Linking the Environment, the Battery, and the Application in Energy Harvesting Wireless Sensor Networks

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Introduction

Energy Harvesting

- **Energy Harvesting**
  - Collecting energy from the environment or other ambient energy sources and converting it into Electrical Energy

- **In Wireless Sensor Networks (WSN)**
  - Nodes extract ambient energy and use it as a power source
  - Nodes recharge autonomously
  - Enhance performance
  - Go Green!

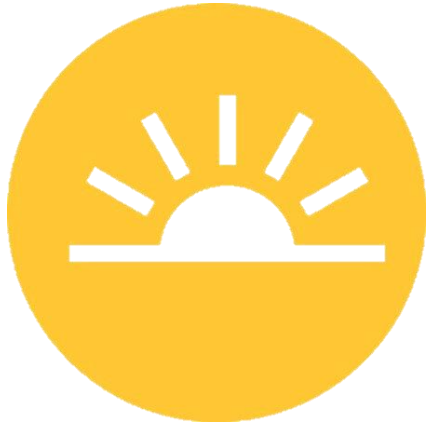
Harvestable Energy Sources

Source: http://hi-globe.com/

Energy Harvesting Model

Energy Harvesting Model

The Environment

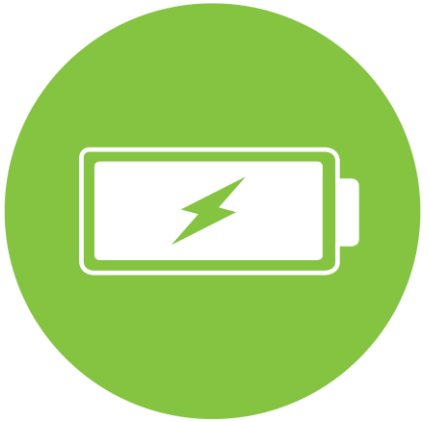


- Light intensity
- Energy collection

The Application

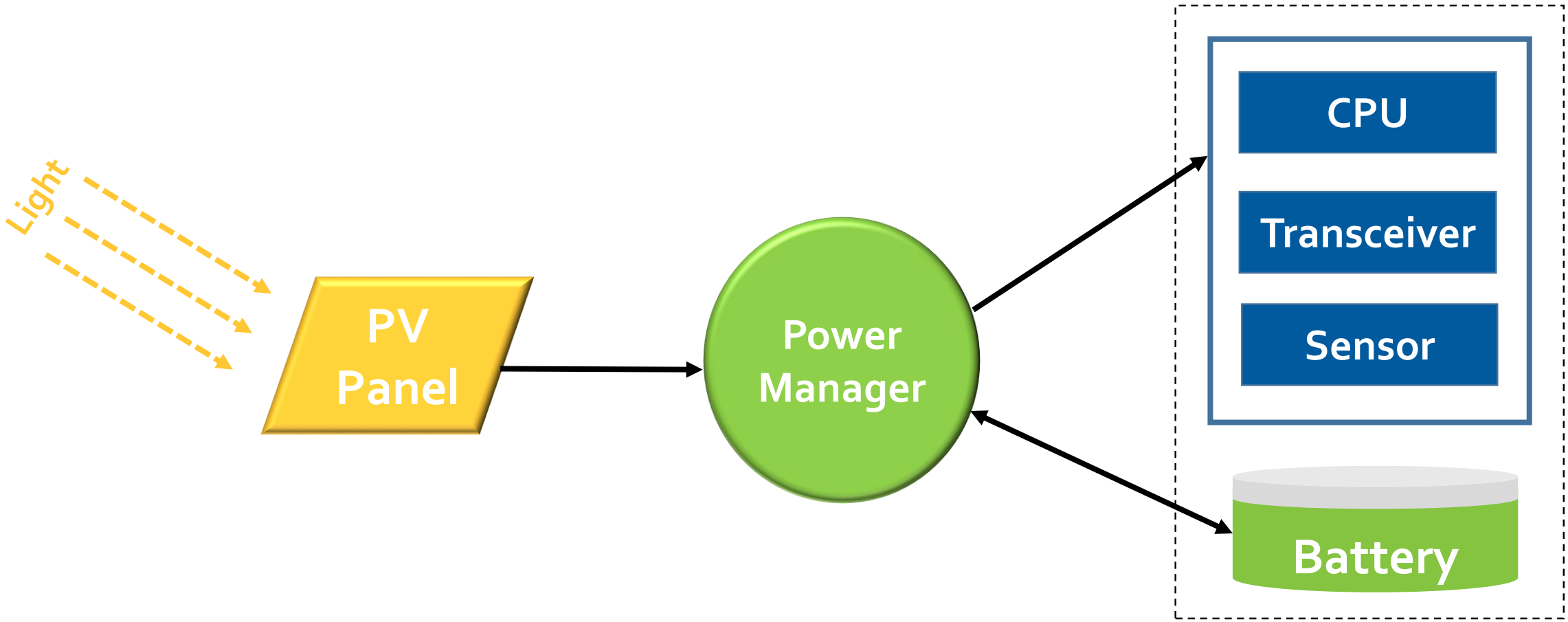
- Requirements
- Energy consumption

The Battery

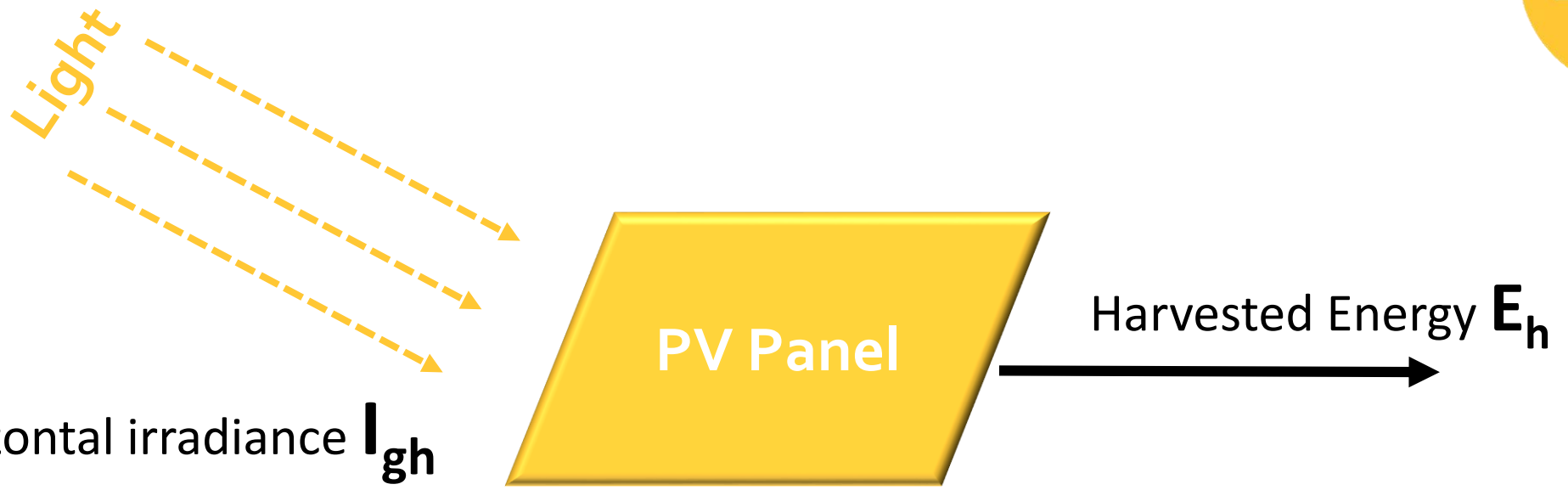


- Power storage
- Energy management

Energy Harvesting Model



The Environment



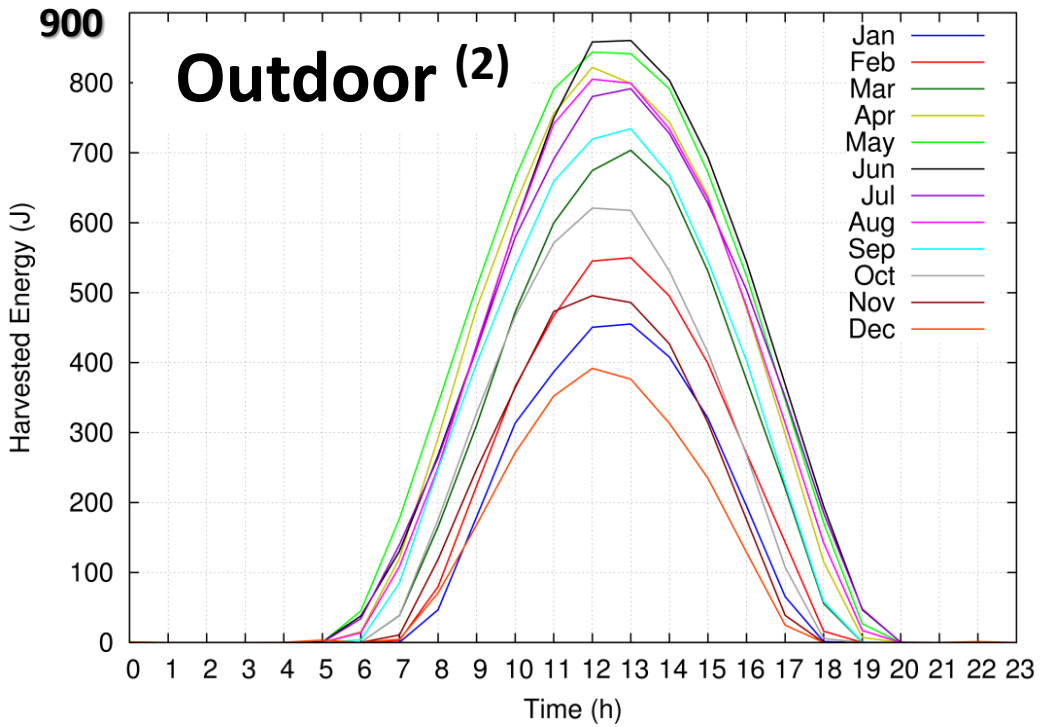
- Global horizontal irradiance I_{gh}
- Natural
- Artificial

