Reducing Charge Redistribution Loss for Supercapacitor-Operated Energy Harvesting Wireless Sensor Nodes

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Outlines

- Research Background
- Charge Redistribution of Supercapacitor
- Impact of Charge Redistribution on PW in WSN
- New PM algorithms to Reduce Charge Redistribution Loss
- Conclusions & Future work

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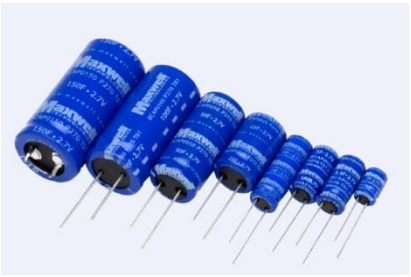
Background

Energy Harvester

Energy Storage Device



More than 500,000 life cycles

High Power Density

High charging/discharging efficiency

Low Energy Density

Self discharge

Charge Redistribution

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Motivation

- How to better use SC in harvesting aware WSN?

Previous Literatures:

Empirical SC Model

Leakage Power

Our Research:

Variant Leakage Resistance(VLR) Model

Charge Redistribution Loss

Propose new PM algorithm to reduce Charge Redistribution Loss

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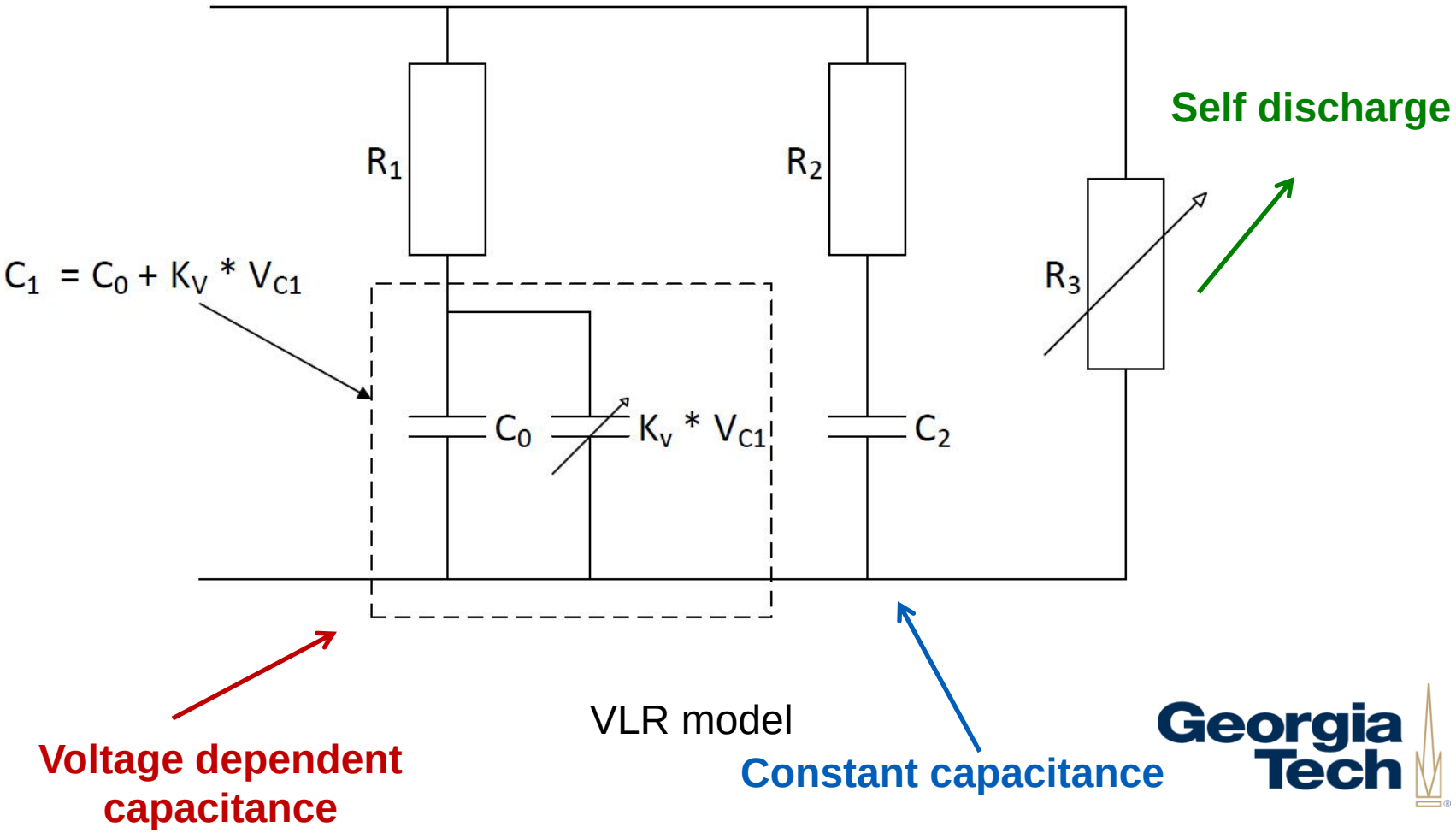
Charge Redistribution of SC

- VLR----a simplified SC equivalent circuit model



VLR parameters for different size of SC

Capacitance(F)	Manufacturer	V_{nom}(V)	VLR Parameters				
			$R_1(\Omega)$	C_0(F)	K_v(F/V)	$R_2(\Omega)$	C_0(F)
10	Maxwell	2.7	0.067	7.278	2.136	139.340	1.914
50	Maxwell	2.7	0.014	35.193	13.773	33.760	11.850

For 10 F SC:

$$R_3 = \begin{cases} (-2.969 * V_{SC} + 8.043) * 10^6 & 2.68 \le V_{SC} \le 2.7 \\ (-5.515 * V_{SC} + 14.87) * 10^6 & 2.662 \le V_{SC} < 2.68 \\ (-5.821 * V_{SC} + 15.66) * 10^6 & 0 \le V_{SC} < 2.662 \end{cases}$$

