# IE 613 Project Presentation

Multi-player multi-armed Stochastic Bandits for Energy Harvesting

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# Introduction

# What is Energy Harvesting

- Energy Harvesting is the process of converting energy that is obtained from external energy sources such as wind, thermal, kinetic and solar energy into electricity.
- RF energy is one form of electromagnetic energy which consists of radio waves of magnetic and electrical energy radiating through free space. RF-EH becomes a propitious solution for wireless networks with a limited lifetime

# Why is Energy Harvesting becoming a buzz word?

- The market has noticed a tremendous growth in the energy consumption patterns due to continuously expanding network of connected devices
- The alternative wireless information and power transfer techniques are important from the operational cost saving apart from the theoretical research.
- It allows wireless nodes to recharge their batteries from the radio frequency signals instead of fixed power grids and traditional sources of energy

# Technologies used in Harvesting Energy

- Wireless Power Transfer (WPT): uses the transmission of electrical energy from a power source, using electromagnetic fields to the electrical component in the circuit that uses electrical power without wired connections.

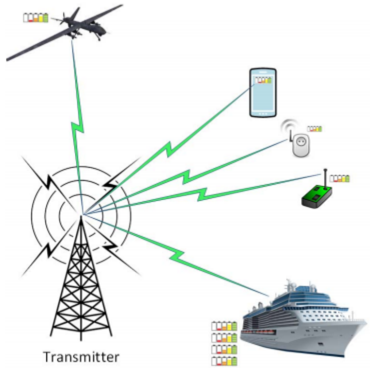
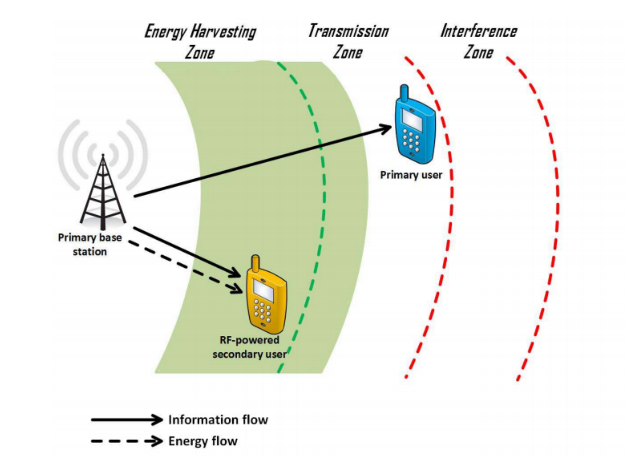



Fig. 2. RF Wireless Power Transfer - Devices such as cellular phone, sensors, drones, electronic devices in vessels receive and harvest energy from RF signals and recharge their batteries.

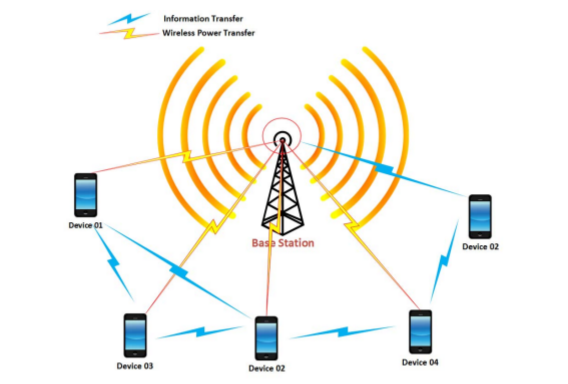
# Technologies used in Harvesting Energy

- Simultaneous Wireless Information and Power Transfer (SWIPT): It enables the simultaneous transfer of information and power wirelessly and hence a trade-off has to be made between the information rate and the harvested energy level. This trade-off varies with the system.



