Dynamic Resource Allocation for 5G Device-to-Device Communication Based on Expected SARSA

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ULTRAS

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Contents:

1. Background

Background

- Problem: Increasing demand on communication and mobile device usage overwhelm the base station

- Solution: Usage of Device-to-Device (D2D) communication

- Issues with D2D communication that hinder user experience
  - Peer Discovery
  - Interference Management

- Components contributing to interference management
  - Resource Allocation
  - Resource Management
  - Power Control

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2. Objectives

Objectives

- Analyzing the available strategies of resource allocation for D2D communication
- Developing a mechanism for dynamic resource allocation for network authorized underlay D2D communication to realize a high system performance in terms of
  - Achieved throughput
  - Signal-to-noise ratio
  - Delivery delay
  - Delivery ratio

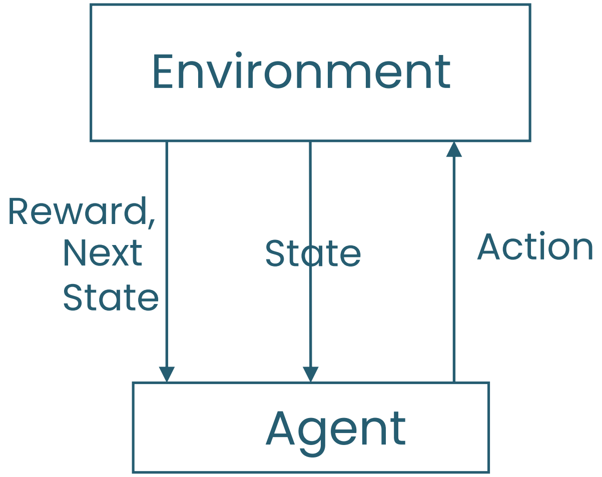
3. Methodology

Methodology

- Proposed method: Applying **Expected SARSA** reinforcement learning algorithm for dynamic resource allocation in 5G D2D communication

Reinforcement Learning

- Consists of 5 elements : state, action, reward, agent and environment
- Concept: Searching for the optimal policy depending on the rewards gained by performing actions in a certain state



Methodology

SARSA

- Stands for:
State–Action–Reward–Next State–Next Action
- On-policy exploration method
- Q value: Return expected for taking a certain action in a certain state following the policy

Expected SARSA

- Extension of SARSA
- Consider the weighted average of Q-values of all possible actions in the next state for Q-value estimation
- Reduced variance
- Converges faster
- Requires less training

