# 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

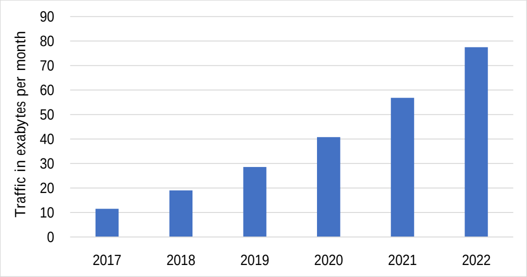


Figure: Mobile data traffic growth prediction [1]

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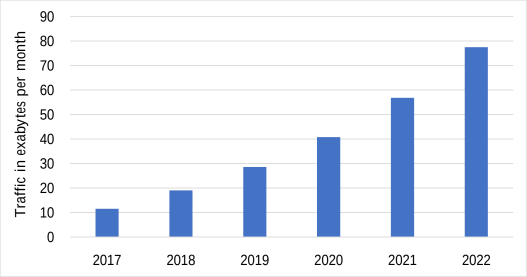


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This increase in data traffic has lead to spectrum scarcity.

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  **Use case**: device-to-device (D2D) transmissions among its users.
- **D2D Communications:** enables devices to communicate directly without base stations.

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  - **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

[2] Towards a win-win spectrum sharing channel

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- 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.

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# Optimal Device Selection: System Model

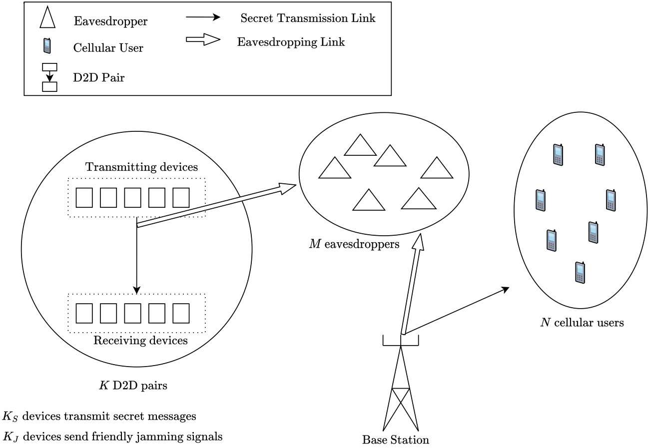


Figure: System Model

# Optimal Device Selection: System Model

**Received Signals are given by :**

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

$X_C$, $\mathbf{X}_D$ 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.
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$n_{C_n}$, $n_{D_i}$, and $n_{E_m}$ represent the additive white Gaussian noise (AWGN).
**Jamming Signals Generation:**

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

# Optimal Device Selection: Scenario 1

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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.

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

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

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# Scenario 1: Algorithm

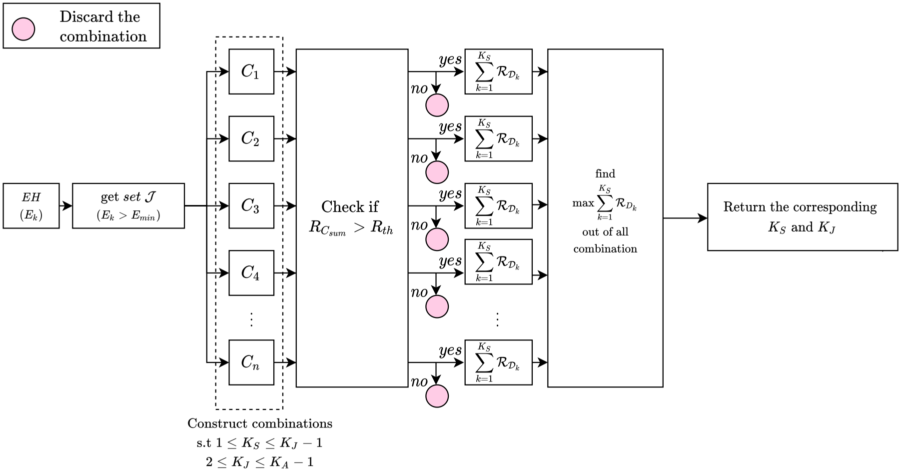


Figure: Device selection algorithm

# Scenario 1: Results

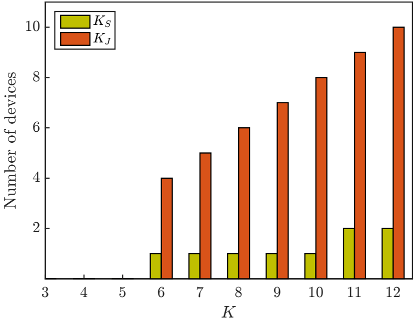


Figure: Optimum number of device

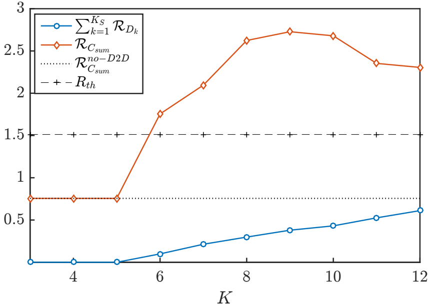


Figure: Achievable secrecy sum-rates

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- Solution:

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- 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 $E_{min} = P_d * t$.

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**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 $\delta$.
- Now, the minimum energy required to transmit any signal for the duration $\delta$ 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 $\tau$ that maximizes the secondary secrecy throughput over all the sub-slots i.e.