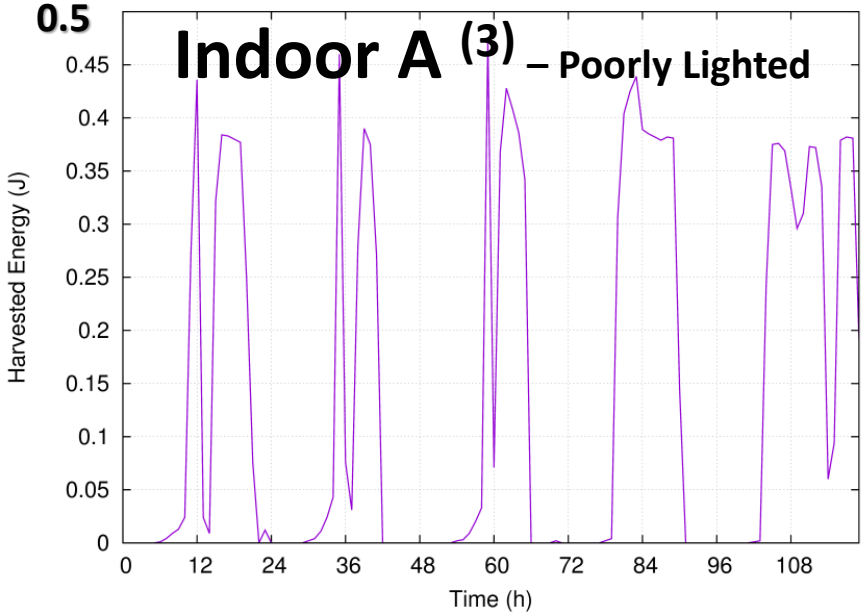
- Efficiency η_{PV} = 25% (1)
- Surface S_{PV} = 10 cm^2

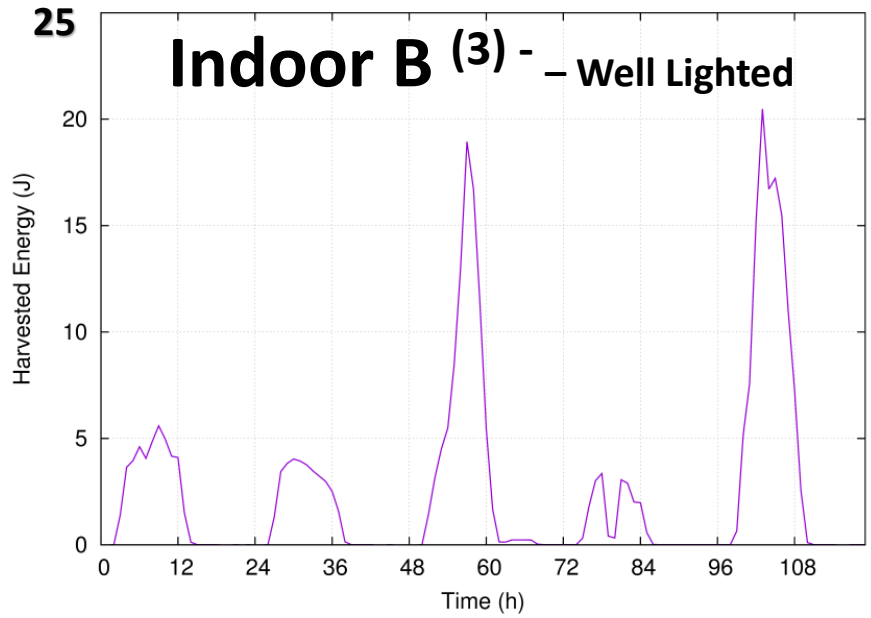
$$E_h(\tau) = I_{gh}(\tau) \cdot S_{PV} \cdot \eta_{PV} \cdot T$$

(1) M. Green, K. Emery, Y. Hishikawa, W. Warta, E. Dunlop, "Solar Cell Efficiency Tables (v. 45)", Progress in Photovoltaics: Research and Applications, 2015.

The Environment

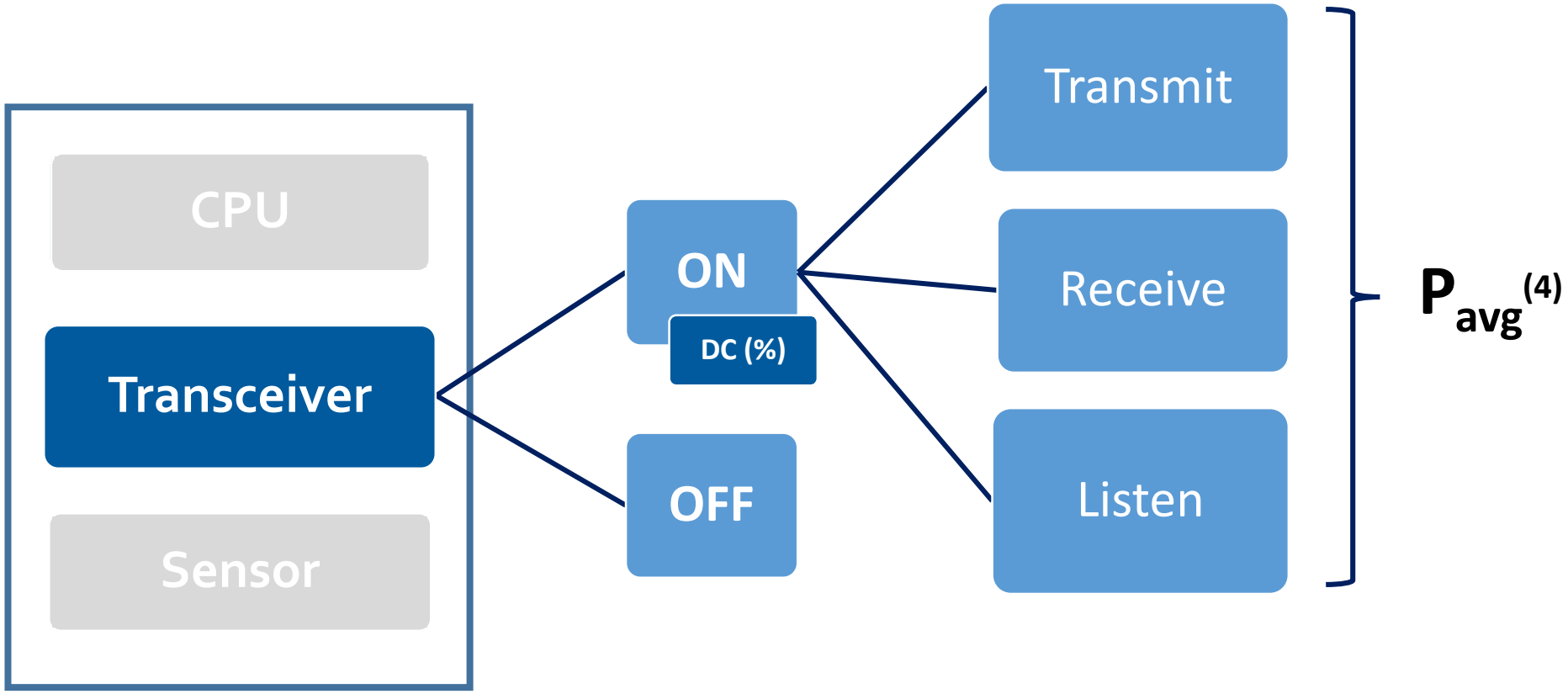






(2) A. Andreas, S. Wilcox, "SOLARMAP", Rotating Shadowband Radiometer, NREL Report No. DA-5500-56502, Los Angeles, CA, USA, 2012.
(3) M. Gorlatova, M. Zapas, E. Xu, M. Bahlke, I. Kymissis, G. Zussman, "CRAWDAD Dataset Columbia/Enhants, 2011.

The Application

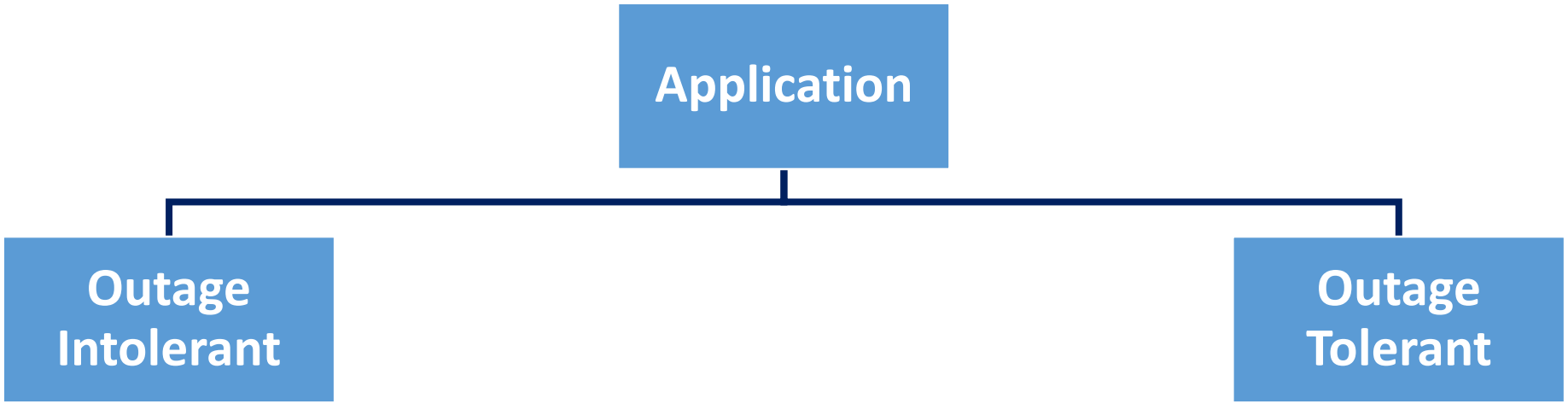


- Energy consumption **Ec**
- Duty Cycle **DC**

$$E_c(\tau) = P_{avg} \cdot DC(\tau) \cdot T$$

(4) A. Prayati, C. Antonopoulos, T. Stoyanova, C. Koulamas, G. Papadopoulos, "A Modeling Approach on the TelosB WSN Platform Power Consumption", Journal of Systems and Software, 1355-1363, 2010.

