Forward Power-Train Energy Management Modeling for Assessing Benefits of Integrating Predictive Traffic Data into PHEVs

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Outline

- Introduction
- Plug-in Hybrid Electric Vehicles (PHEV) and conventional vehicle models
- Cycle optimization algorithm
- Selected Findings
- Conclusions

Introduction

- Energy is the key factor for sustainable transportation mobility
- Hybrid Electric Vehicles (HEVs), PHEVs can contribute to energy sustainability
- ITS is a pathway to this issue as well
- This paper presents an ITS-enable PHEV system that supports
  - Cycle optimization
  - Optimization in PHEV power management

Vehicle models

» PHEV

> Power-split powertrain

> Forward modeling approach

> Optimization in power management

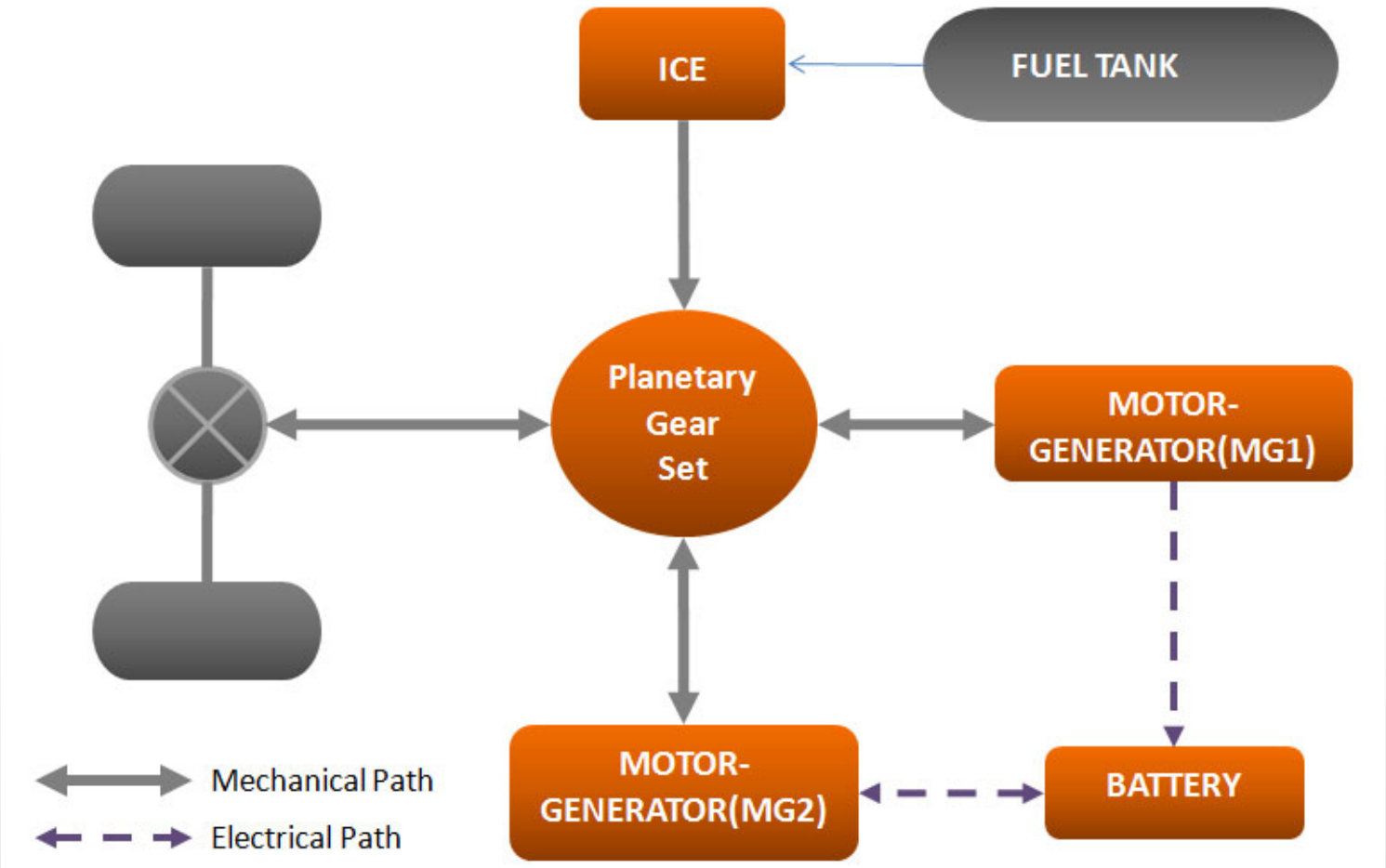
$$\dot{m}_{f,eq}(t) = \dot{m}_{f,eng}(t) + \dot{m}_{f,eq,batt}(t)$$

$$\dot{m}_{f,eq,batt}(t) = \left(S_{chg} \frac{P_{el1}(t)}{\eta_{el1,dis}(P_{el1}(t))} - S_{dis}\eta_{el2,chg}(P_{el2}(t))P_{el2}(t) \right) \frac{1}{Q_{LHV}}$$