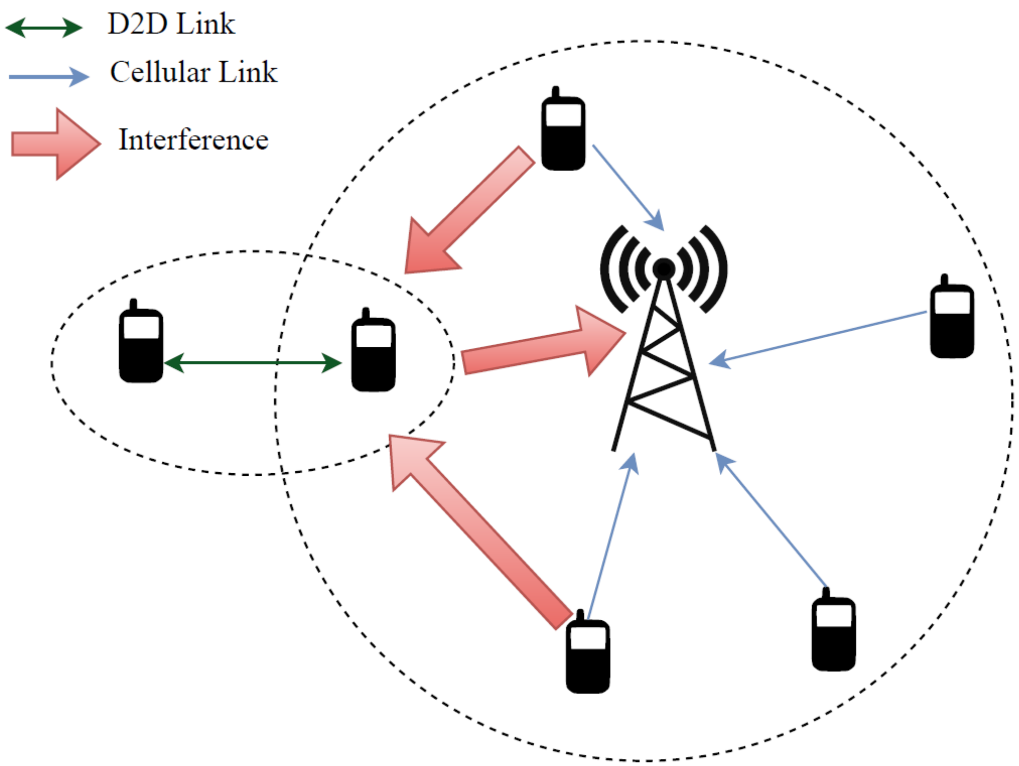
Methodology | Expected SARSA

- Agent observes the current state
- Agent selects an action according to the policy : ε – Greedy policy
- ε – Greedy policy :
    - $0 \leq \varepsilon \leq 1$
    - With probability 1-ε : Action with the highest estimated Q-value (Exploitation)
    - Else : Random action selection (Exploration)
- Agent observes the obtained reward for the action taken and the next state
- Agent estimates the Q-values
- Agent update the policy for the current state based on estimated Q-values

Methodology | Implementation

Scenario Definition

- One D2D pair and number of interfering devices
- Simulation duration : 30 s
- Packet size : 1000 bytes
- Transmission protocol : UDP
- Base station transmission power: 46dBm
- Simulation framework :
    - OMNeT ++ (version 6.0) [1]
    - Simu5g (version 1.2.1) [2]



Methodology | Implementation

Other Parameters

- Distance between base station and D2D user pair: 50m
- Mobility model: Mass Mobility
- Two methods in comparison :

Default Case

- Default setup in simu5G
- Carrier frequency: 2GHz
- Number of resource blocks: 50
- Numerology index: 0
- Bandwidth: 5 MHz
- D2D transmission power: 26 dBm

Our Work

- Carrier frequency: 2GHz
- The following parameters are changed according the table
  - ❑ Number of resource blocks
  - ❑ Numerology index
  - ❑ Bandwidth
  - ❑ D2D transmission power

Considered Parameters for Expected SARSA

- Number of states = 3
- In our work: State and reward functions are based on system throughput
- Number of actions = 5
- Action consists of Number of resource blocks, Numerology index and Transmission power
- Action space:

Action	Bandwidth (MHz)	Number of Resource Blocks	Numerology Index	Transmission Power (dBm)
1	25	125	0	23
2	20	100	0	23
3	20	50	1	26
4	5	25	0	26
5	30	75	1	26

Methodology | Implementation

Experiment	Parameter	Considered values
Average throughput comparison of our work and default case	D2D pair distance(dD2D)	20m , 40m, 60m
	Number of Interfering Devices (NI)	None, 10, 25
SNR result comparison of our work and default case	dD2D	20 m
	NI	25
Reliability and delay assessment	dD2D	60 m
	NI	25
Investigating the impact of mobility	3 cases	Mobile D2D, No NI
		Mobile D2D NI: 25 & stationary
		Mobile D2D NI: 25 & mobile