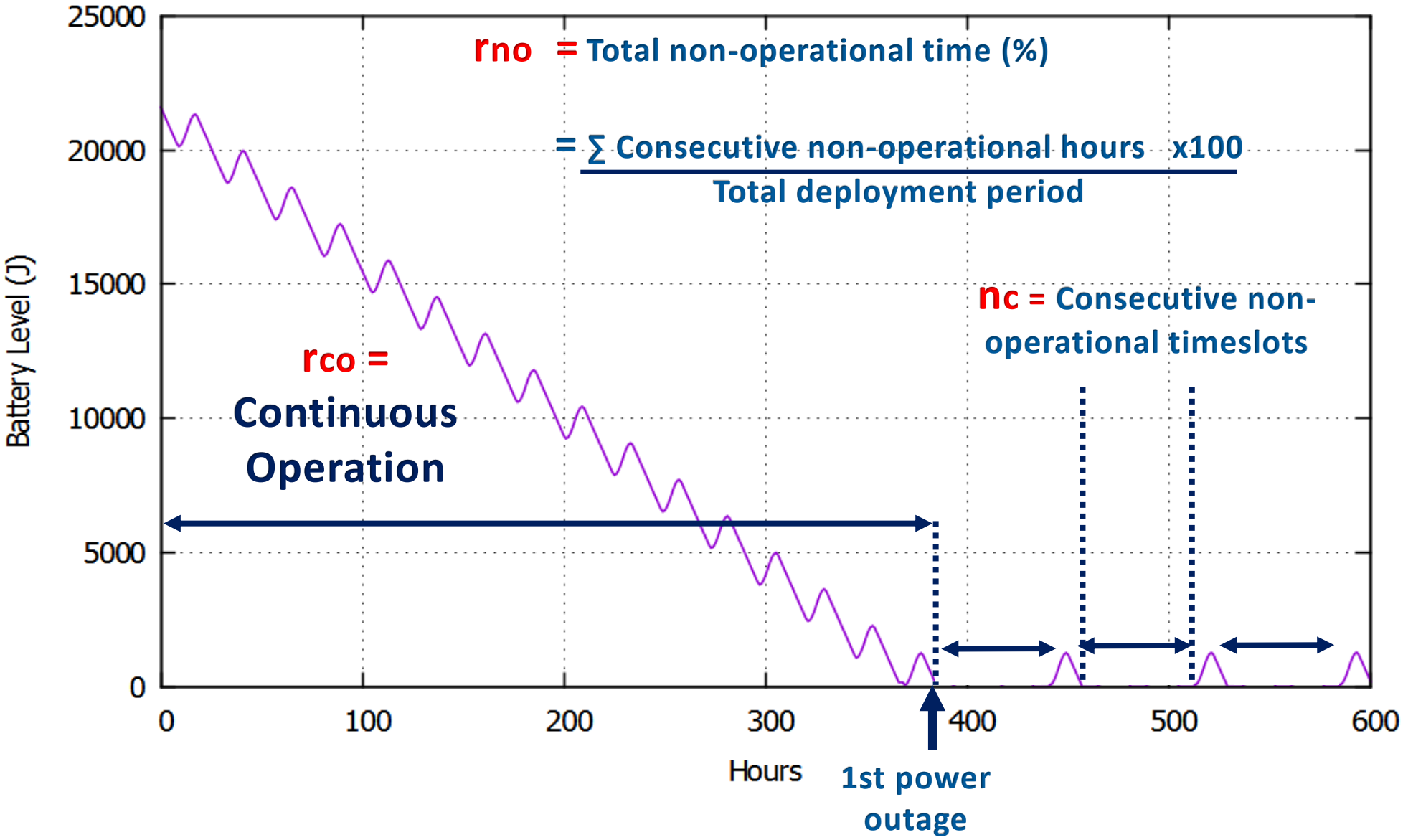
The Application



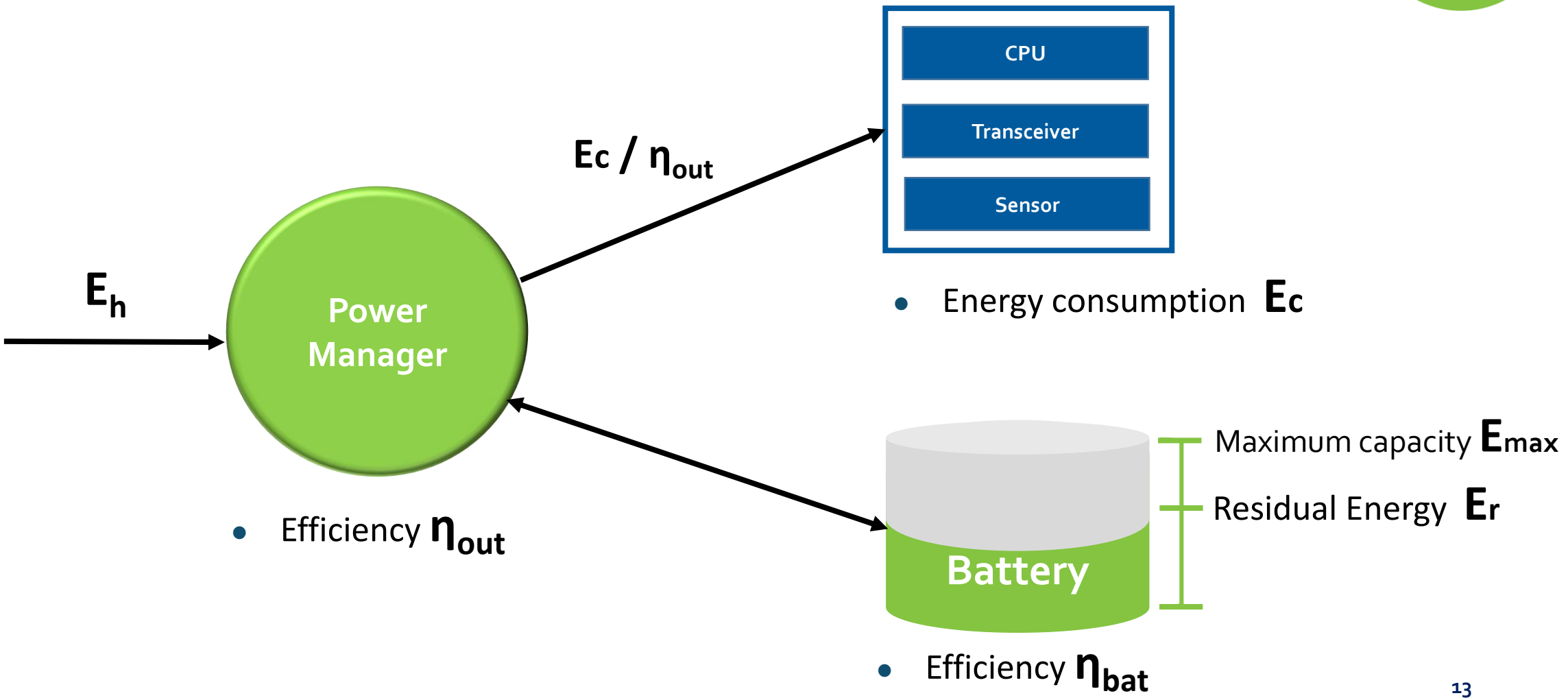
- Continuous operation required
- Outage situation:
  → Operation stops

- Non-operational time tolerated
- Outage situation:
  → Operation stops
  → Battery recharges
  → Operation resumes