For 50 F SC:

$$R_3 = \begin{cases} (-1.942 * V_{SC} + 5.291) * 10^6 & 2.666 \le V_{SC} \le 2.7 \\ (-2.340 * V_{SC} + 6.354) * 10^6 & 2.625 \le V_{SC} < 2.666 \\ (-3.656 * V_{SC} + 9.566) * 10^6 & 0 \le V_{SC} < 2.625 \end{cases}$$

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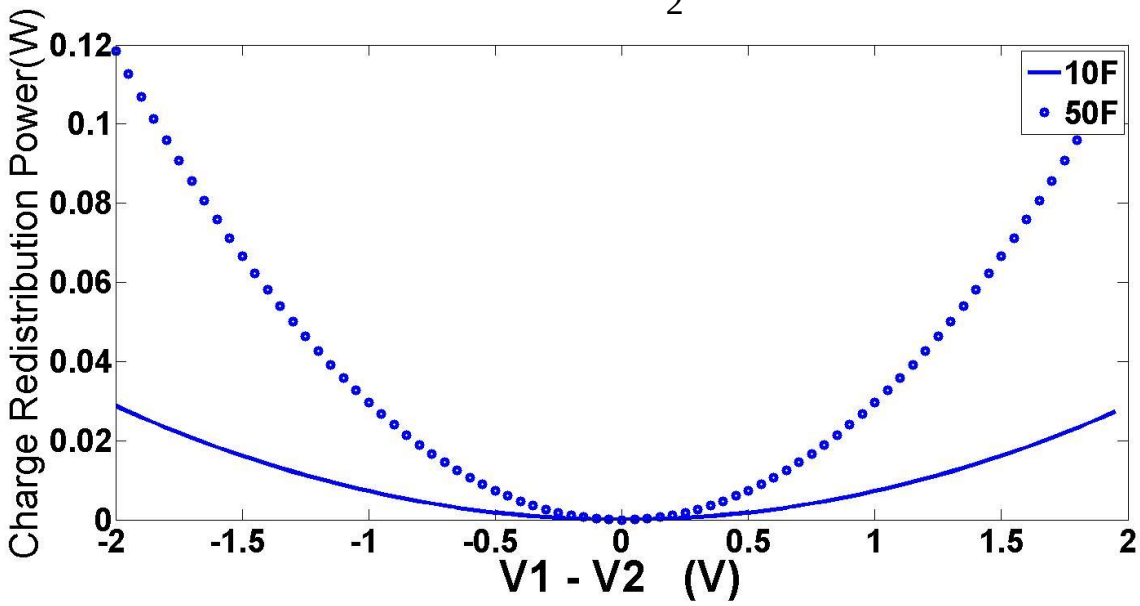
Charge redistribution

- When V_{C_1} and V_{C_2} unbalances with each other, the charges stored in the SC begin to migrate from the high voltage branch to the lower one.

$$P_{chd} = \frac{(V_{C_1} - V_{C_2})^2}{R_2}$$



Larger SC tends to have smaller R_2, which causes higher charge redistribution loss with the same voltage difference

Charge redistribution power of different sizes of SC

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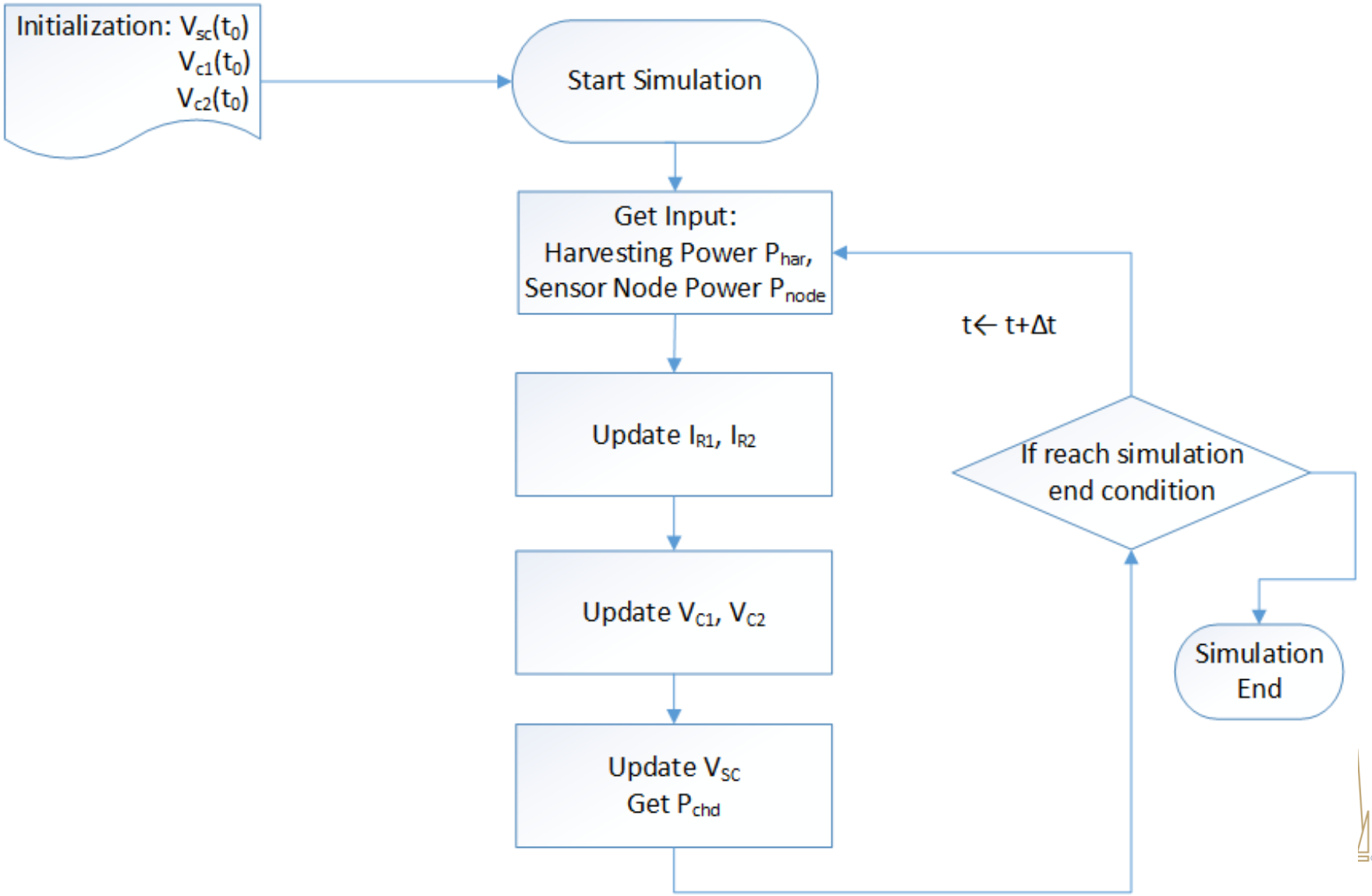
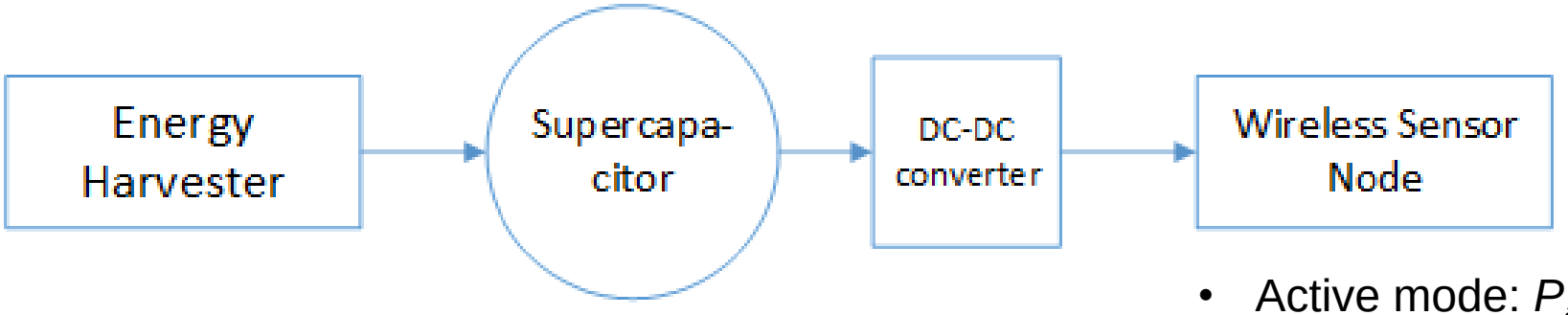
Long Term SC charge redistribution