Methodology | Implementation

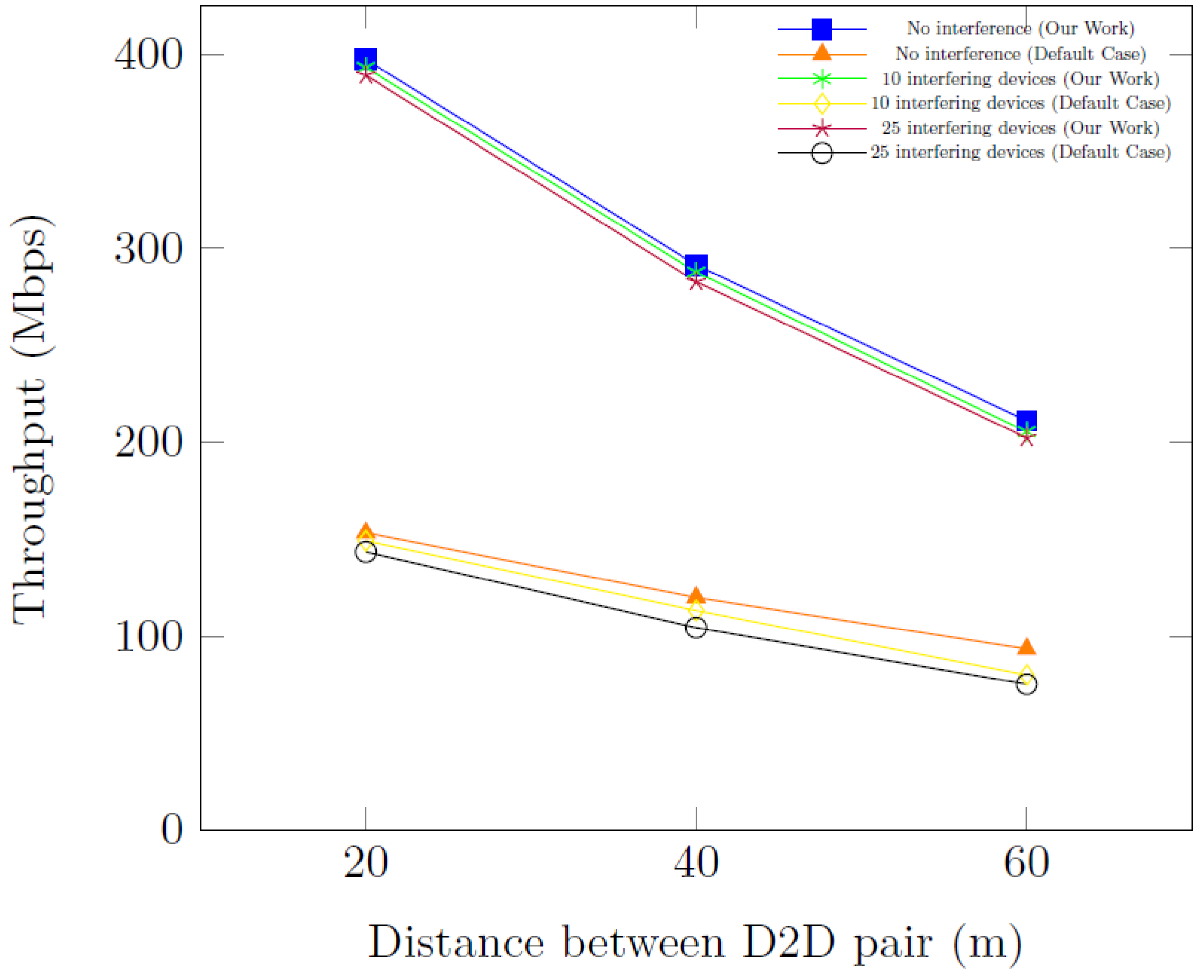
Performance Evaluation Criteria

- System throughput (Mbps)
- Signal to noise ratio
- Delivery delay (ms)
- Delivery ratio