# Technologies used in Harvesting Energy

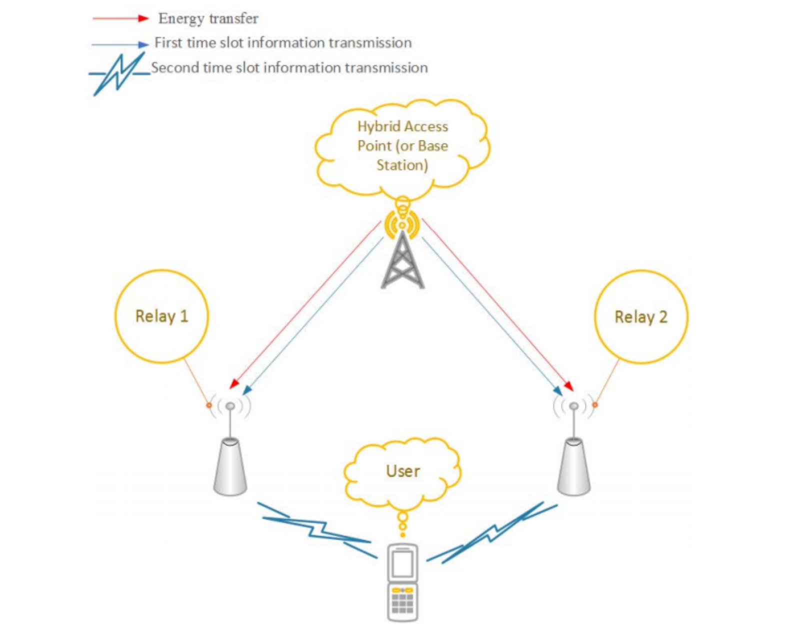
- SWIPT assisted Device to Device Communication: It provides a direct connection between the users with partial or almost no network infrastructure utilization.



# Efficient ways of Energy Harvesting

- Cooperate Relaying: In a wireless communication network, the location of nodes vary and sometimes even hinder each other nodes due to geographical or climatic reasons, leading to infeasible communication in the line of sight.Relay nodes acts as such intermediate idle nodes which overhears the source's transmission and re-transmit its modified version to the destination to help the overall decoding process.

