Achieving Optimal Age of Information with Wireless Energy Transfer

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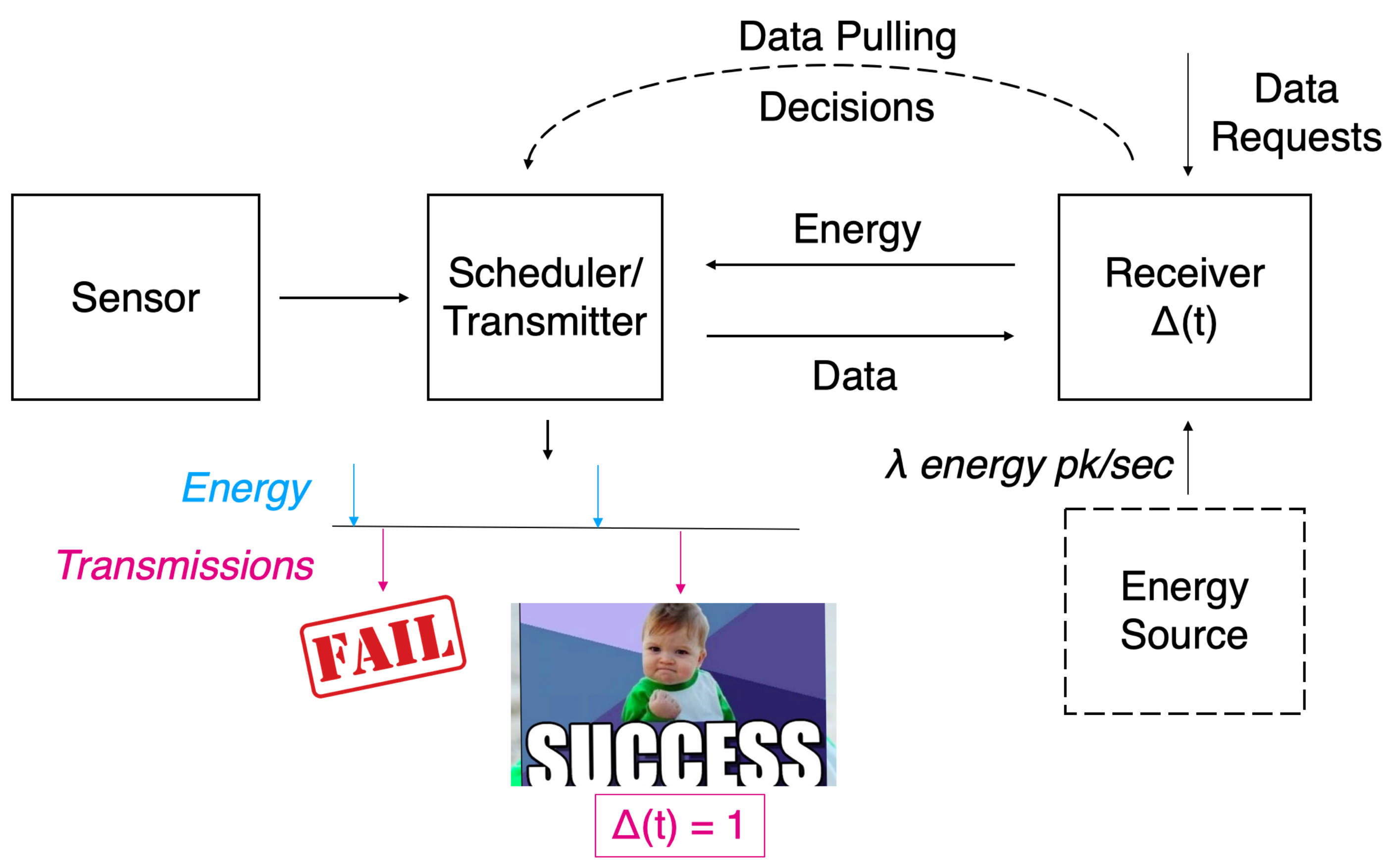
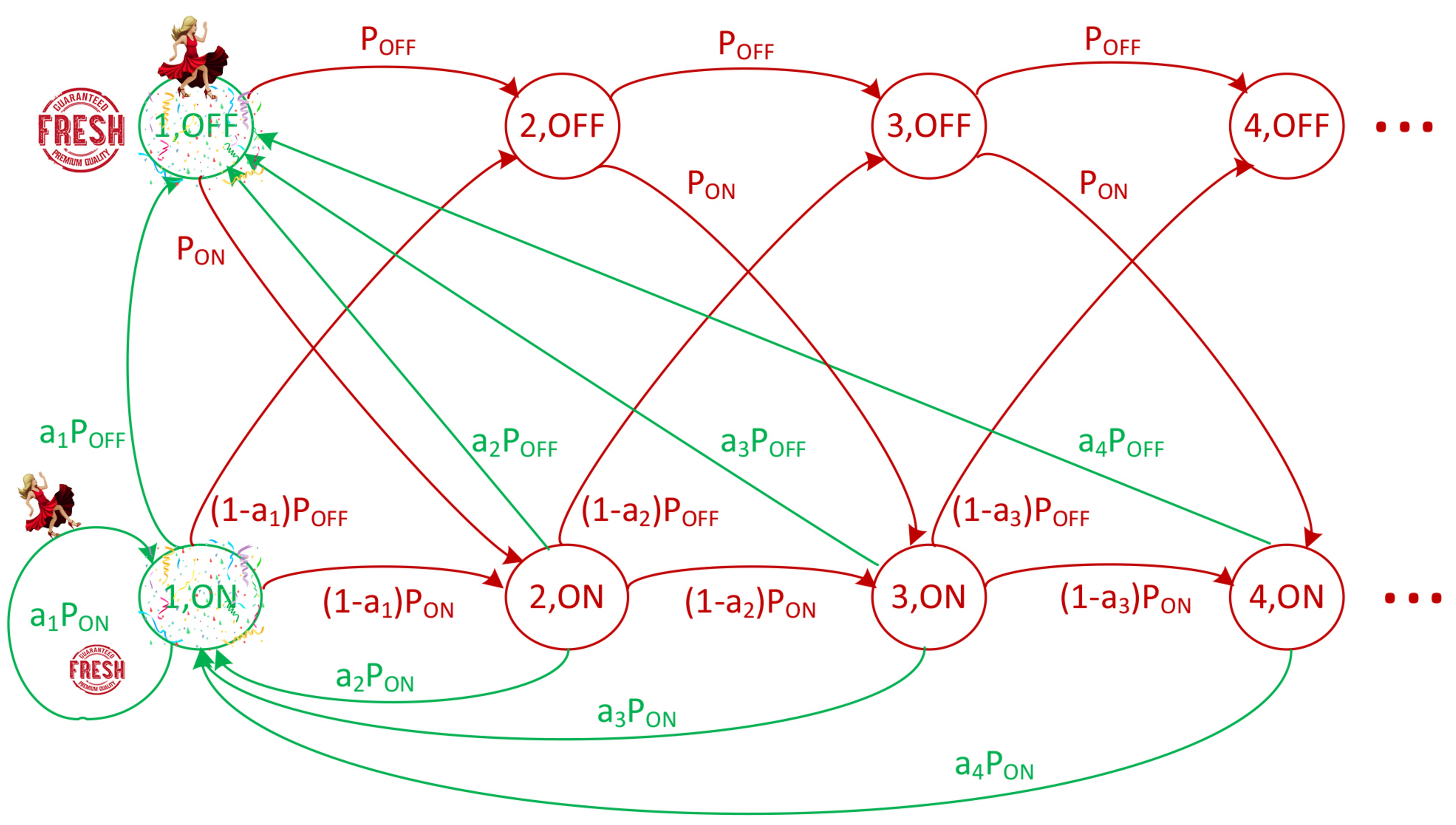
Overview



