Optimal Device Selection in Spectrum Sharing Channel under Energy Harvesting Aided D2D Communication

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Outline

- Introduction
- Previous work
- Project Objective
- Proposed Method for Optimal Device Selection
- Results and Discussion
- Conclusion

Introduction: Cellular Data Traffic

Widespread use of portables devices has led to a tremendous surge in demand for mobile data traffic

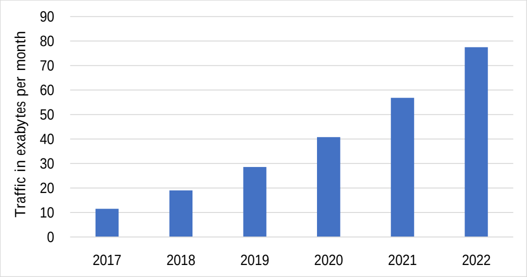

Figure: Mobile data traffic growth prediction [1]

This increase in data traffic has lead to spectrum scarcity.

[1] Cisco visual networking index:global mobile data traffic forecast update, 2017–2022

Introduction: Enhancing Spectral Efficiency

- **Spectrum Sharing:** helps to access the licensed spectrum in an opportunistic manner.
  Use case: device-to-device (D2D) transmissions among its users.
- **D2D Communications:** enables devices to communicate directly without base stations.

Introduction

- **Challenge 1**: Wireless communication is susceptible to numerous attacks.
  - **Solution**: Use Physical Layer Security (PLS).
- **Challenge 2**: Power-limited devices: Difficult to maintain power cable connection.
  - **Solution**: Use Energy harvesting (EH) to recharge power-limited devices.

Previous work and Project Objective

Previous Work

- Hyadi et al.[2] investigated the optimality of sharing cellular spectrum with the underlying D2D system when both system are interested in transmitting secret message.
- No energy limitation on the devices in the D2D system.

Project Objective:

- We introduce Energy harvesting in the underlying D2D system.
- We propose an optimal device selection scheme to improve the secrecy performance of both cellular system and EH-aided D2D pairs.

[2] Towards a win-win spectrum sharing channel

Optimal Device Selection: System Model

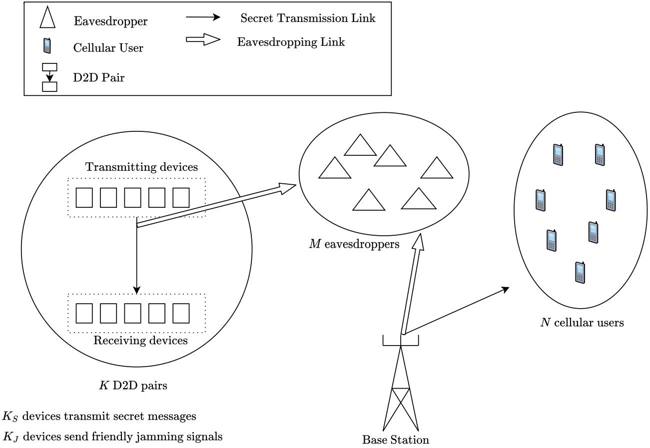

Figure: System Model

Optimal Device Selection: System Model

Received Signals are given by :

$$
\begin{aligned}
Y_{C_n} &= h_{c_n} X_C + \mathbf{L}_{D_n}\mathbf{X}_D + \mathbf{L}_{A_n}\mathbf{X}_J + n_{C_n} \\
Y_{D_i} &= h_{d_i} X_{D_i} + l_{c_i} X_C + \hat{\mathbf{L}}_{D_i}\hat{\mathbf{X}}_D + \hat{\mathbf{L}}_{A_i}\mathbf{X}_J + n_{D_i} \\
Y_{E_m} &= g_{c_m} X_C + \mathbf{G}_{D_m}\mathbf{X}_D + \mathbf{G}_{A_m}\mathbf{X}_J + n_{E_m}
\end{aligned}
$$

X_C, $\mathbf{X}_D$ is the primary and secondary secret data signals.
$\mathbf{X}_J$ is secondary jamming signals.
$\mathbf{L}_{D_n}$, $\mathbf{L}_{A_n}$, $\hat{\mathbf{L}}_{D_i}$, $\hat{\mathbf{L}}_{A_i}$, $\mathbf{G}_{D_m}$, and $\mathbf{G}_{A_m}$ are channel gain vectors.
n_{C_n}, n_{D_i}, and n_{E_m} represent the additive white Gaussian noise (AWGN).
Jamming Signals Generation:

$$
\begin{aligned}
\hat{\mathbf{L}}_A \mathbf{X}_J &= 0 \\
\mathbf{L}_{A_{n*}} \mathbf{X}_J &= 0
\end{aligned}
$$

Optimal Device Selection: Scenario 1

Recap: The work by Hyadi et al. considers no energy limitation on the underlying D2D system.