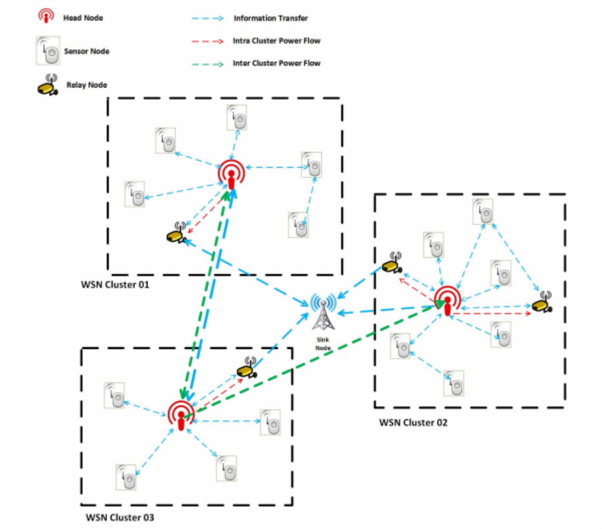
# Relay Network



# Efficient ways of Energy Harvesting

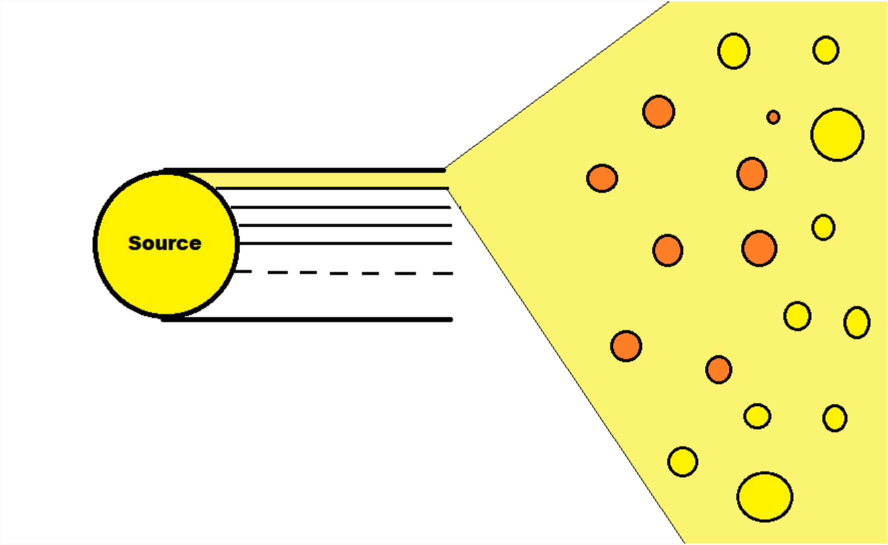
- Clustering: clustering the wireless sensor networks together with applying SWIPT to recharge low energy relay nodes. In such a setting, we would consider a wireless sensor network consisting of multiple clusters of sensors and a common sink node. This sink node is responsible for collecting data from all the sensors. The head node of each cluster works as information and power transferrer. Relay nodes harvest the radio frequency energy from this head node of their cluster and uses this energy to recharge the batteries.

# Clustering of Wireless Sensor Networks

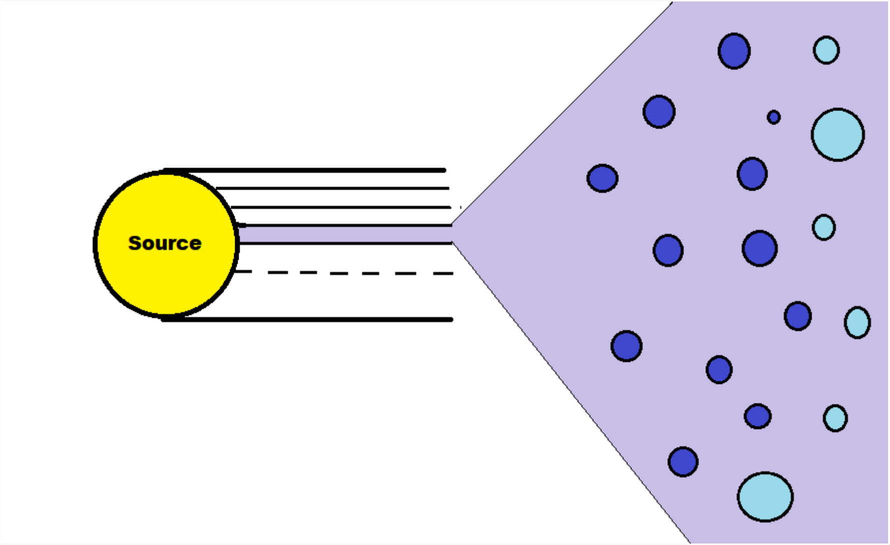


# Energy Harvesting in an Online Setting

# Propagation of Energy through a particular channel



# Energy received differentially with different channels



# Assumptions

- We assume that no node hinders the other in any of the K channels
- Our Source is the main Radio Frequency emitting source
- We are not assuming any sort of clustering of the nodes or sources
- The models are in an energy harvesting setting only and does not include Information transfer simultaneously or otherwise

# Approaching the Problem statement

- We might want to know the channel which maximises the total energy consumption across all energy harvestors. i.e. we would like to find:

$$arg\ \max_k \sum_{n \in [N]} \mu_{kn}$$

- In the previous approach to the problem, it might so happen that the optima is achieved for a value of k for which one or more nodes might die out. In that case, we can frame our objective function as the maximum energy consumed across all nodes such that none of the nodes die out. i.e. we would like to find:

$$arg\ \max_k \min_n \mu_{nk}$$

# Minimizing the sum of Energies Received in total by N nodes

Input: No. of channels K; No. of nodes N.

Step 1: for t=1,2,...,K, do:

Source emits energy through channel t. Observe the energy harvested by each node and calculate the estimated gain of all nodes $\hat{\mu}_t$ for channel t.