- Point-to-point communication link powered by **Wireless Energy Transfer (WET)**
- Receiver pulls data from the sensor support data requests it receives
- **Receiver's Goal:** Pull the **freshest data from the sensor** by sending energy to it at opportune instants with regard to the channel state
- **Freshness Metric:** Age of Information (AoI)

System Model

- Receiver constrained by time-average energy λ.
- The receiver can send at most **one unit of energy** per slot.
- Transmitter directly uses the harvested energy (**no storage**).
- Each transmission consumes **unit** energy.
- IID ON - OFF channel: ON with probability P_{ON}.
- When the channel state is ON, any transmitted packet is correctly decoded.
- When the channel state is OFF, there is no transmission.
- The transmit decision in slot t is denoted by $\mathbf{a_t \in \{0,1\}}$.
- The Age of information (AoI), $\mathbf{\Delta_t}$, either increases by 1 slot, or drops to 1, depending on success of transmissions: a Markov model.
- **Age Violation Probability:** The probability that the age exceeds a certain value.



Time-Average Expected AoI Minimization Problem

$$\min_{\pi} \Delta^{\pi}(s_0) = \lim_{T\to\infty} \frac{1}{T} E[\sum_{t=1}^{T} \Delta_t^{\pi} | s_0],$$

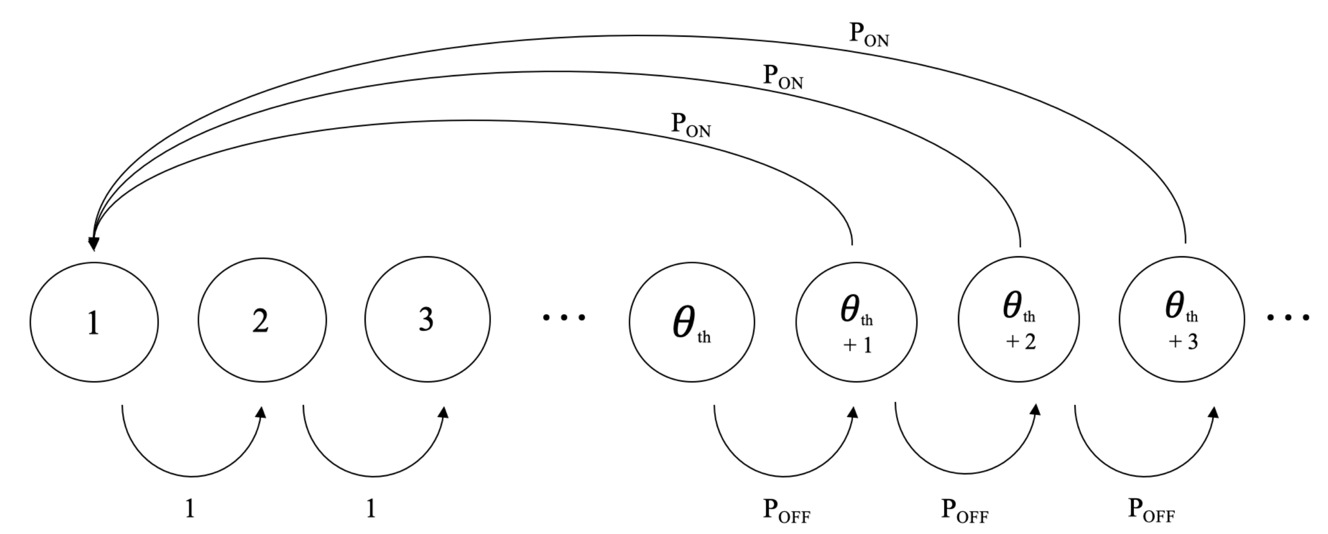
$$\text{subject to } E^{\pi}(s_0) = \lim_{T\to\infty} \frac{1}{T} E[\sum_{t=1}^{T} a_t^{\pi} | s_0] \leq \lambda$$

- Stationary policy (π): Maps the states s into actions a with some probability π(a l s).
- s_0: Initial state, consists of initial AoI and channel state.