- Algorithm 1: VLR based SC Simulation



Simulation Configuration

- EH-WSN with Supercapacitor



- Pulse-wised harvester profile

$$\overline{P_{har}} * T = \sum_{i=1}^{K} P_i * t_{di}$$

- Boost DC-DC converter

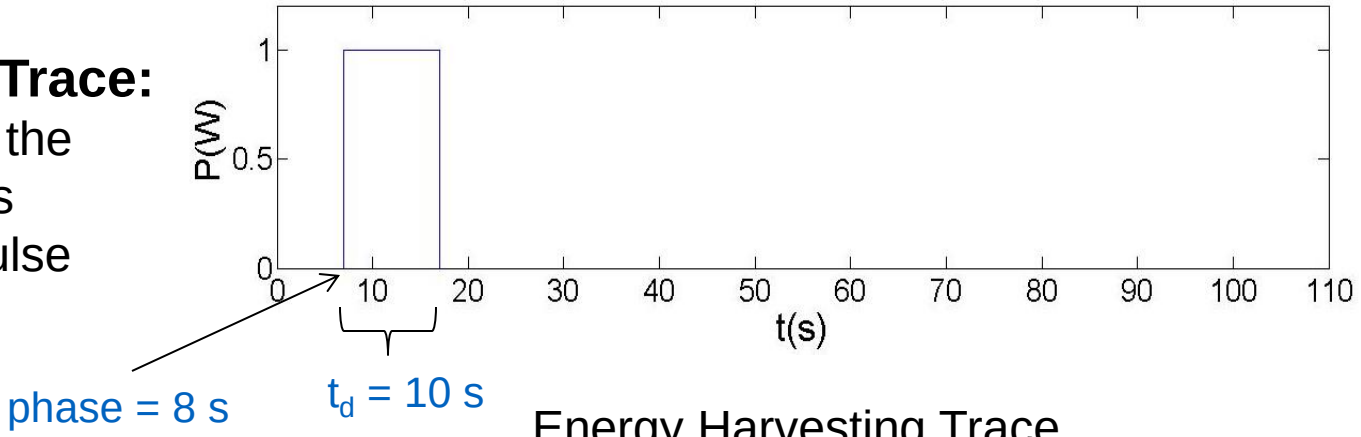
- Active mode: P_{active}
- Sleep mode: P_{sleep}
- Duty cycle: D
- Assigned with periodic tasks

$$\overline{P_{node}} = D * P_{active} + (1 - D) * P_{sleep}$$

Harvesting Energy Trace and Task Trace

Harvesting Energy Trace:

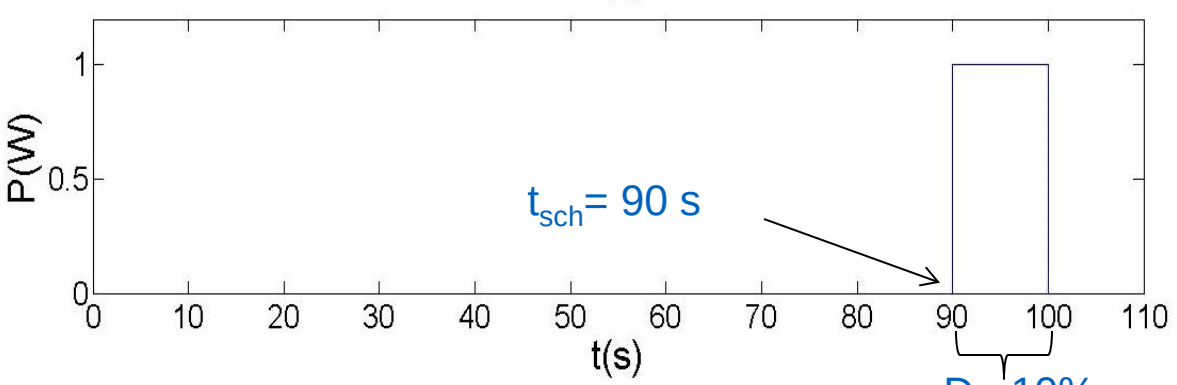
- phase: the time that the charging pulse starts
- t_d: Duration of the pulse