Step 2: for t=K+1, K+2, ..., do:

$K_t = arg\ \max_k \{\hat{\mu}_k + \sqrt{\frac{\alpha \log(t)}{Total\ No.\ of\ times\ channel\ k\ has\ been\ used}}\}$

Source emits energy through channel $K_t$. Observe the energy harvested by each node and calculate the estimated gain of all nodes $\hat{\mu_{K_t}}$ for channel t.

Step 3: At whichever round we decide to stop, the channel $K_t$ found at that last round would give us the optimum value to our problem.

where

$$\hat{\mu}_k = \frac{\sum_{t=1}^{T} \sum_{n \in N} X_{nkt}}{Total\ No.\ of\ times\ channel\ k\ has\ been\ selected\ till\ T\ rounds}$$

# Maximizing the minimum energy harvested by any of the N nodes

Input: No. of channels K; No. of nodes N.

Step 1: for t=1,2,...,K, do:

Source emits energy through channel t. Observe the energy harvested by each node and calculate its estimated gain $\hat{\mu_{tn}}$ for channel t.

Step 2: for t=K+1,K+2, ..., do:

for each channel $k$, compute $n_k$ as:

$$n_k = arg\,\underset{n}{min}\{\hat{\mu_{kn}} - \sqrt{\frac{\alpha \log(t)}{Total\ No.\ of\ times\ channel\ k\ has\ been\ used}}\}$$

Now, determine $k_t^*$ as:

$$k_t^* = arg\,\underset{k}{max}\{\hat{\mu_{kn_k}} - \sqrt{\frac{\alpha \log(t)}{Total\ No.\ of\ times\ channel\ i\ has\ been\ used}}\}$$

# Maximizing the minimum energy harvested by any of the N nodes (Cont.)

Source emits energy through channel $k_t^*$. We observe the energy harvested by each node and calculate the estimated gain of them $\hat{\mu_{K_t}}$ for channel t.

Step 3: At whichever round we decide to stop, the channel $k_t^*$ found at that last round would give us the optimum value to our problem.

# Analyzing the Proposed Algorithms

# Minimizing the sum of Energies Received in total by N nodes

We conducted the simulation for K=10, N=50, T=25000 and sample paths=20. We also fixed the parameters $\mu_{nk}$ as $\mu_{nk} = \frac{nk}{(K+1)(N+1)^2}$ for n=1(1)50 and k=1(1)10.

We considered two different cases:

- Gains follow Bernoulli distribution with the above parameters.
- Gains follow Exponential distribution with the above parameters.