We consider that all K D2D transmitters have energy harvesting abilities.

- **Scenario 1:**
  - Enough energy to transmit secret messages.
  - Only devices with harvested energy above certain energy threshold can send friendly jamming signals.

Scenario 1: Problem Statement

Given the primary's secrecy sum-rate condition [3]$\mathcal{R}_{C_{sum}} > \mathcal{R}_{th}$ and energy constraint $E_k \geq E_{min}\ \forall k \in \{1, \ldots, K\}$. Find the optimal number of K_S^* and K_J^* that maximizes the secondary secrecy throughput.

$$K_S^* \text{ and } K_J^* = \begin{cases} \underset{\substack{1 \leq K_S \leq K_J - 1 \\ 2 \leq K_J \leq K-1}}{\text{argmax}} & {}^4 \sum_{k=1}^{K_S} \mathcal{R}_{D_k} \\ \text{subject to} & \mathcal{R}_{C_{sum}}(K_S, K_J) \geq \mathcal{R}_{th} \\ \text{s.t.} & K_S + K_J \leq K \end{cases} \tag{1}$$

[3] Ref: Page 12 in report for the primary's secrecy sum-rate expression

[4] Ref: Page 13 in report for the the secondary's secrecy sum-rate expression

Scenario 1: Algorithm

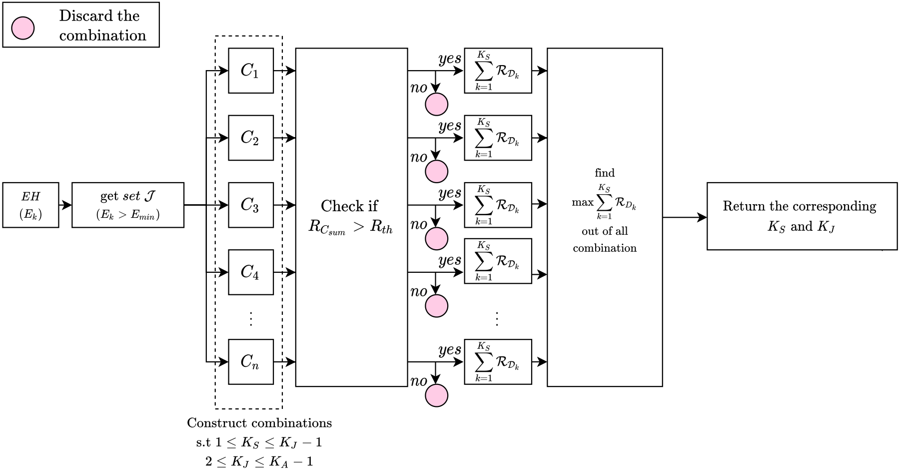

Figure: Device selection algorithm

Scenario 1: Results

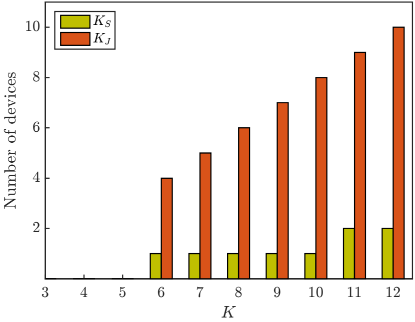

Figure: Optimum number of device

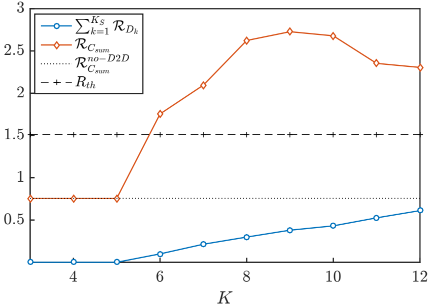

Figure: Achievable secrecy sum-rates

Scenario 1: Issues

Recap: $E_k > E_{min} \; \forall k \in \{1, \ldots, K\}$

- What's the issue? **Energy inefficient!**
  Devices with the energy less than the threshold (E_{min}) will be inactive for the entire time duration.
- Solution:
  Reduce E_{min}, we know that $E_{min} = P_d * t$.

