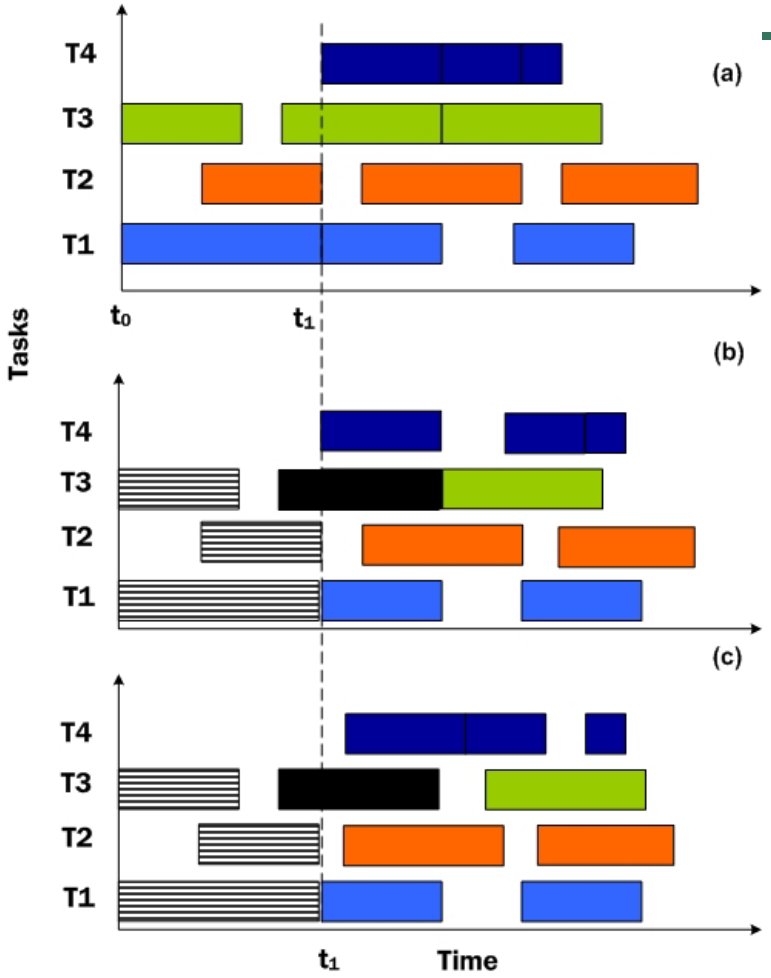
Problem Representation



- There is a set of tasks to be completed
- Each task consists of a sequence of operations
- Every operation has associated constraints
- Operation sequences are non repetitive
- To perform an operation is to activate/power up the associated node
- At any instant an operation can be associated with only one task
- Multiple tasks can have the same operation at different times

Problem Representation

- Multiple tasks can be scheduled in parallel
- Some or all of the operations of the active tasks can be scheduled at the same time