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$$
\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}
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# Scenario 2: Algorithm

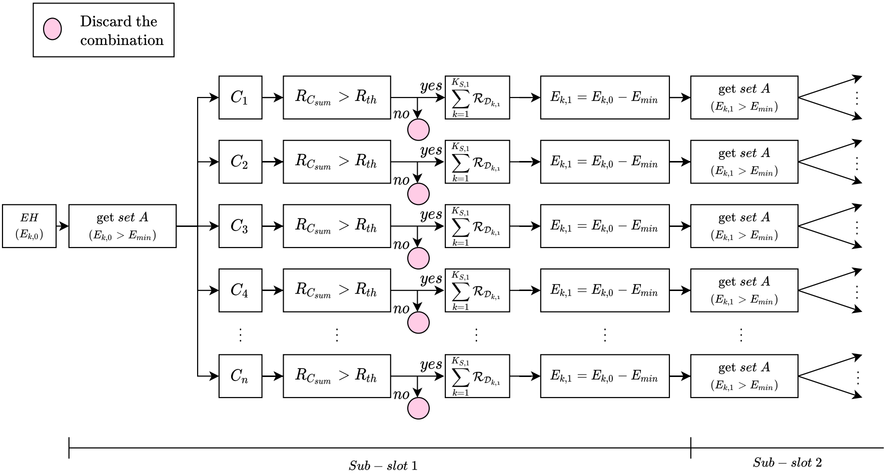


Figure: Optimal device selection algorithm

# 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 |

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**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

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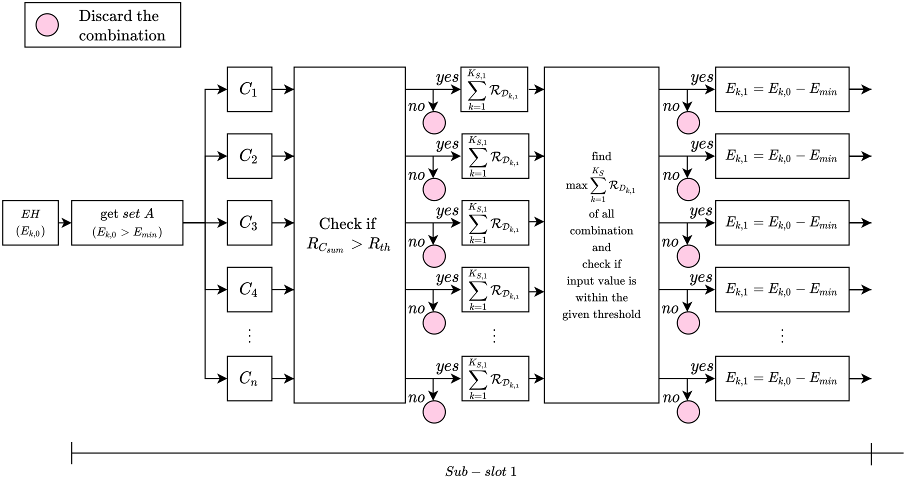


Figure: Sub-optimal device selection algorithm

# Scenario 2: Results

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

| Device selection scheme | K | (KS,KJ) S1 | (KS,KJ) S2 | RD throughput | Rc_sum |
|---|---|---|---|---|---|
| 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) |

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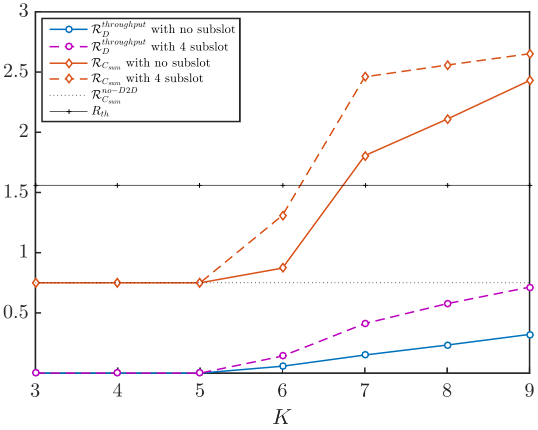


Figure: Achievable secrecy rate with 4 sub-slots and no sub-slot by fixing sub-optimal max $\mathcal{R}_D$ threshold ($\Gamma_{th}^{maxRD}$) to 20%.

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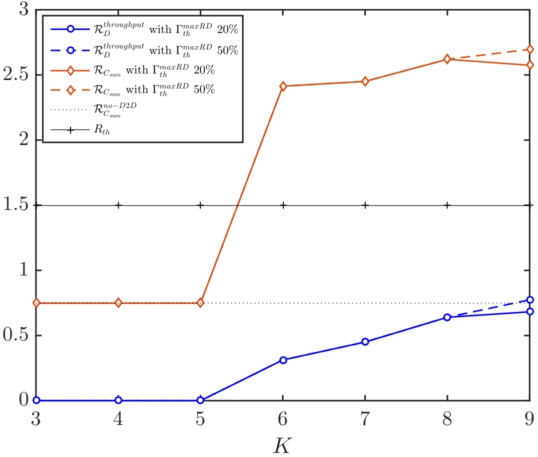


Figure: Achievable secrecy rate with $\Gamma_{th}^{maxRD}$ 20% and $\Gamma_{th}^{maxRD}$ 50% using sub-optimal device selection scheme, with 4 sub-slots.

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- We also observe an improvement in the secrecy performance of secondary and primary system when increasing the number of sub-slots.

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**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.