Optimal Device Selection: Scenario 2

Scenario 2

- The harvested energy is utilized in transmitting either data signals or jamming signals.
- To increase the energy and spectral efficiencies, we divide the operating time duration into T sub-slots of equal duration δ.
- Now, the minimum energy required to transmit any signal for the duration δ is given by:

$$E_{min} = P_d * \delta \tag{2}$$

where P_d is the transmit power of secondary devices.

Scenario 2: Problem Statement

Given the primary's secrecy sum-rate condition [5] $R_{C_{sum},\tau} > \mathcal{R}_{th}$ and energy constraint $E_{k,\tau} \geq E_{min}$. Find $K^*_{S,\tau}$ and $K^*_{J,\tau}$ for each sub-slot τ that maximizes the secondary secrecy throughput over all the sub-slots i.e.

$$
\begin{aligned}
\text{Find} \quad & \left[(K^*_{S,1}, K^*_{J,1}), \ldots, (K^*_{S,T}, K^*_{J,T})\right] \\
\textit{maximize} \quad & {}^{6}\sum_{\tau=1}^{T} \mathcal{R}_{\tau} \\
\text{subjected to} \quad & \mathcal{R}_{C_{sum},\tau}(K_{S,\tau}, K_{J,\tau}) \geq \mathcal{R}_{th} \quad \forall \tau, \\
\text{s.t} \quad & 1 \leq K_{S,\tau} \leq K_{J,\tau} - 1 \text{ and } 2 \leq K_{J,\tau} \leq K - 1, \\
& K_{S,\tau} + K_{J,\tau} \leq K
\end{aligned} \tag{3}
$$

[5] Ref: Page 23 in report for the primary's secrecy sum-rate expression

[6] Ref: Page 23 in report for the secondary's secrecy throughput expression

Scenario 2: Algorithm

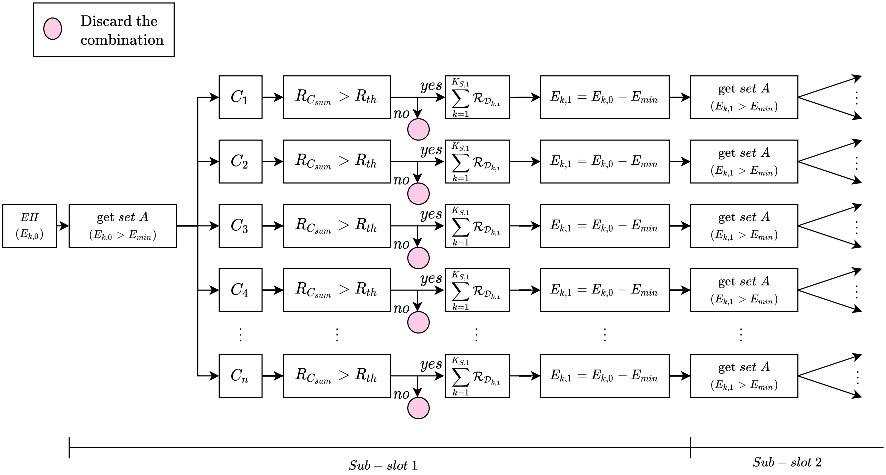

Figure: Optimal device selection algorithm

Scenario 2: Computation time

Table: Computation time optimal device selection

K	Time taken (sub-slot 1)	Time taken (sub-slot 2)
6	2.7947 sec	16.7562 sec
7	24.322 sec	20.23 min

Issue: Computation complexity

- The computation complexity grows exponentially, as the number of sub-slots increases

Solution: Sub-optimal solution

- Decrease the search space. That is, reduce the number of combinations at each sub-slot that the algorithm has to search