» Conventional vehicle

All parameters are the same as PHEV except the engine power was doubled

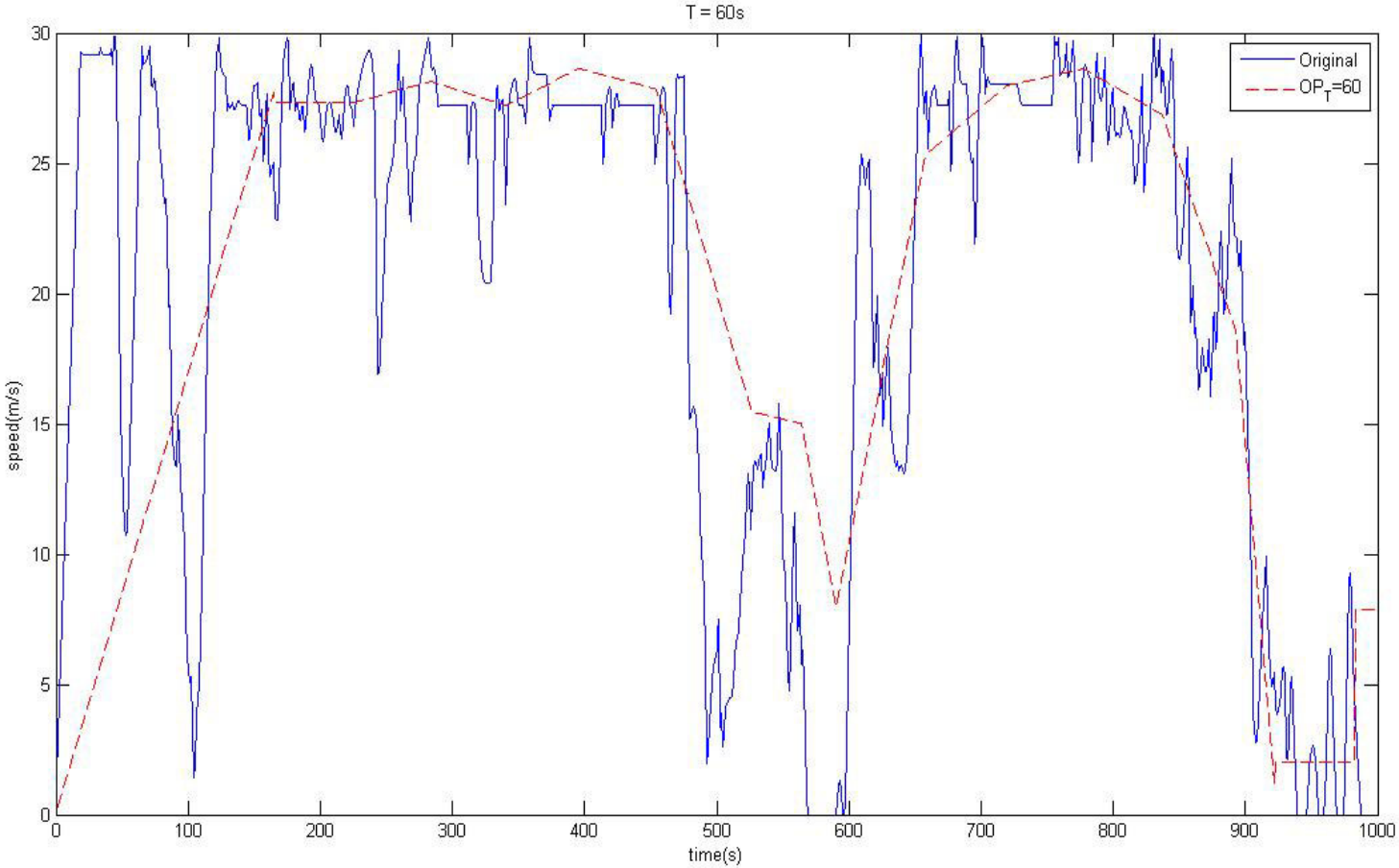
Vehicle model - PHEV



Cycle optimization algorithm

- General idea: reduce frequent acceleration / deceleration and stop-and-go behaviors
- Approach:
  - $f(t_o) = v_0$
  - $f(t_o + T) = v_p$
  - $\int_{t_0}^{t_o+T} f(t)dt = s$
  - Constant acceleration/deceleration a