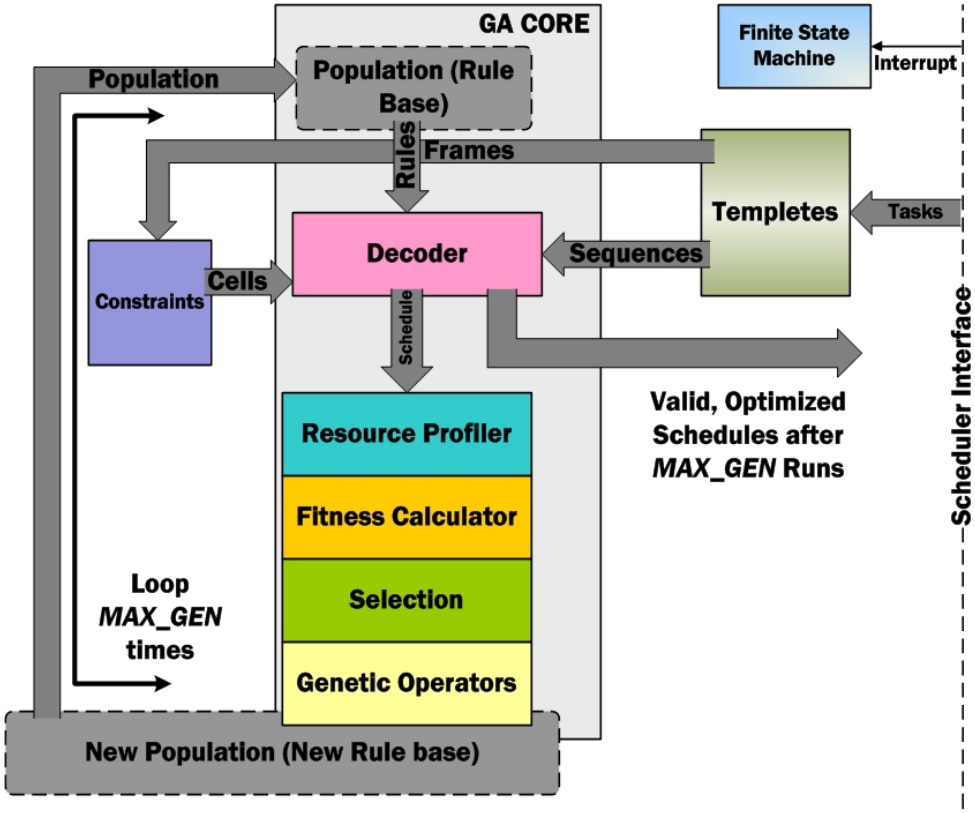


Genetic Algorithm

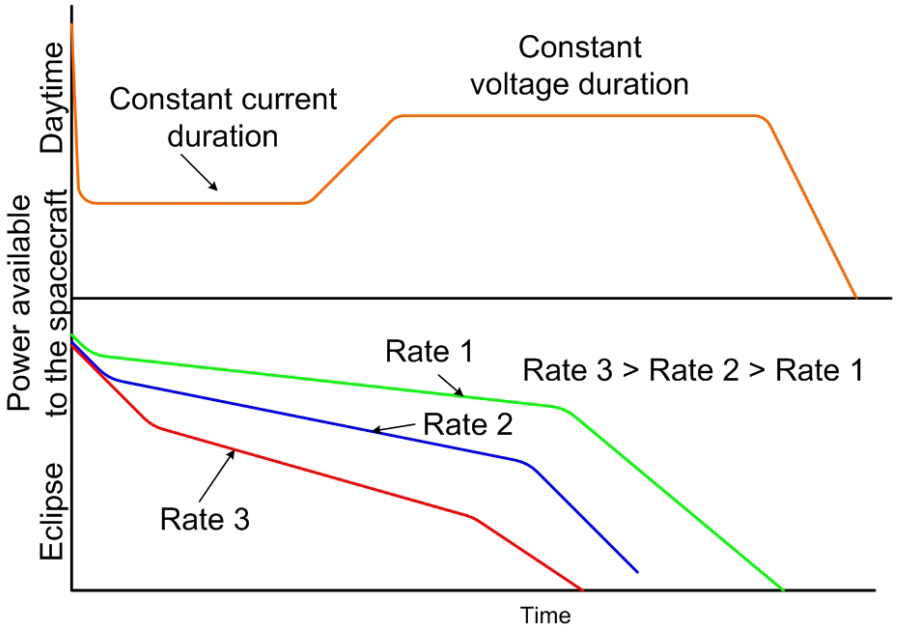
- Genetic Algorithm (GA) is an optimization method based on the mechanics of natural selection
- Good for multi-objective optimization problems
- Operates on a population of possible solutions, enhances them in successive iterations (generations) while converging towards the optimum

Modified Genetic Algorithm

- A rule base is evolved and optimized by the GA
- The rule base is then decoded to the actual schedule by a decoder
- Fixed number of GA iterations are done to generate a schedule
- Schedule processing, i.e. the operations activate the corresponding nodes



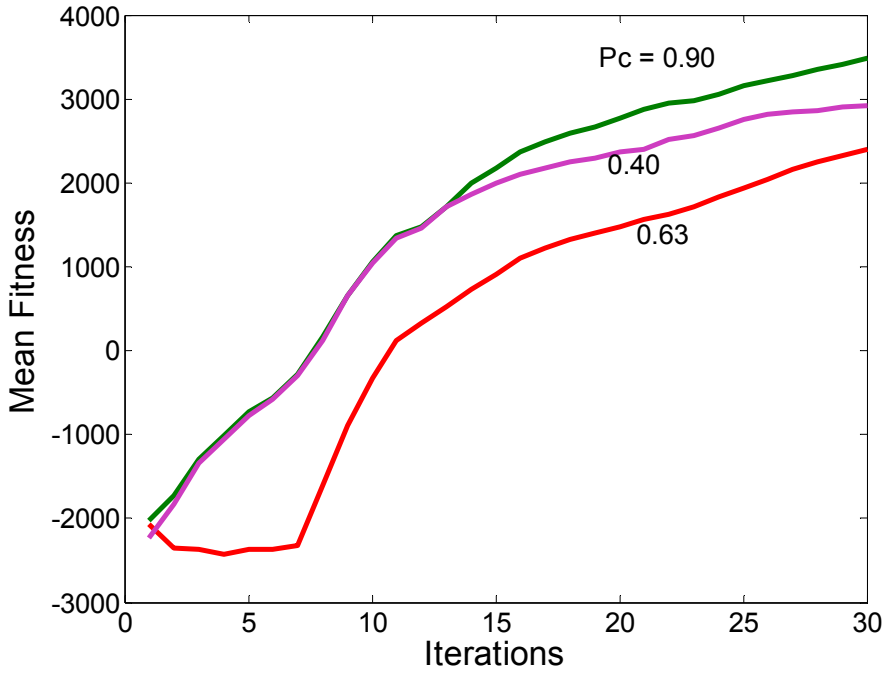
Modified Genetic Algorithm



- Different fitness functions are used for day and night
- Daytime - to achieve maximum charge and the tasks completion in minimum time
- Eclipse - to achieve minimum depth of Li-Ion battery discharge while not interrupting any other operation