Energy Harvesting Trace

Sensor Node Task Trace:

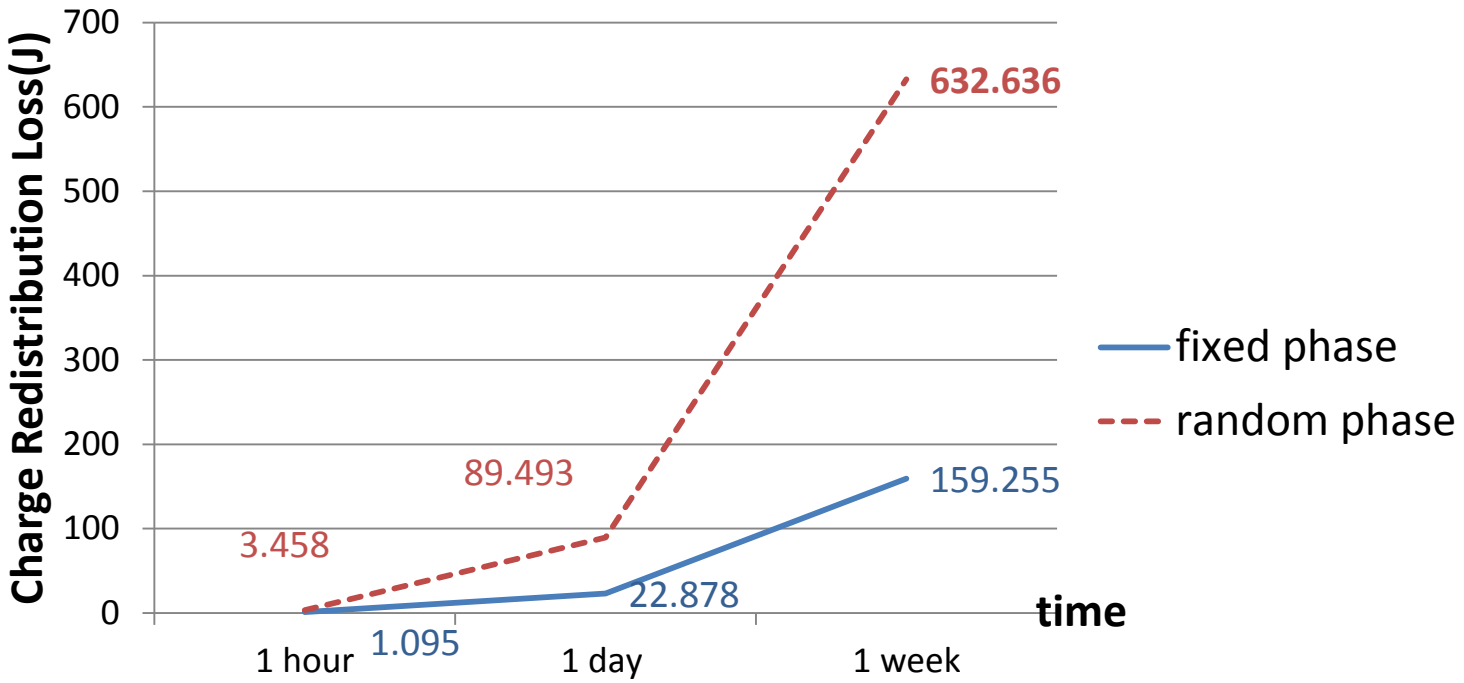
- t_{sch}: the time that the node start to execute