Scenario 2: Sub-optimal algorithm

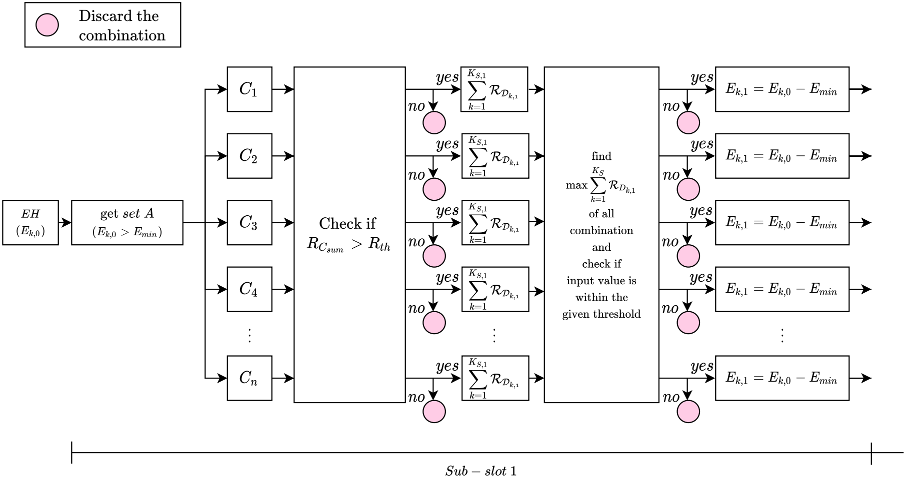

Figure: Sub-optimal device selection algorithm

Scenario 2: Results

Table: Comparison of device selection and secrecy throughput between optimal and sub-optimal solutions

Device selection scheme	K	(KS,KJ)		RD throughput	Rc_sum
		S1	S2		
Optimal	6	(0,2)	(0,2)	0.115	0.872
	7	(1,5)	(1,4)	0.356	2.46
Sub-optimal (maxRD threshold 20%)	6	(0,2)	(0,2)	0.115	0.872
	7	(1,5)	(1,4)	0.356	2.46

Scenario 2: Sub-optimal solution results

Table: Device selection using sub-optimal solution across 4 sub-slots

Number of sub-slots	K	(KS, KJ)			
		S1	S2	S3	S4
No sub-slot	6	(0,2)			
	7	(1,4)			
	8	(1,5)			
	9	(1,6)			
4	6	(1,3)	(0,2)	(0,2)	(0,2)
	7	(1,6)	(1,5)	(1,4)	(1,4)
	8	(1,6)	(1,6)	(1,6)	(1,7)
	9	(1,7)	(1,7)	(1,7)	(1,7)

Scenario 2: Sub-optimal solution results

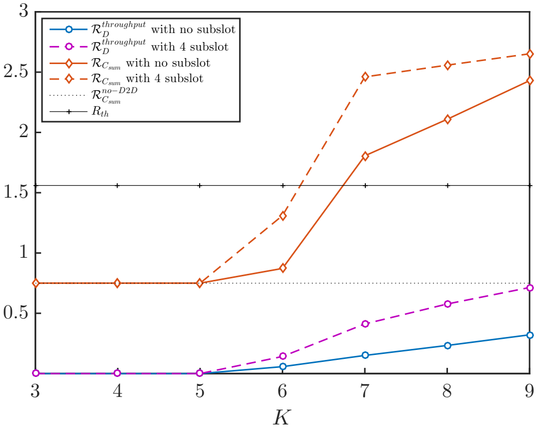

Figure: Achievable secrecy rate with 4 sub-slots and no sub-slot by fixing sub-optimal max $\mathcal{R}_D$ threshold (Γ_{th}^{maxRD}) to 20%.

Scenario 2: Sub-optimal solution results

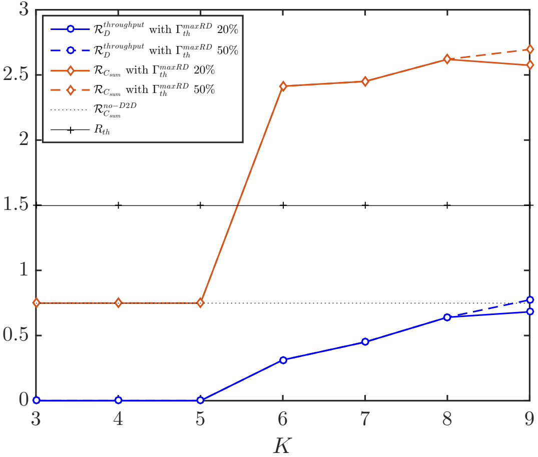

Figure: Achievable secrecy rate with Γ_{th}^{maxRD} 20% and Γ_{th}^{maxRD} 50% using sub-optimal device selection scheme, with 4 sub-slots.

Conclusion

- We propose sub-optimal solution to reduce computational complexity.
- The secondary devices at each sub-slot are chosen based on energy constraint. Proposed algorithm selects K_S and K_J such that the overall secondary throughput across all the sub-slots is maximized.
- We also observe an improvement in the secrecy performance of secondary and primary system when increasing the number of sub-slots.

Future work

- Perform analysis on online energy harvesting scheme.

Thank you!

References

Amal Hyadi and Fabrice Labeau. “Towards a Win-Win Spectrum Sharing Channel: A Secrecy Perspective”. In: *ICC 2019-2019 IEEE International Conference on Communications (ICC)*. IEEE. 2019, pp. 1–6.