4. Results

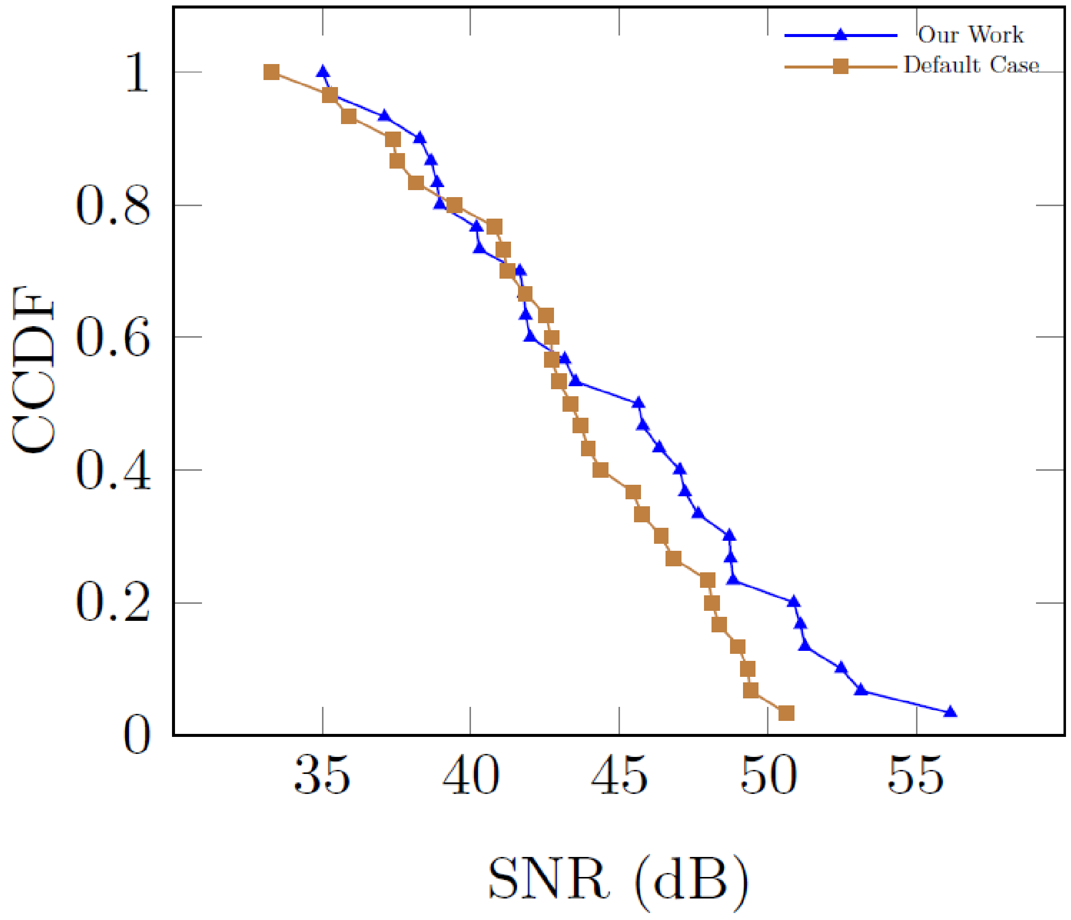
Results

Average D2D throughput comparison for various distances between the D2D pair with different interference scenarios