Task Trace

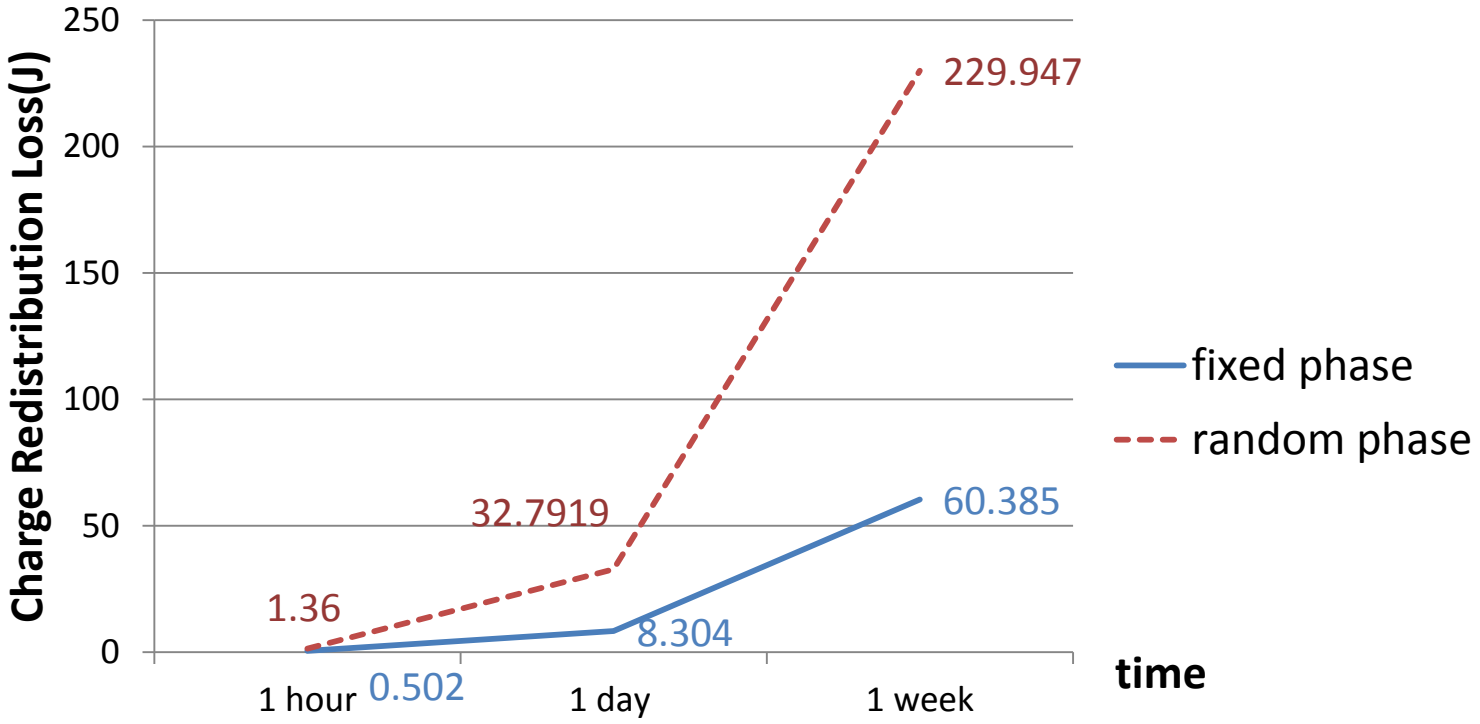
Charge Redistribution Simulation--10F

- Harvesting Profile: fixed phase VS random phase
- Sensor Node: Lazy Scheduling



Charge Redistribution Loss Analysis for 10 F SC

Charge Redistribution Simulation— 50F



Charge Redistribution Loss Analysis for 50 F SC

Conclusion: Random phase leads to more charge redistribution loss.

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Alg. 1 Validation

- Validation of the VLR based simulation model:

MACCOR Test Platform

Using MACCOR Test System to validate the proposed algorithm 1.

Algorithm 1 validation for 10 F Supercap in one hour

	Charge Redistribution Loss(J)		
	MACCOR Test	Alg.1 Simulation	
Fixed Phase	1.064	1.095	**2.83%**
Random Phase	3.663	3.458	**5.59%**

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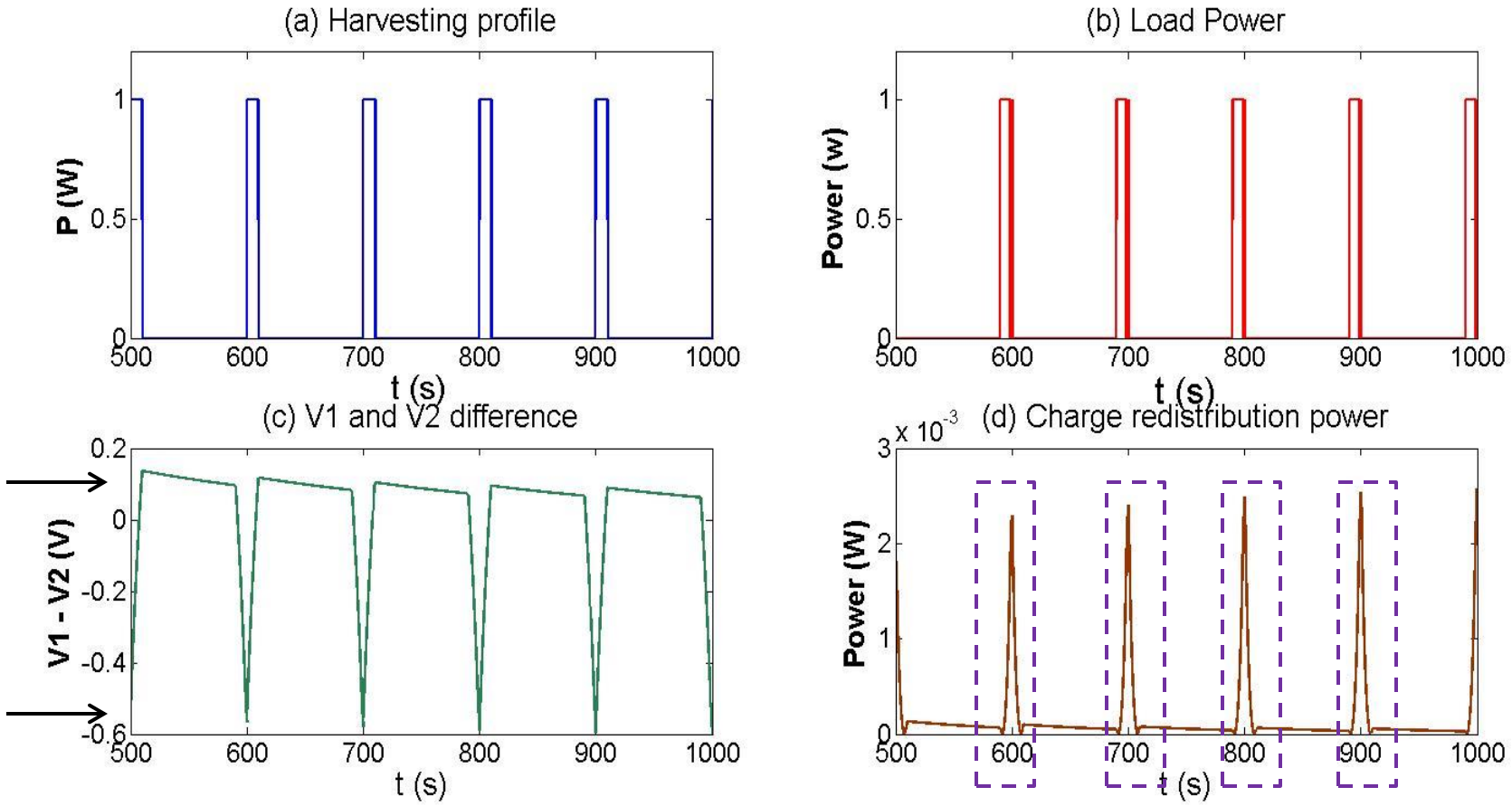
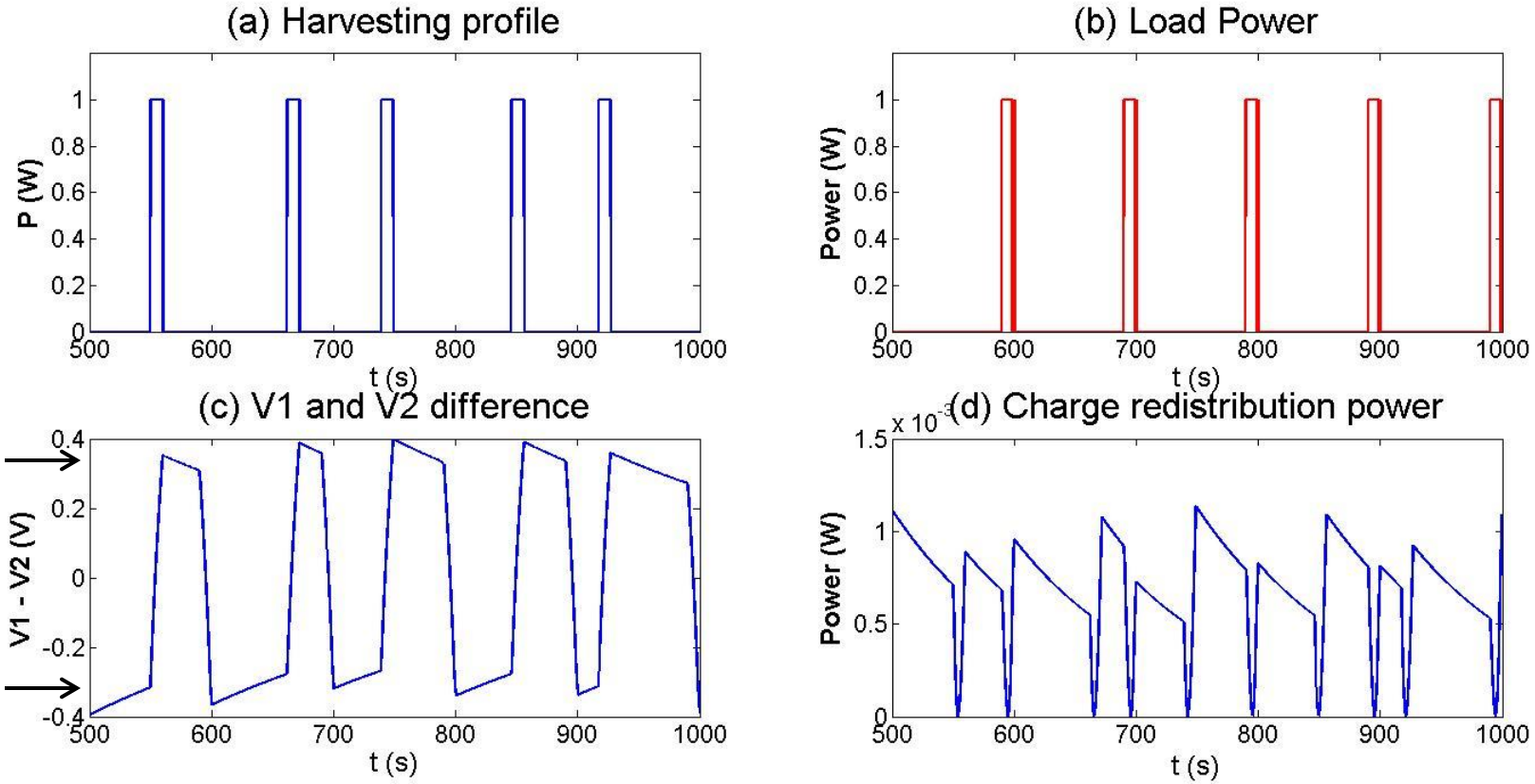
A snapshot into the simulation—Fixed Phase