Results - Matlab

Mean Fitness (slack) vs. Iteration for Eclipse Period



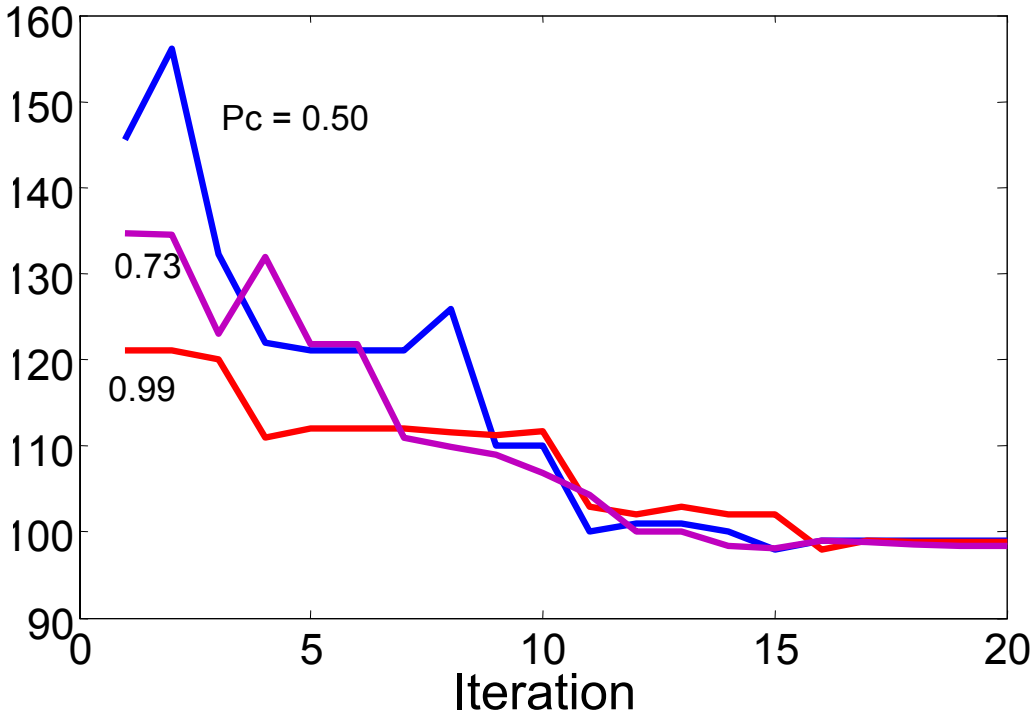
Charge remaining in the battery after all the operations are completed

POP = 20
GEN = 30

Pc = probability of crossover

Results – Matlab

Mean Cost (time) vs. Iteration for Daylight Period



Time to complete all the tasks (mean flow time)

POP = 40

GEN = 20

TIME = 92 min

Results - FPGA/VHDL

- Implementation using single precision arithmetic
- Total duration of scheduling is 20 min
- Evaluation frequency is 3.9 KHz

	Actual VHDL Output	*Theoretical Output*
Time	148.41	148.14
Time	89.09	89.09
Charge	2555.62	2555.70

Conclusions and Future Work

- The optimizer has achieved satisfactory performance
- Better tuning and longer runs of the GA can result in better solutions
- A complete hardware system test needs to be done
- Simplification of the cost function for discharging can be done by using methods like Kalman Filters
- Other satellite based applications of GAs can be
  - control algorithm tuning
  - mission planning
  - physical layout optimization
  - test plan generation

Questions

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Questions

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Backup Slides

Mathematical Definitions

Mathematical Definition of the Priority Rules Used

Priority rule		*Formula*
SPT	shortest processing time	$\min d_i$
LFT	latest finish time	$\min LFT_i$
LST	latest start time	$\min LFT_i - d_i$
MST	most total successors	$\max \left\|\overline{S}_j\right\|$
MSLK	minimum slack	$\min(due\_time - current\_time - remaining\_time)$
WRUP	weighted resource utilization and precedence	$\max 0.7\left\|S_i\right\| + 0.3r_{ie} / R_e$
FCF	first come first	First element of $\mathbf{S}_e$

Li-Ion Equations

$$\sigma = \sum_{k=0}^{n-1} I_k \left[\Delta_k + 2 \sum_{m=1}^{\infty} \frac{e^{-\beta^2 m^2 (T - t_k - \Delta_k)} - e^{-\beta^2 m^2 (T - t_k)}}{\beta^2 m^2} \right]$$

$$(\kappa = \alpha - \sigma)$$

$$\langle F \rangle = \frac{1}{J} \sum_{i=1}^{J} C_i - R_i$$