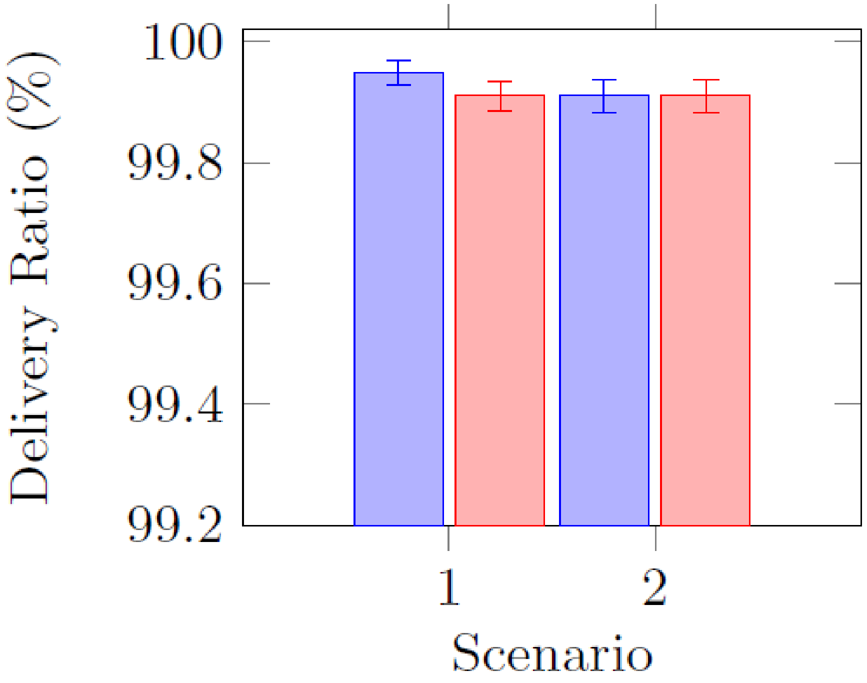
Results

CCDF plot of measured SNR with 25 interfering devices for a 20 m D2D pair distance

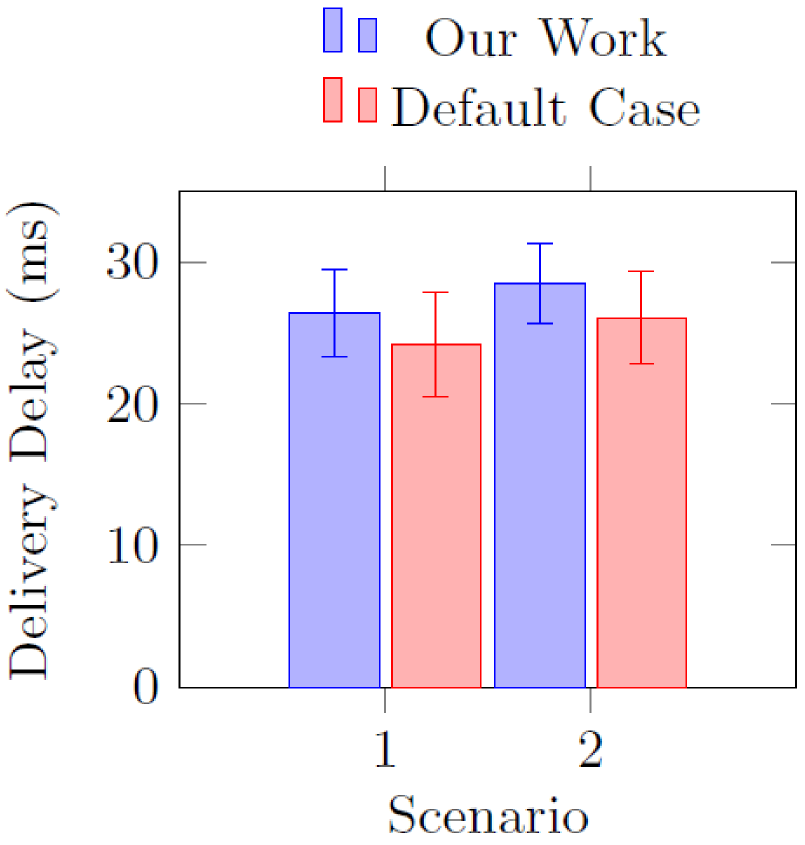


Results

Reliability and delay assessment



Average Delivery Ratio (%)



Average Delivery Delay (ms)