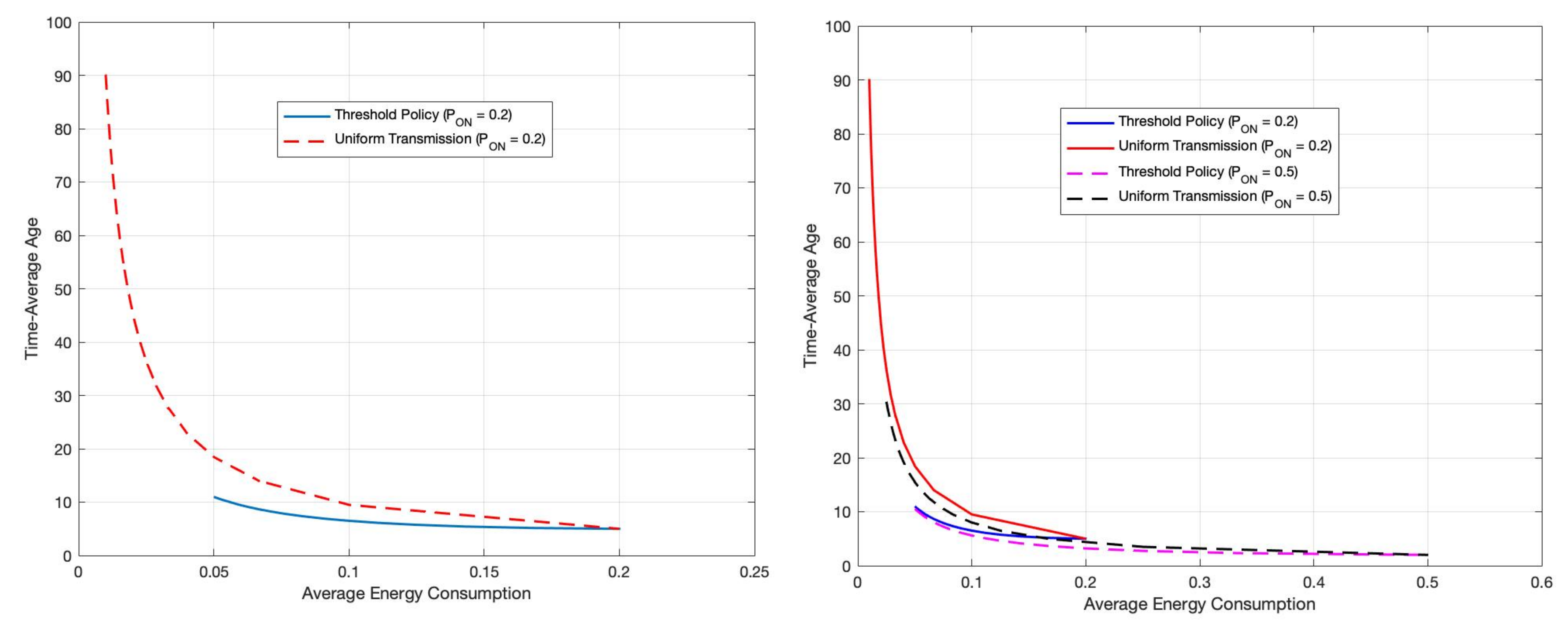
Optimal Threshold Policy

$$a_t = \begin{cases} 1 & \text{if } \Delta_t \geq \Theta_{th}, \\ 0 & \text{if } \Delta_t < \Theta_{th} \end{cases}$$

$$\Theta_{th} = \frac{P_{ON} + \lambda P_{ON} - \lambda}{\lambda P_{ON}} = 1 + \frac{1}{\lambda} - \frac{1}{P_{ON}}$$