# Minimizing the sum of Energies Received in total by N nodes (Contd.)

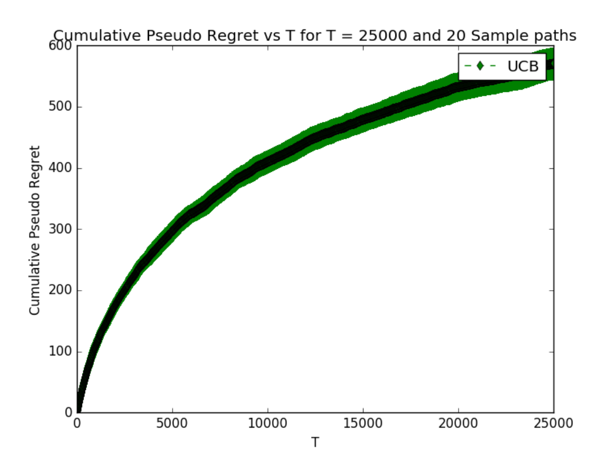



**Figure 1:** Pseudo Cumulative Regret vs T [Gains∼ Benoulli]

# Minimizing the sum of Energies Received in total by N nodes (Contd.)

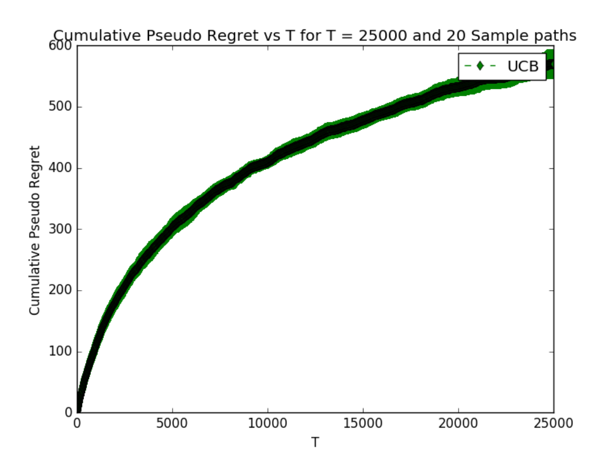



**Figure 2:** Pseudo Cumulative Regret vs T [Gains∼ Exponential]

# Minimizing the sum of Energies Received in total by N nodes (Contd.)

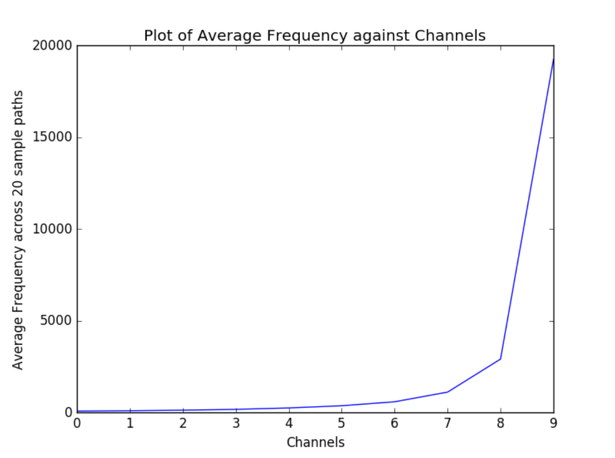



**Figure 3:** Avg. Frequency vs Channels [Gains$\sim$ Bernoulli]

# Minimizing the sum of Energies Received in total by N nodes (Contd.)

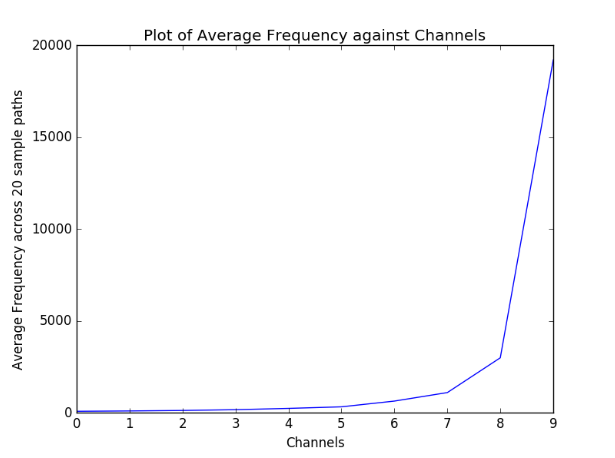



**Figure 4:** Avg. Frequency vs Channels [Gains$\sim$ Exponential]

# Maximizing the minimum energy harvested by any of the N nodes

We conducted the simulation for K=8, N=15, T=25000 and sample paths=20. We also fixed the parameters $\mu_{nk}$ as $\mu_{nk} = \frac{nk}{(K+1)(N+1)^2}$ for n=1(1)15 and k=1(1)8.

We considered two different cases:

- Gains follow Bernoulli distribution with the above parameters.
- Gains follow Exponential distribution with the above parameters.