The Application



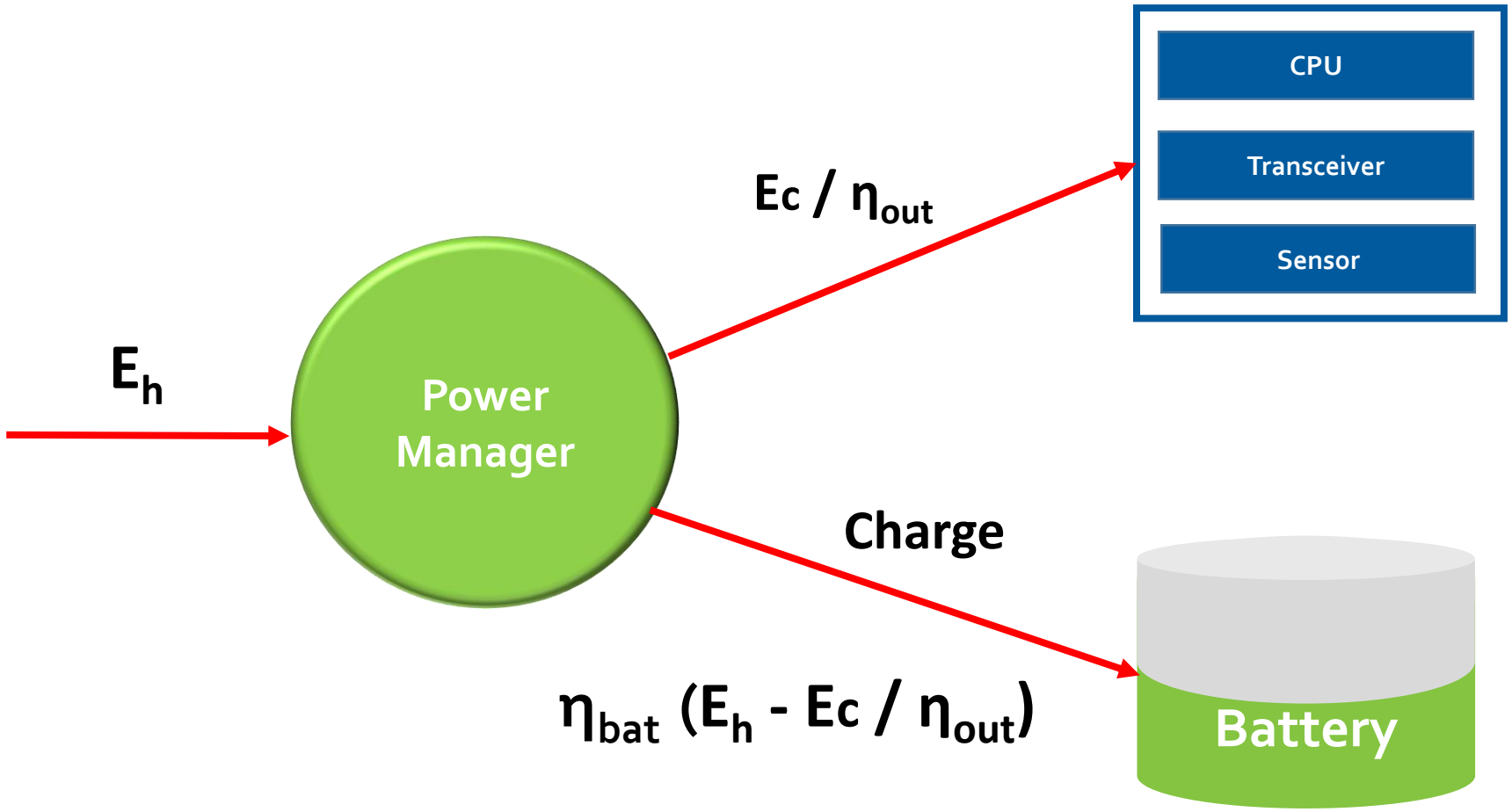
The Battery



(5) V. Raghunathan, A. Kansal, J. Hsu, J. Friedman, M. Srivastava, "Design Considerations for Solar Energy Harvesting Wireless Embedded Systems", Proc. ACM/IEEE IPSN 2005, Los Angeles, CA, USA, 2005.