Snapshot for the fixed phase harvesting profile

A snapshot into the simulation—Random Phase



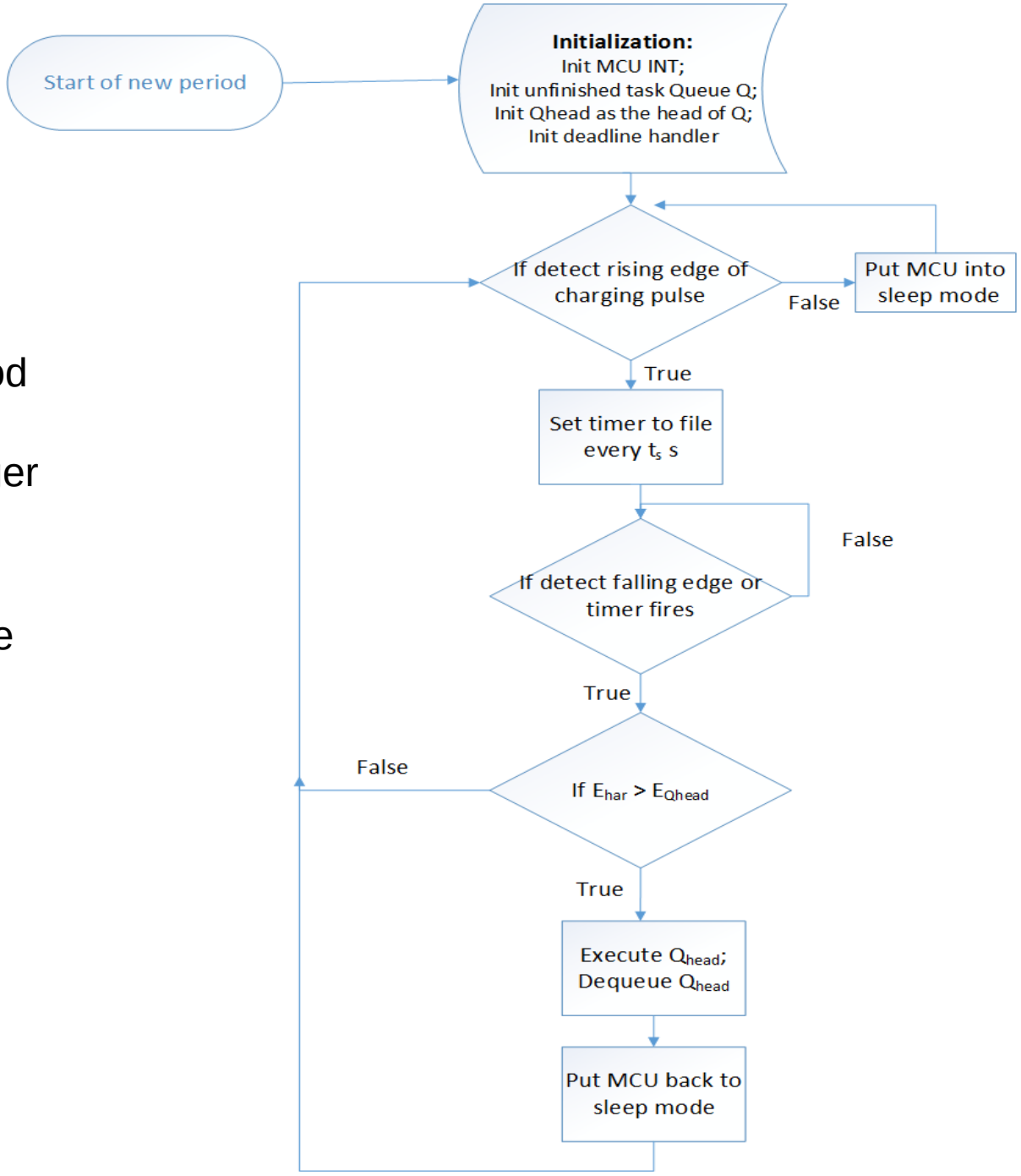
Snapshot for the random phase harvesting profile