Results

Investigating the impact of mobility

Scenario	No Interference	25 Stationary Interfering Devices	25 Mobile Interfering Devices
Our Work	294.25 Mbps	292.78 Mbps	293.78 Mbps
Default Case	113.60 Mbps	114.23 Mbps	115.33 Mbps

Results – Remarks on the Simulation

Computational Complexity

- **Compared to default case:**
  - **Time required for simulation:** 3 times higher
  - **Additional memory consumption:** 15 %

- **Time required to simulate 30 s** : 1 min in real time
- **Memory consumption**: 38%

5. Conclusion & Outlook

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Conclusion & Outlook

Conclusion

- Proposed algorithm delivers improved system throughput with high reliability
- Slight degradation of delivery delay values
- Computational complexity of the algorithm stands within a tolerable range
- Expected SARSA based resource allocation enhance performance with reduced interference in 5G D2D

Outlook

- Extend the concept with multiple D2D user pairs
- Analysis with real mobility scenarios
- Implement and evaluate the case of switching carrier frequency and other parameters
- Study the means of degrading delivery delay alongside applying our algorithm

References

[1] Varga, A.: The OMNET++ discrete event simulation system. In: Proc. ESM'2001, vol. 9, 01 2001

[2] Nardini, G., Sabella, D., Stea, G., Thakkar, P., Virdis, A.: Simu5G–An OMNeT++ library for end-to-end performance evaluation of 5G networks. IEEE Access 8, 181176–181191, 2020

[3] 3GPP: Technical specification group services and system aspects; study on architecture enhancements to support proximity services. Techn. rep. 23703, 2013

[4] Mantilla, I., Turau, V.: Comparison of WiFi interference mitigation strategies in DSME networks: Leveraging reinforcement learning with Expected SARSA, 2023

[5] Gupta, S., Patel, R., Gupta, R., Tanwar, S., Patel, N.: A survey on resource al- location schemes in device-to-device communication. In: 2022 12th Int. Conf. on Cloud Comp., Data Science Eng. (Confluence). pp. 140–145, 2022

[6] Austine, A., Pramila, R.S.: A review on recent research directions in device to device communication. In: 3rd Int. Conf. on Inventive Computation Tech., 2018

[7] Randhava, K.S., Roslee, M., Nmenme, P.U., Yusoff, Z.: Radio resource allocation for interference management in device to device (D2D) 5G networks. In: 2021 Int. Conf. on Electrical, Comm. , and Computer Eng. pp. 1–6, 2021

[8] Van Seijen, H., van Hasselt, H., Whiteson, S., Wiering, M.: A theoretical and empirical analysis of expected sarsa. In: 2009 IEEE Symposium on Adaptive Dynamic Programming and Reinforcement Learning. pp. 177–184, 2009

Thank you for your attention

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Methodology | Expected SARSA

$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha[R + \gamma(\sum_{A_t \in \delta_t} \pi(A_t|S_{t+1})Q(S_{t+1}, A_t) - Q(S_t, A_t))$$

S_t = Current state
A_t = Current action
R = Reward
S_{t+1} = Next state
A_{t+1} = Next action
Π = ε – Greedy policy, where $0 \leq \varepsilon \leq 1$
α = Learning rate (0.5)
δ_t = Set of all actions applicable in state S_t
γ = Discount factor (0.99)

Methodology | Implementation

- State and reward functions depend upon throughput

$$\text{Throughput} = B \log_2(1+\text{SNR})$$

$$\text{SNR} = \frac{\text{Transmitted Power}}{\text{No} + \Sigma\text{I}}$$

$$B = 2^{\mu}\,\frac{\text{Number of Resource Blocks}}{5}$$

ΣI = summation of total interference at the receiving end

μ = Numerology index

Performance Metrics

- System Throughput: The amount the data transmitted over a communication link within a certain time period
- Signal-to-noise ratio: Ratio of signal power to noise power
- Delivery ratio: The ratio of delivered packets to the number of generated packets
- Delivery delay: The time difference between actual packet generation and reception