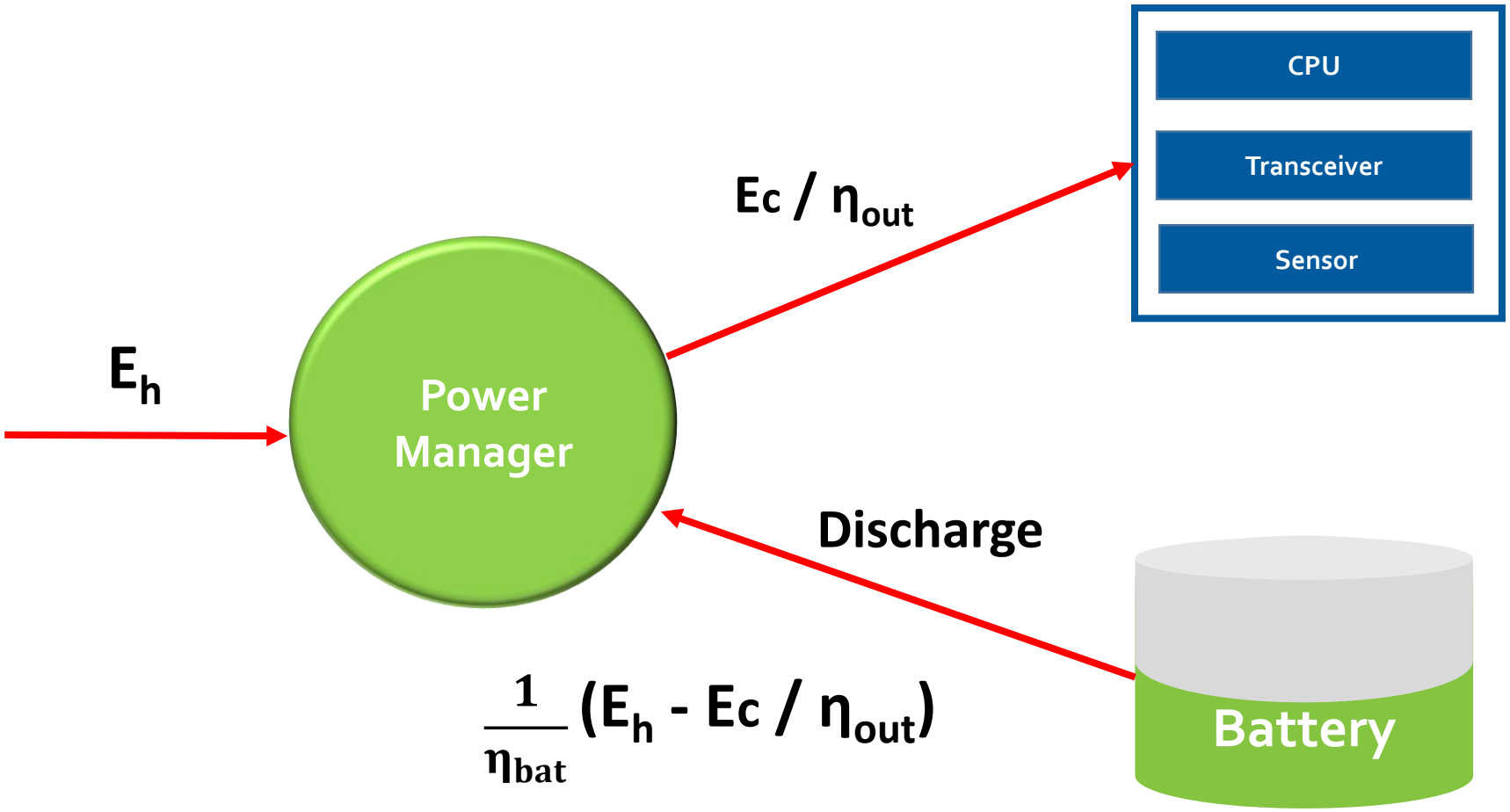
The Battery

$$E_h(\tau) \geq E_c(\tau)/\eta_{out}$$



The Battery

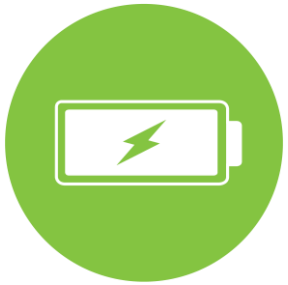
$$E_h(\tau) < E_c(\tau)/\eta_{out}$$

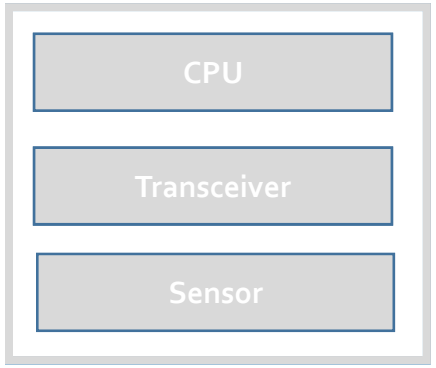


The Battery

$$E_h(\tau) < E_c(\tau)/\eta_{out}$$

$$E_h(\tau) + \eta_{bat} \cdot E_r(\tau) < \frac{E_c(\tau)}{\eta_{out}}.$$





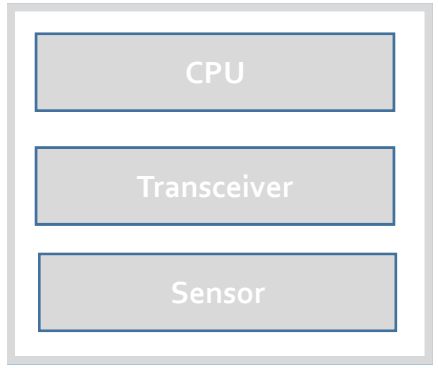
End of operation

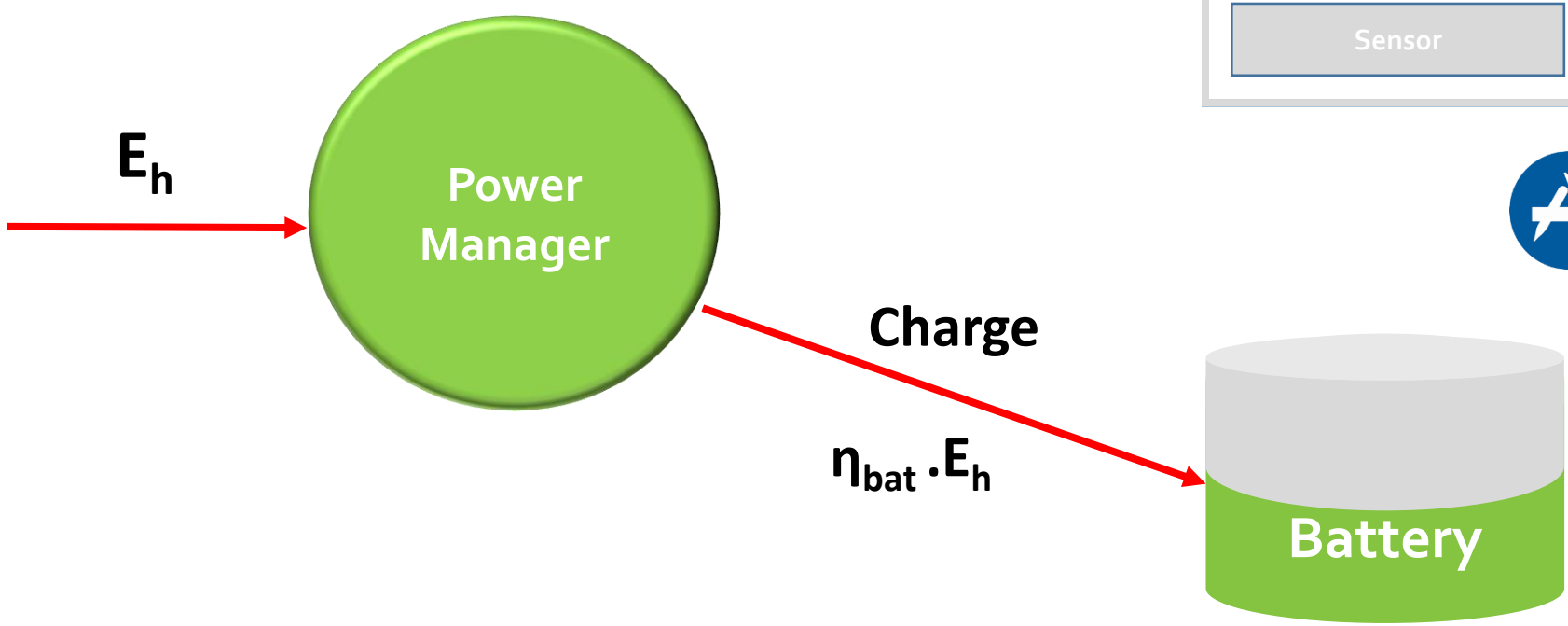
Outage Intolerant

The Battery

$$E_h(\tau) < E_c(\tau)/\eta_{out}$$

$$E_h(\tau) + \eta_{bat} \cdot E_r(\tau) < \frac{E_c(\tau)}{\eta_{out}}$$



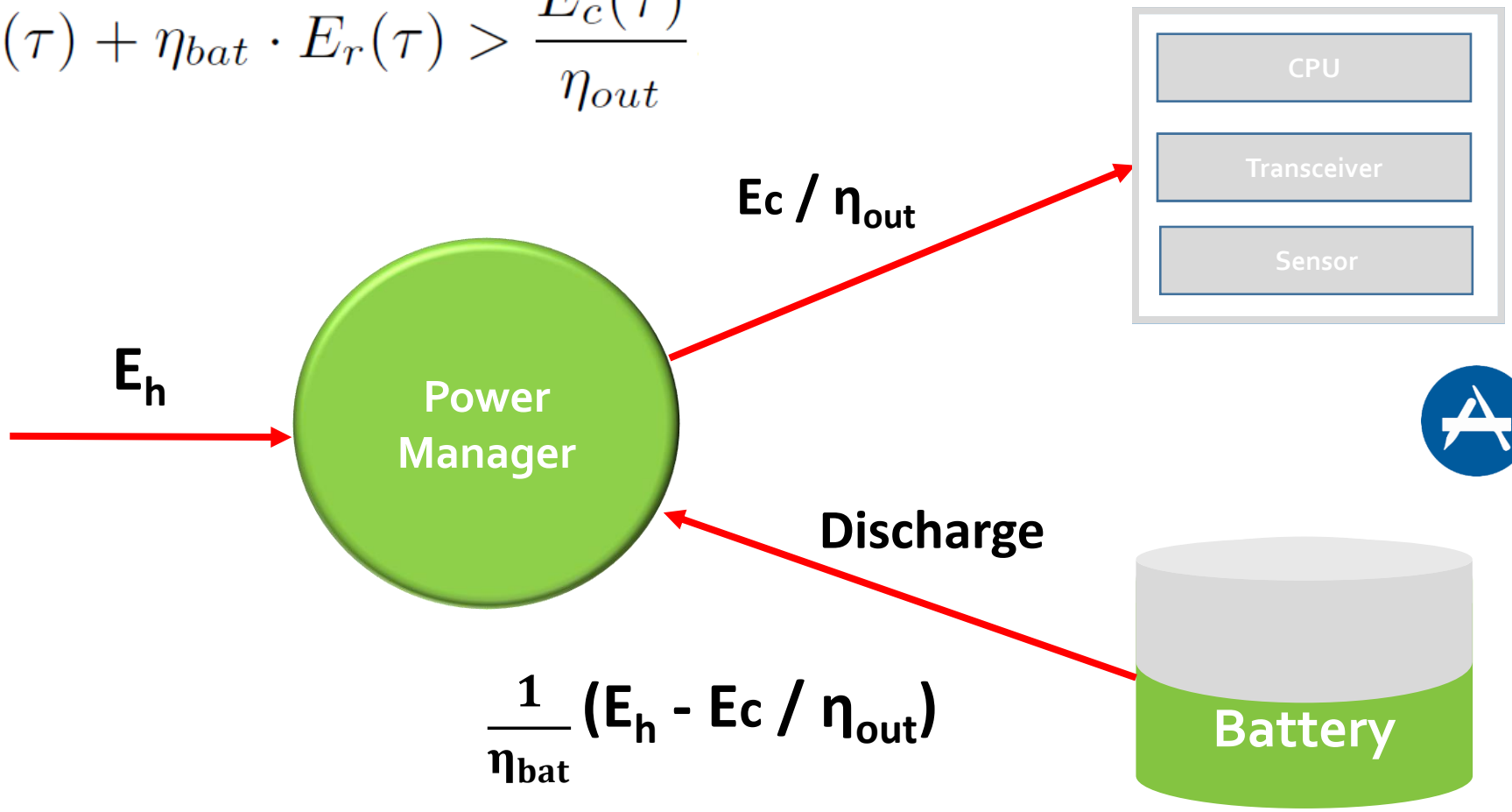


Outage Tolerant

The Battery

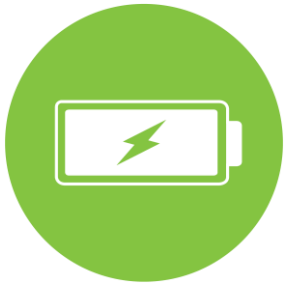
$$E_h(\tau) < E_c(\tau)/\eta_{out}$$

$$E_h(\tau) + \eta_{bat} \cdot E_r(\tau) > \frac{E_c(\tau)}{\eta_{out}}$$



Outage Tolerant

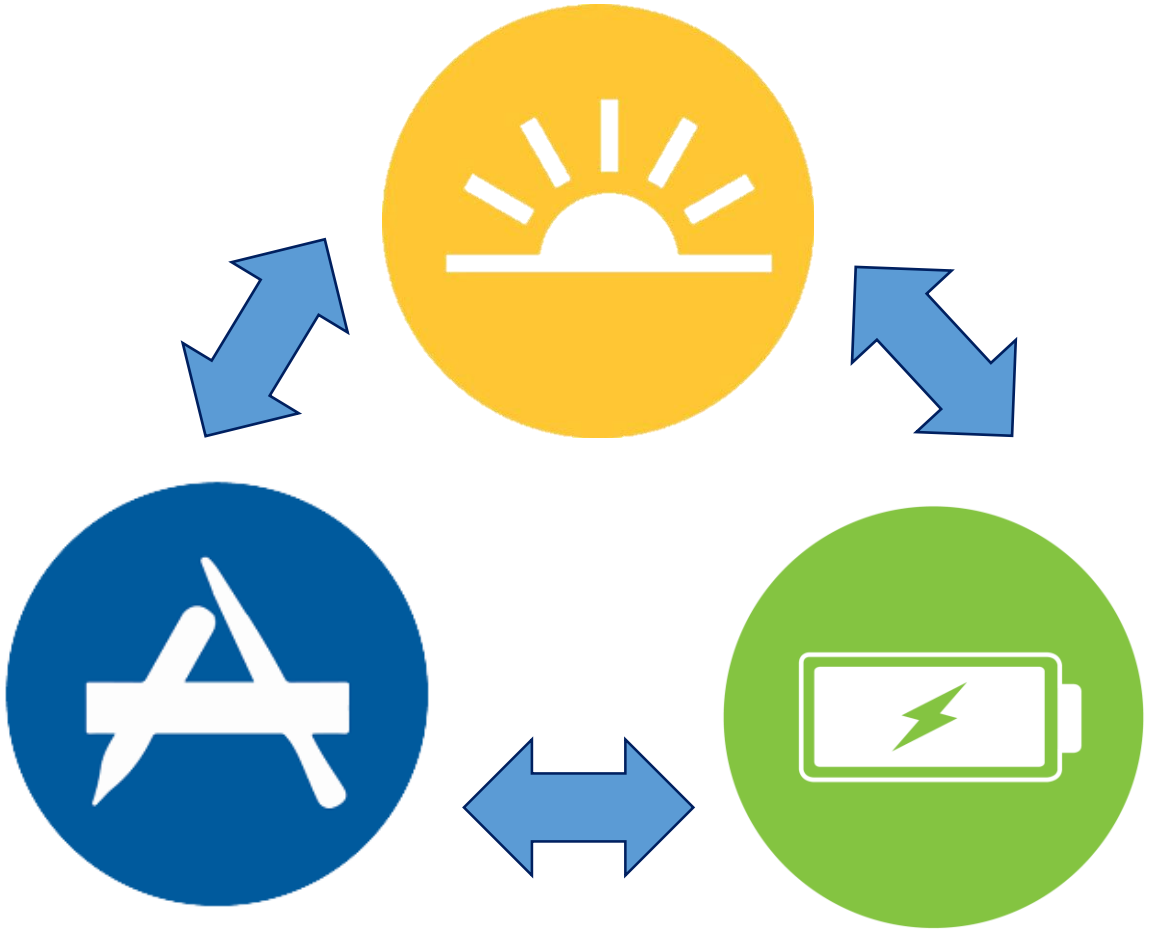
The Battery



Model	Type	Volume	Emax (J)	Capacity (mAh)	ηout
AA	NiMH	7.7	10800	2500	0.66
AAA	NiMH	3.8	5625	1250	0.66
AA	Li	7.7	9857	740	0.99
Ultrathin_200	Li	2.7	2664	200	0.99
Ultrathin_100	Li	1.3	1332	100	0.99
Ultrathin_43	Li	0.6	573	43	0.99
Ultrathin_10	Li	0.6	133	10	0.99