How to reduce charge redistribution loss?

- If task can be executed right after the charging pulse, charge redistribution loss will be reduced
- We propose a pulse tracking algorithm to minimize charge redistribution loss
- Objective: Low computational overhead; effective in tracking harvesting pulses;

Algorithm 2

- HW & SW combined method
- Guaranteed Eager Scheduling
- Put Sensor Node back to sleep as much as it can



Simulations:

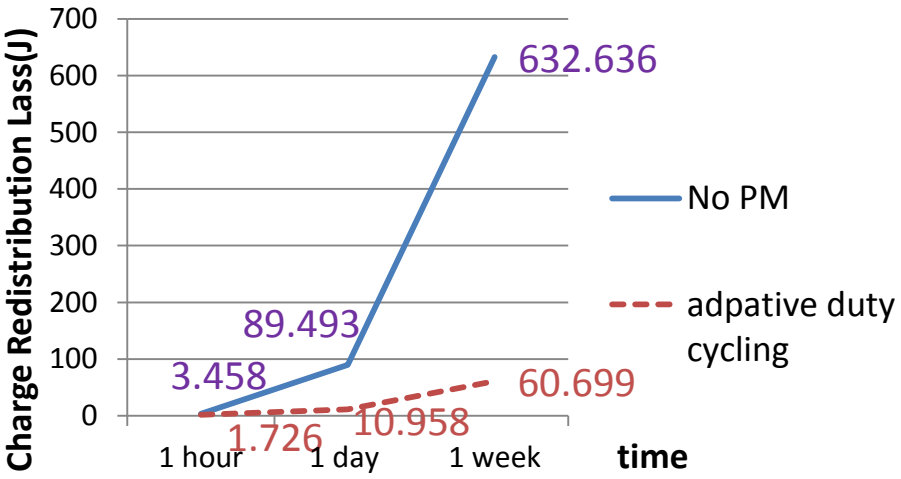
Four Power Management strategies are tested under ENO condition:

No Power Management(PM)

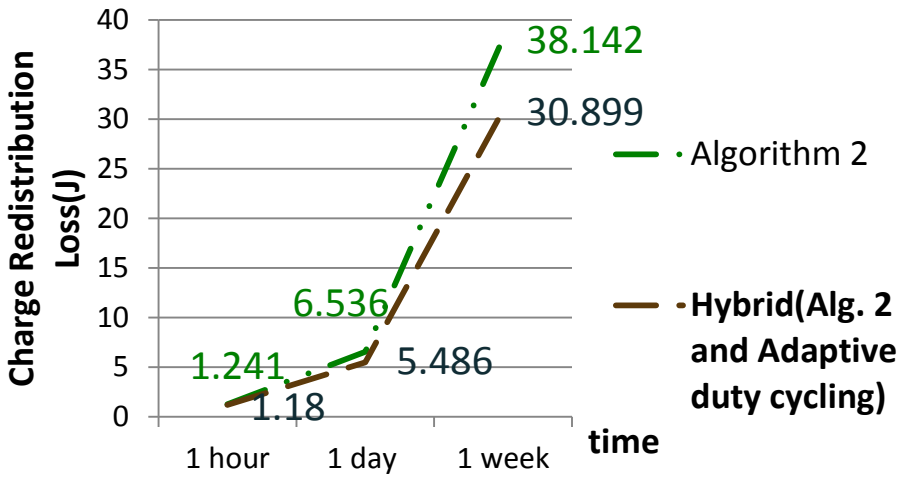
Adaptive duty cycling

Proposed Algorithm 2

Hybrid(duty cycling and Alg.2)