Optimal Threshold Policy vs. Uniform Transmission

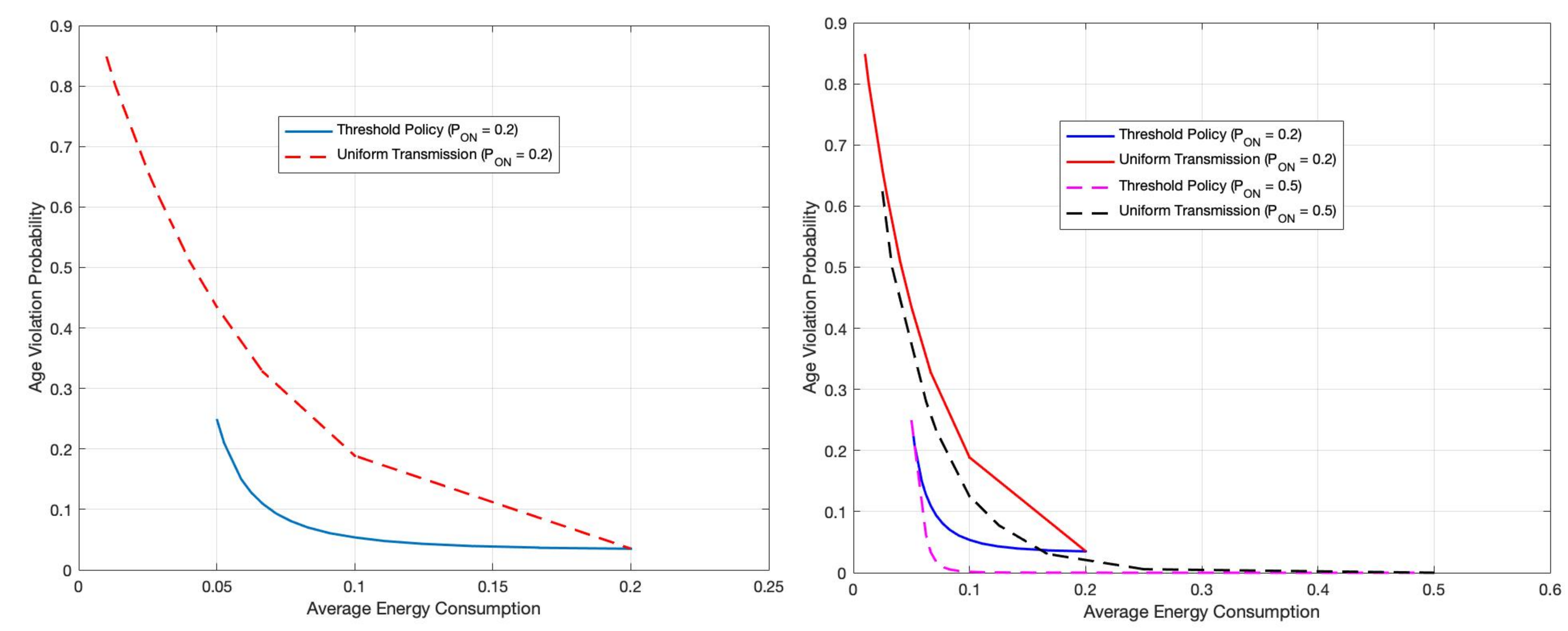


Age Violation Probability

$$Pr(\Delta_t > \gamma) = 1 - Pr(\Delta_t \leq \gamma)$$

$$= \begin{cases} 1 - \gamma * q_{\Theta_{th}} & \text{if } \gamma \leq \Theta_{th}, \\ 1 - [(\Theta_{th} + \sum_{i=1}^{\gamma-\Theta_{th}} (1-P_{ON})^i) * q_{\Theta_{th}}] & \text{if } \gamma > \Theta_{th} \end{cases}$$

$$= \begin{cases} 1 - \gamma * \frac{P_{ON}}{\Theta_{th} * P_{ON} + 1 - P_{ON}} & \text{if } \gamma \leq \Theta_{th}, \\ 1 - [(\Theta_{th} + (\frac{P_{OFF} * (P_{OFF}^{\gamma-\Theta_{th}} - 1)}{P_{OFF} - 1}) * \frac{P_{ON}}{\Theta_{th} * P_{ON} + 1 - P_{ON}}] & \text{if } \gamma > \Theta_{th} \end{cases}$$



Conclusion

- Even in this simple setting with an ON/OFF channel, uniformly pulling data is inefficient.
- Getting fresh data through wireless energy transmission is possible by using an age threshold that depends on the average power available, and the channel capacity.

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