(6) S. Sudevalayam, P. Kulkarni, "Energy Harvesting Sensor Nodes: Survey and Implications", IEEE Communications Surveys & Tutorials, 13(3), 443-461, 2011.
(7) Ultrathin Rechargeable Lithium Polymer Batteries from Powerstream, http://www.powerstream.com/thin-lithium-ion.htm, Accessed: Apr. 2016.

Linking the Environment, the Battery, and the Application

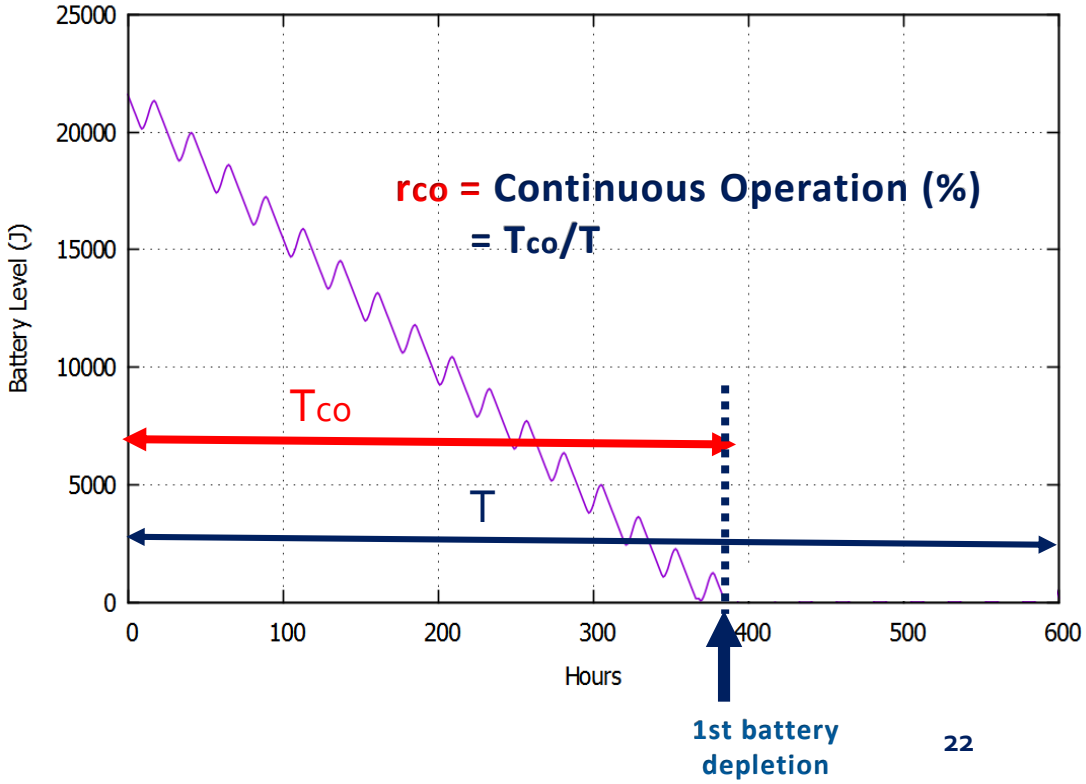


Outage Intolerant Applications

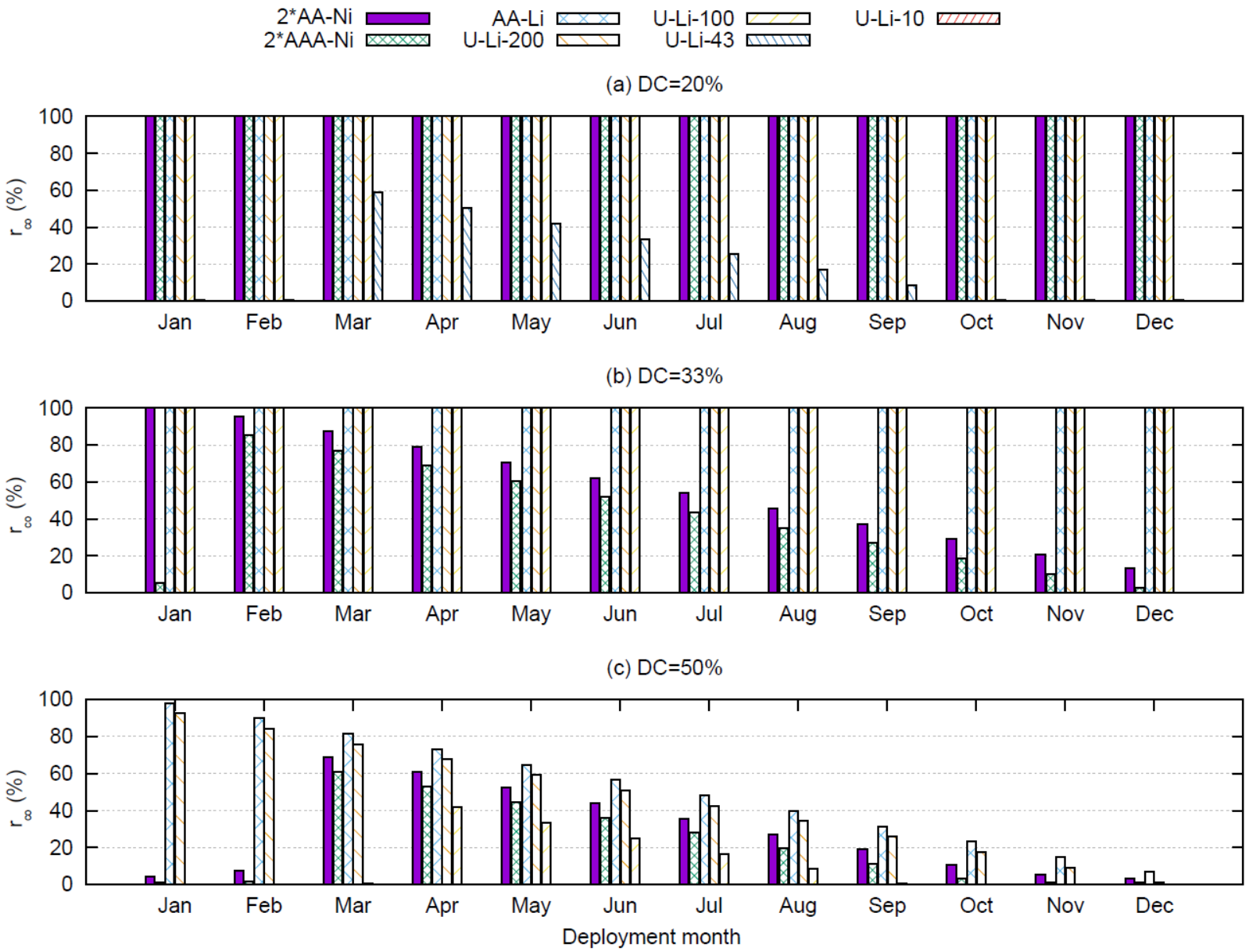
Outage Intolerant Applications

- Determine the continuous operation lifetime **rco**
  = time duration before the first power outage