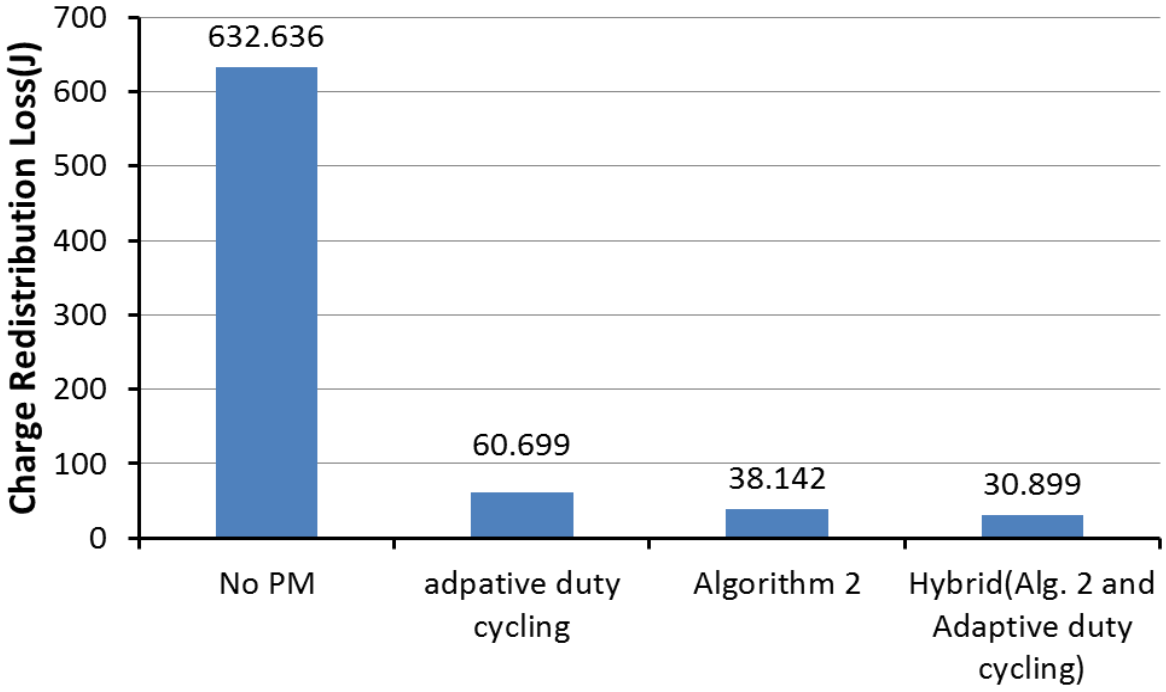


Simulation results of no PM and adaptive DC



Simulation results of Alg2 and Hybrid

One week test case



Power Consumption of Mobile Device

Device	Power Consumption(mW)
Mica2 Sensor Board	2.5
Atmega 128L(active)	24
CC2420(RX at 0 dbm mode)	63
MICA2 EEPROM(write)	61
Proximity(TDA0161)	420
Flow control(FCS-GL1)	1250

The hybrid Alg can save a lot!

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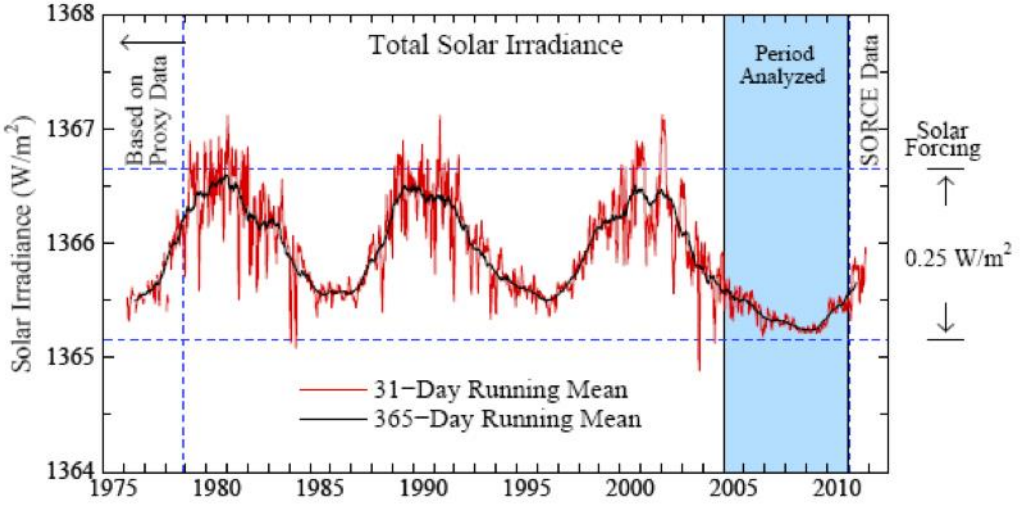
Conclusion

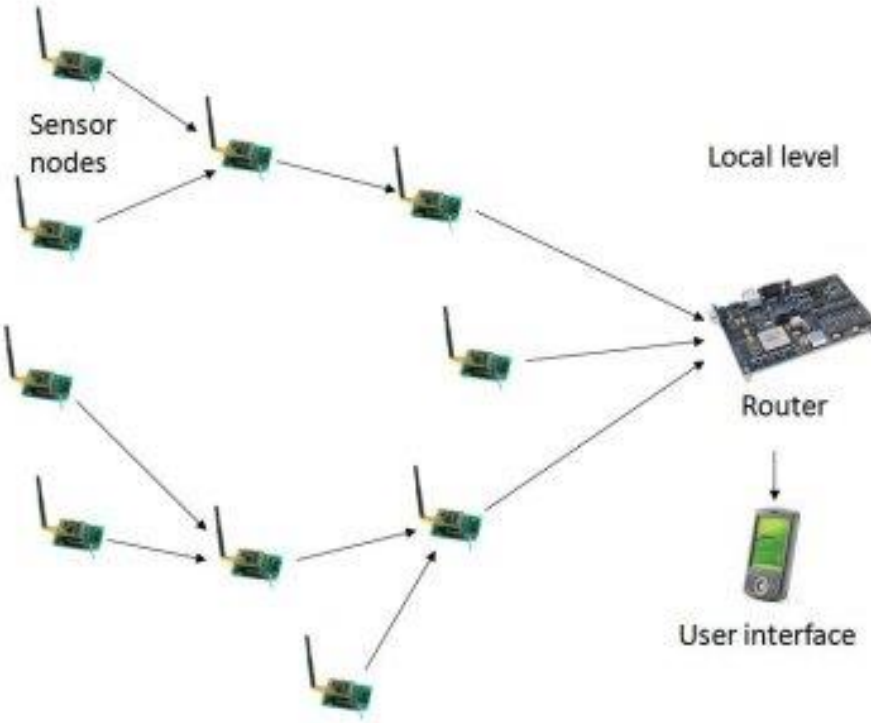
- We propose VLR-based SC simulator to analyze charge redistribution loss.
- We demonstrate that charge redistribution loss can be accumulated to be considerably high.
- We propose a low overhead, wide applicable phase tracking algorithm to mitigate charge redistribution.

Future work

- What is Charge Redistribution Loss with real harvesting profile



- How Charge Redistribution Loss affect network performance?



- What about energy dissipation of SC module?

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Thank you!

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