# Maximizing the minimum energy harvested by any of the N nodes(Contd.)

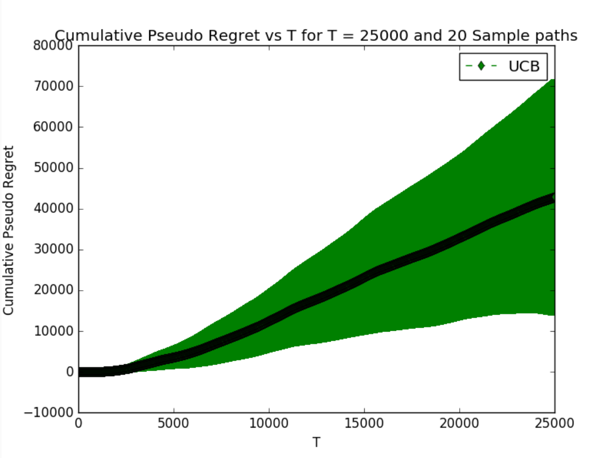



**Figure 5:** Pseudo Cumulative Regret vs T [Gains∼ Benoulli]

# Maximizing the minimum energy harvested by any of the N nodes(Contd.)

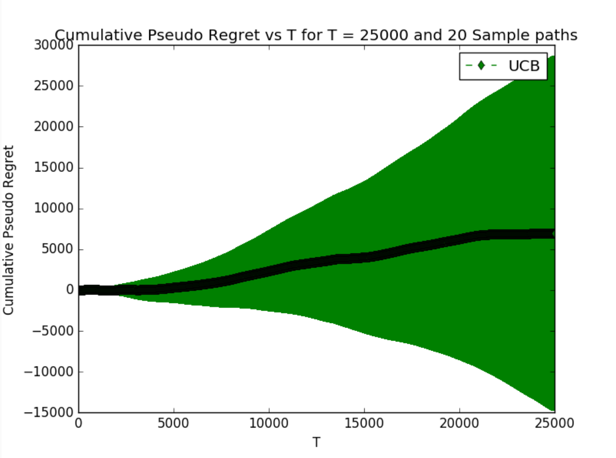



**Figure 6:** Pseudo Cumulative Regret vs T [Gains∼ Exponential]

# Maximizing the minimum energy harvested by any of the N nodes(Contd.)

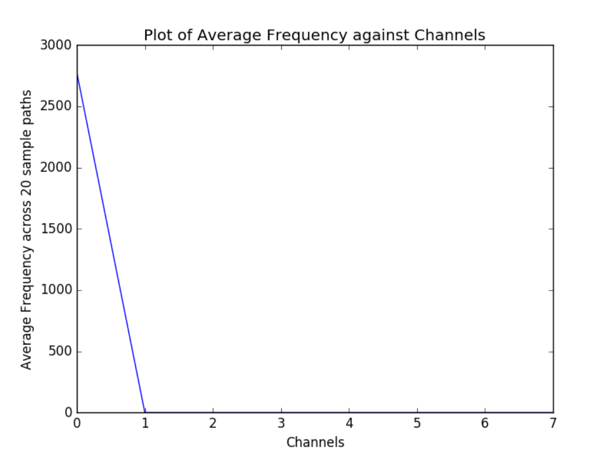



**Figure 7:** Avg. Frequency vs Channels [Gains$\sim$ Bernoulli]

# Maximizing the minimum energy harvested by any of the N nodes(Contd.)

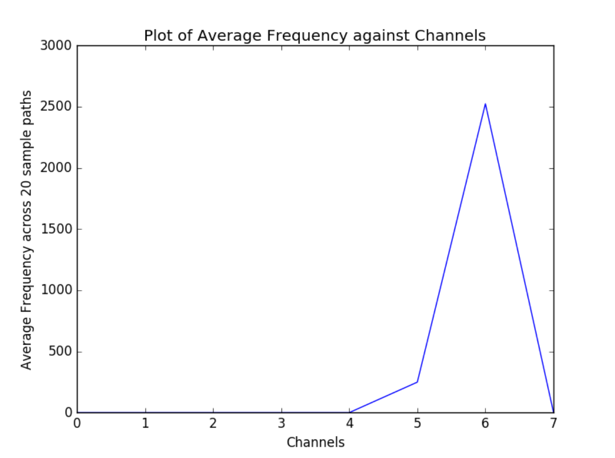



**Figure 8:** Avg. Frequency vs Channels [Gains$\sim$ Exponential]

# Thank you