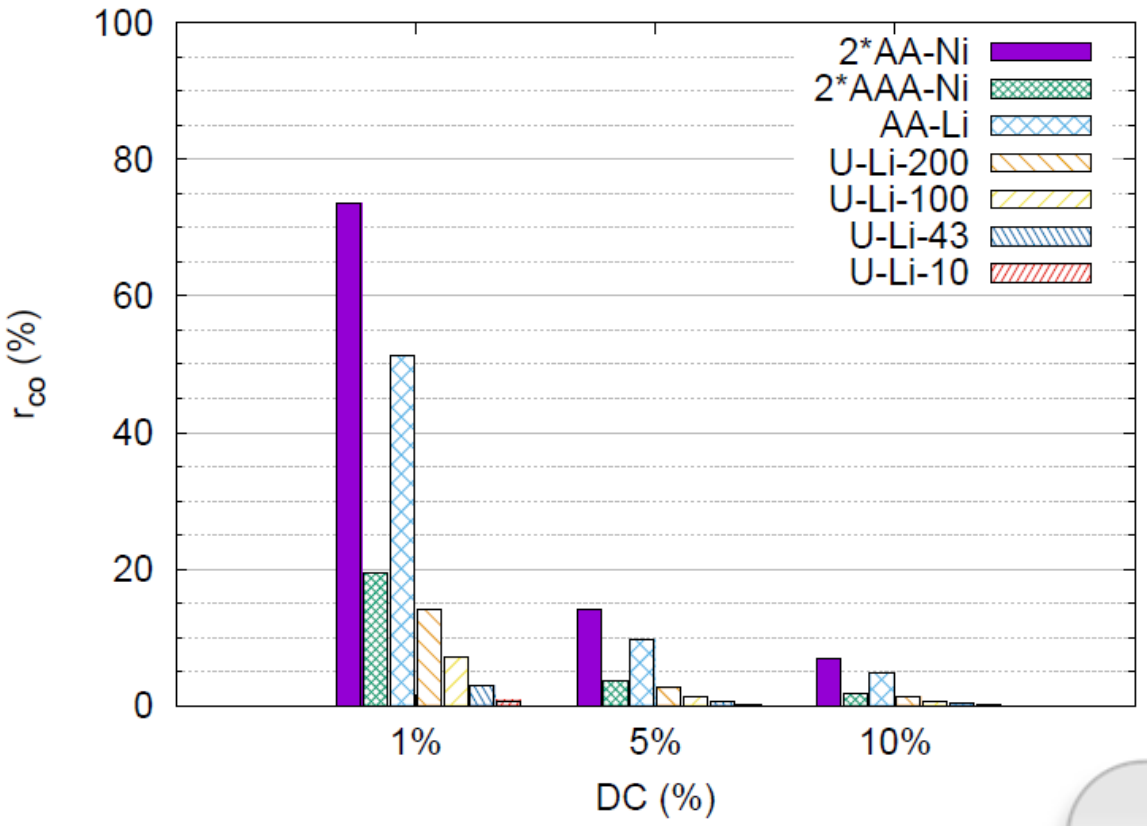
- Function of:
  - Environment
  - Duty Cycle
  - Battery