Cycle optimization algorithm



Selected results – PHEV vs. Conventional

	Conv.(MPG)	PHEV(MPG)	Improvement
1	18.82	31.81	69.00%
2	17.80	59.36	233.40%
3	12.64	38.06	201.13%
4	12.75	34.20	168.14%
5	15.14	23.26	53.61%
6	10.33	24.04	132.71%
7	13.22	33.47	153.25%
8	12.45	25.99	108.73%
9	11.46	28.72	150.59%
10	8.09	21.62	167.19%
Average	**13.64**	**29.27**	**114.57%**

Cycle Optimization for Conventional Vehicles

	Original (MPG)	OP30 (MPG)	Improvement	OP60 (MPG)	Improvement	OP120 (MPG)	Improvement
1	18.82	33.36	77.23%	43.44	130.76%	44.45	136.14%
2	17.80	14.91	-16.24%	15.56	-12.59%	12.15	-31.75%
3	12.64	22.62	79.00%	23.12	82.94%	27.89	120.64%
4	12.75	19.20	50.50%	23.28	82.51%	24.49	92.01%
5	15.14	29.55	95.14%	40.12	164.98%	48.23	218.53%
6	10.33	11.58	12.08%	13.97	35.21%	14.38	39.19%
7	13.22	14.82	12.15%	14.13	6.89%	11.40	-13.77%
8	12.45	21.19	70.18%	22.74	82.60%	25.12	101.76%
9	11.46	7.60	-33.69%	7.13	-37.80%	9.61	-16.16%
10	8.09	10.24	26.59%	10.51	29.83%	9.05	11.79%
Average	**13.64**	**20.99**	**53.86%**	**24.24**	**77.70%**	**25.36**	**85.90%**

Cycle Optimization for PHEVs

	Original (MPG)	OP30 (MPG)	Improvement	OP60 (MPG)	Improvement	OP120 (MPG)	Improvement
1	31.81	64.15	101.63%	72.55	128.03%	67.02	110.65%
2	59.36	65.10	9.67%	71.31	20.12%	66.53	12.07%
3	38.06	64.99	70.77%	67.99	78.63%	59.37	55.99%
4	34.20	60.08	75.67%	55.44	62.10%	57.18	67.21%
5	23.26	61.00	162.24%	54.23	133.15%	74.69	221.13%
6	24.04	56.12	133.40%	57.33	138.44%	64.37	167.73%
7	33.47	43.43	29.75%	68.66	105.16%	35.74	6.80%
8	25.99	80.83	210.99%	70.28	170.39%	65.27	151.13%
9	28.72	49.80	73.40%	40.09	39.61%	43.12	50.15%
10	21.62	65.28	201.91%	68.05	214.71%	64.45	198.08%
Average	**29.27**	**62.93**	**114.95%**	**62.94**	**114.99%**	**63.37**	**116.46%**

Level of Network Penetration and Relative Energy Consumption

Type		ITS-enabled PHEV Penetration Rate				
		0%	1%	5%	10%	20%
ITS-enabled PHEV	Fuel(gal)	0	0.96	5.58	11.82	24.57
	Dis(mile)	0	60.98	413.11	880.91	1829.71
	MPG	--	63.32	74.03	74.54	74.48
Conv.	Fuel(gal)	510.87	507.92	487.89	461.32	410.06
	Dis(mile)	9185.97	9124.93	8772.42	8303.83	7352.31
	MPG	17.98	17.97	17.98	18.00	17.93
Total	Fuel(gal)	510.87	508.88	493.47	473.14	434.63
	Dis(mile)	9185.97	9185.91	9185.53	9184.75	9182.02
	MPG	17.98	18.05	18.61	19.41	21.13
Improvement			**0.39%**	**3.52%**	**7.86%**	**17.52%**

Conclusions

- Fuel efficiency improvement was achieved for the ITS-PHEV system on a vehicle level as well as at a network level
- Fuel consumption was reduced by half for ITS-enabled PHEVs with a cycle optimization strategy that utilizes real time traffic data
- The cycle optimization strategy can be further explored for
  - Acceleration/deceleration profiles
  - Other types of vehicles
  - Influence of driving behavior in the network

Thank you