Outage Intolerant Applications - OUTDOOR

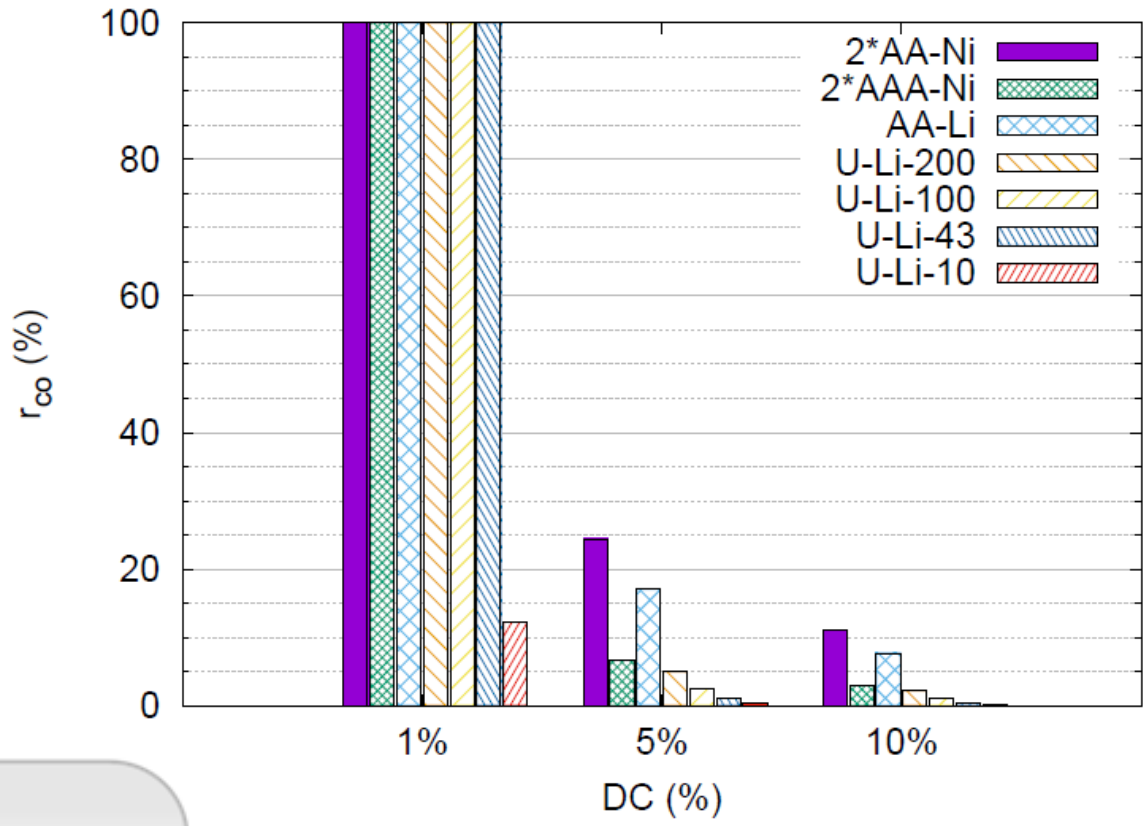


Outage Intolerant Applications - INDOOR



(a) Indoor Location A

Poorly lighted



(b) Indoor Location B

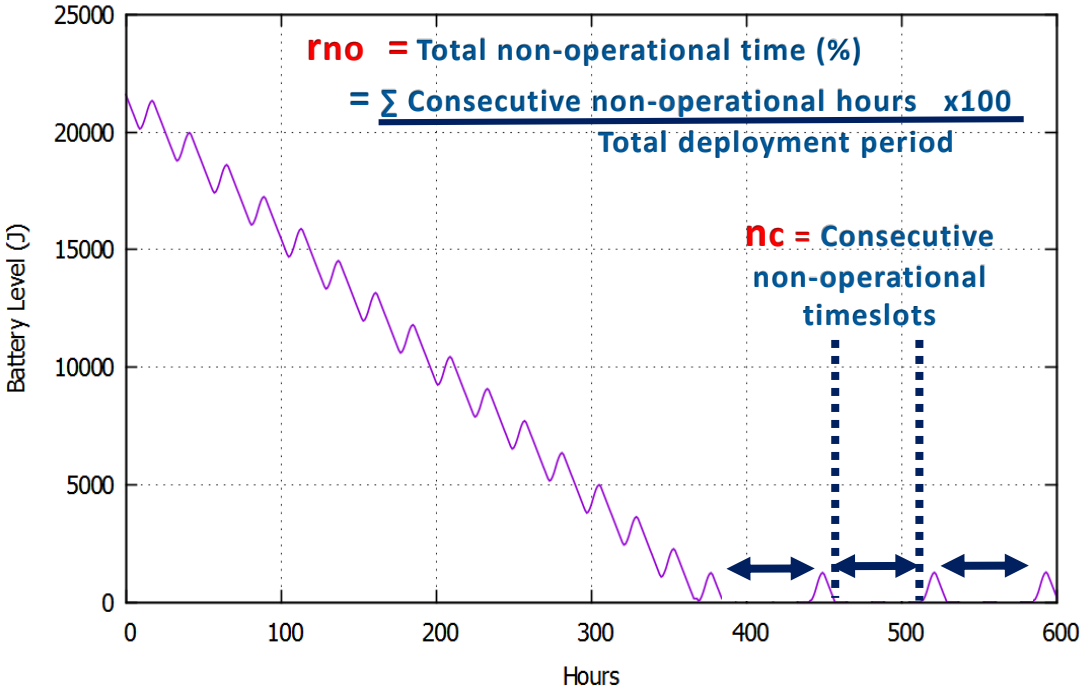
Well lighted

Outage Tolerant Applications

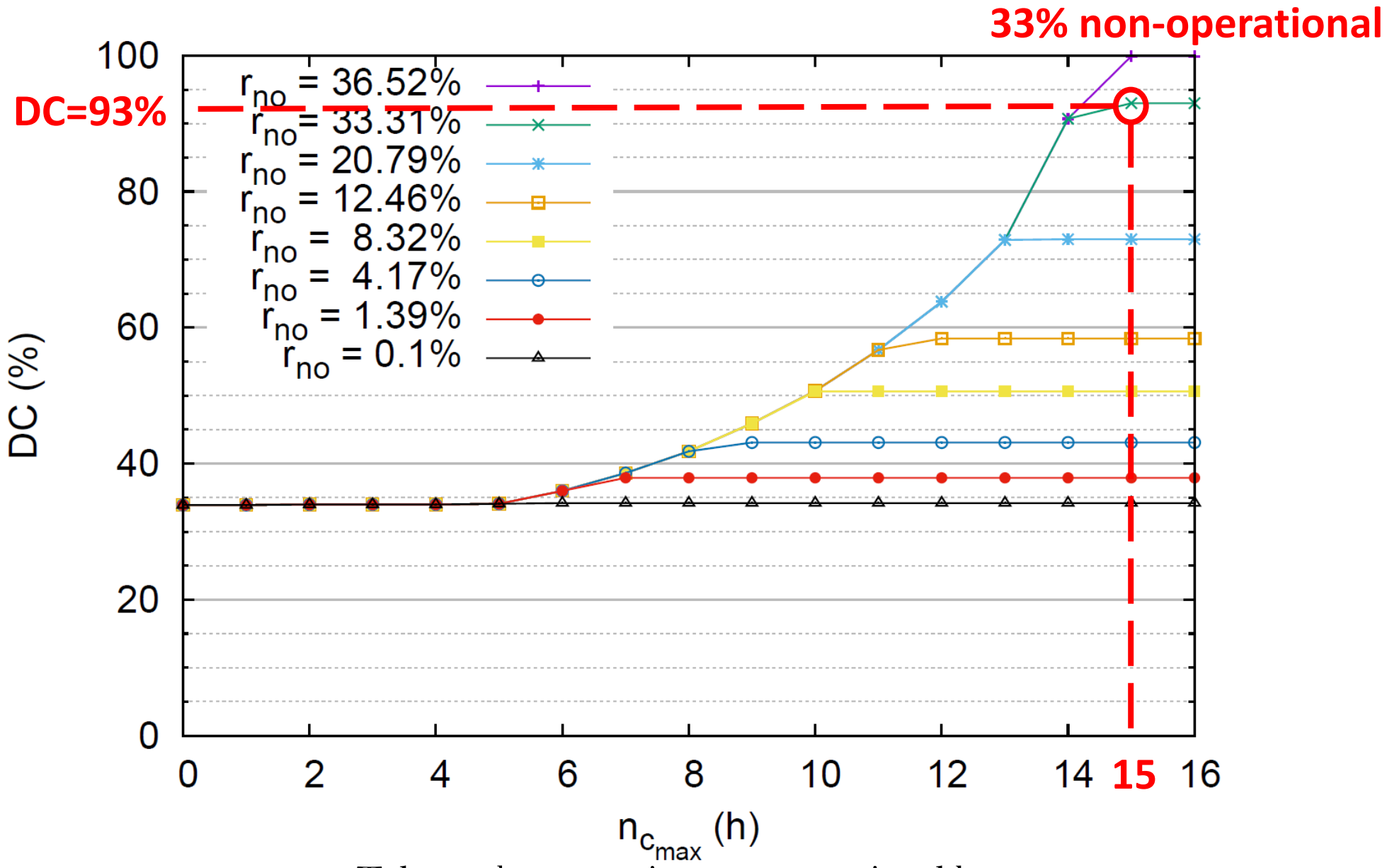
Duty Cycle Dimensioning

- Maximum achievable Duty Cycle value **DC**

- Function of:
  - Environment
  - Battery
  - Total non-operational time r_{no}
  - Maximum number of consecutive non-operational timeslots n_{cmax}

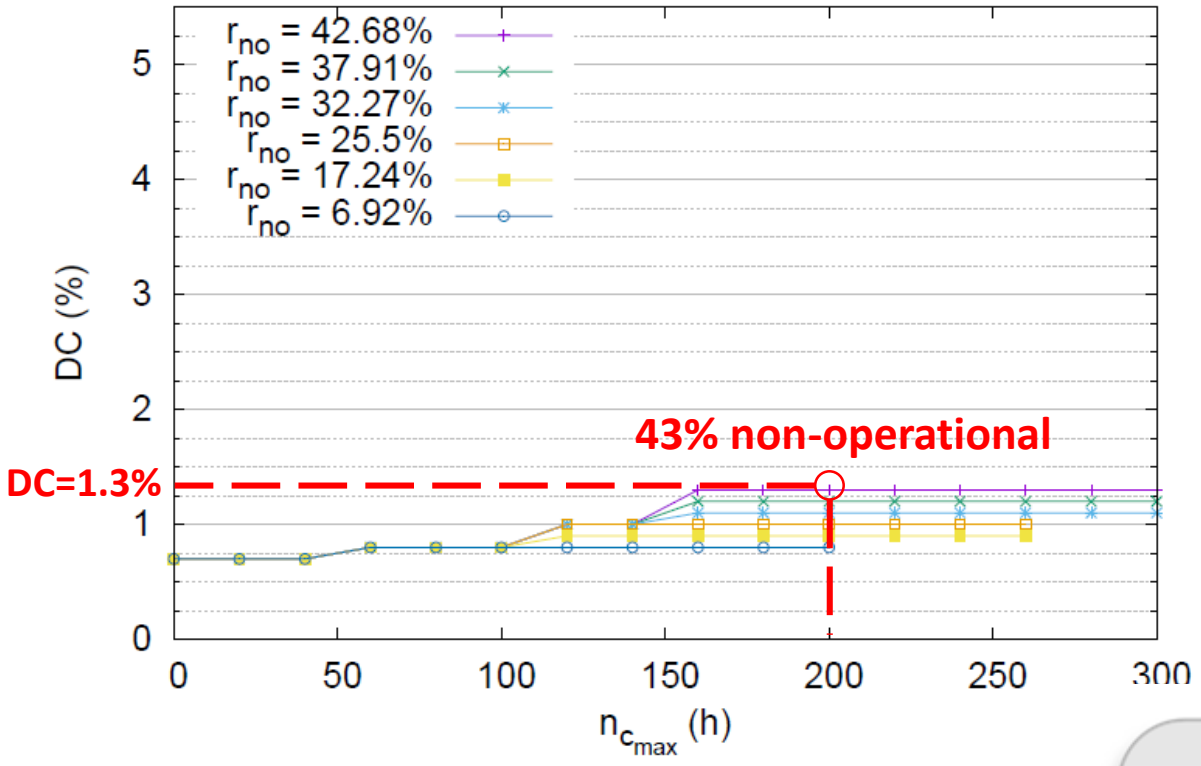


Duty Cycle Dimensioning - OUTDOOR



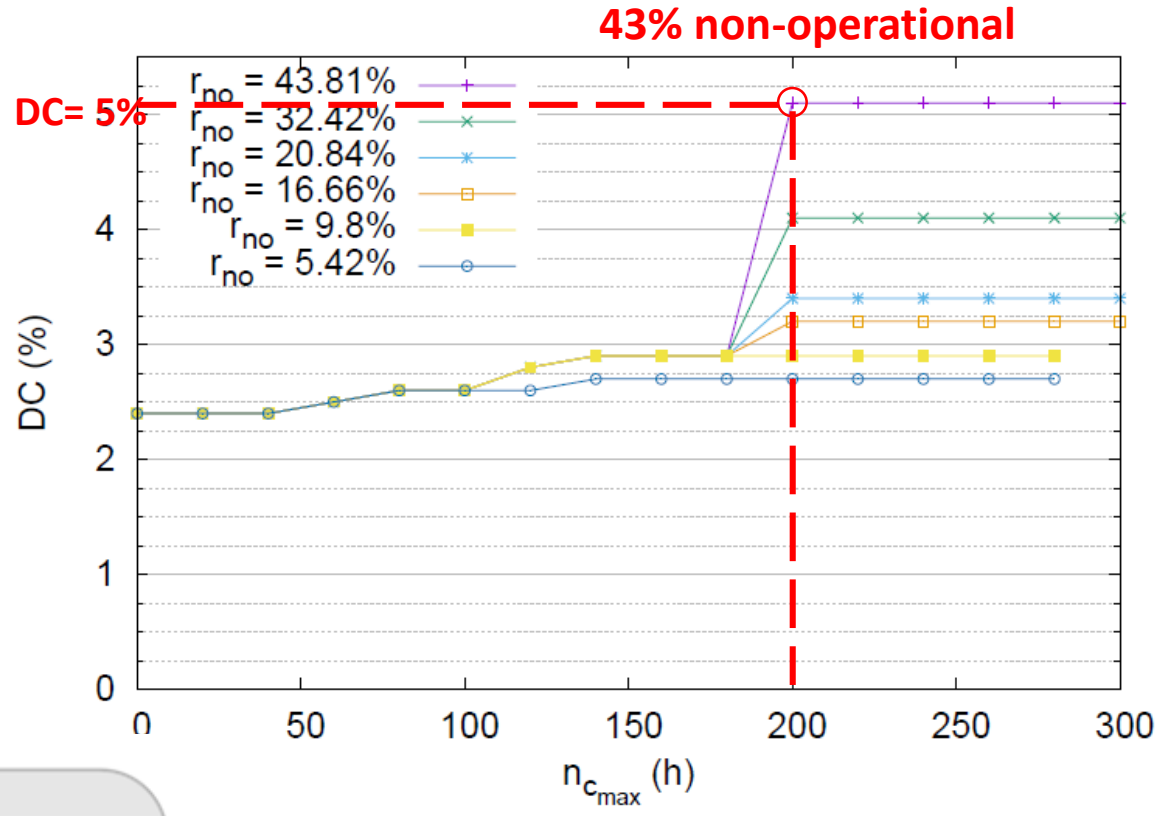
Tolerated consecutive non-operational hours

Duty Cycle Dimensioning - INDOOR



(a) Location A

Poorly lighted



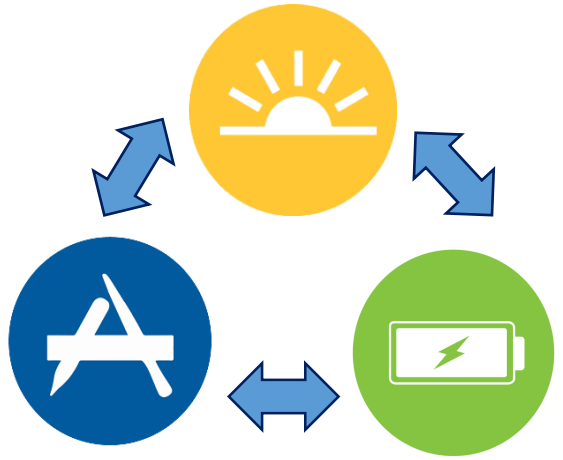
(b) Location B

Well lighted

Conclusion

Conclusion

- Study batteries suitability given required duty cycle (and vice versa)
- Study feasibility of an application in a specific environment
- Tolerating short power outage periods allows:
  - Extending node lifetime
  - High duty cycle values



Perspectives

- Extend study to complete WSN context
- Outage tolerant applications:
  - Study appearance and disappearance of nodes in the network
- Dynamic Duty Cycles[8]

(8) J. Oueis, R. Stanica, F. Valois, “Energy Harvesting Wireless Sensor Networks: From Characterization to Duty Cycle Dimensioning”, IEEE MASS 2016, Brasilia, Brazil, 2016.

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Thank You

Q&A

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