Modeling and Improving Device to Device Discovery

Collin Brady

UNIVERSITY *of* WASHINGTON

DISCLAIMER

This presentation was produced by guest speaker(s) and presented at the National Institute of Standards and Technology's 2019 Public Safety Broadband Stakeholder Meeting. The contents of this presentation do not necessarily reflect the views or policies of the National Institute of Standards and Technology or the U.S. Government.

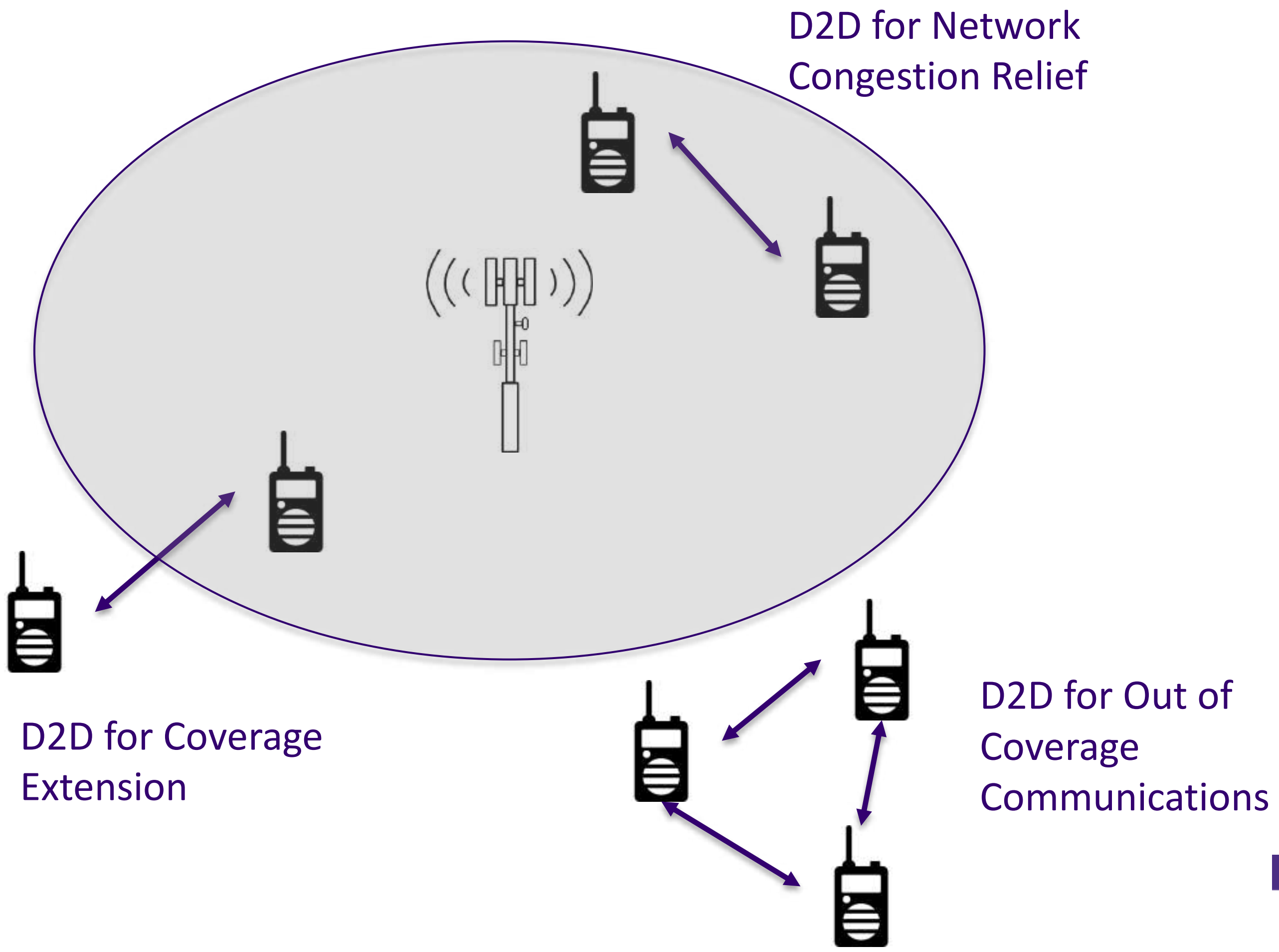
Posted with permission

Overview

- **Motivation:** Current LTE releases lack a robust D2D discovery process. As more public safety users adopt LTE, D2D discovery must be optimized for time critical situations.
- **Approach:** Modeling each discovery round as a random access scheme allows for mathematical analysis with complimenting NS-3 simulations.
- **Future Work:**
  - Algorithmic adaptation of transmission probability

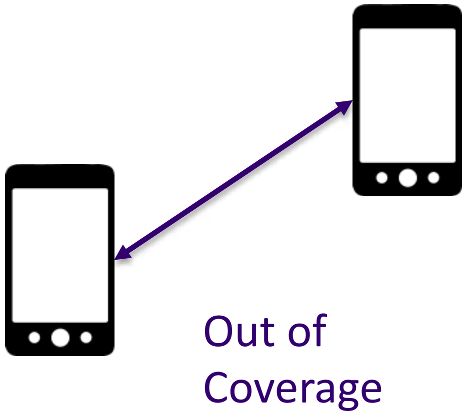
Section 1:
Problem Overview

D2D in LTE

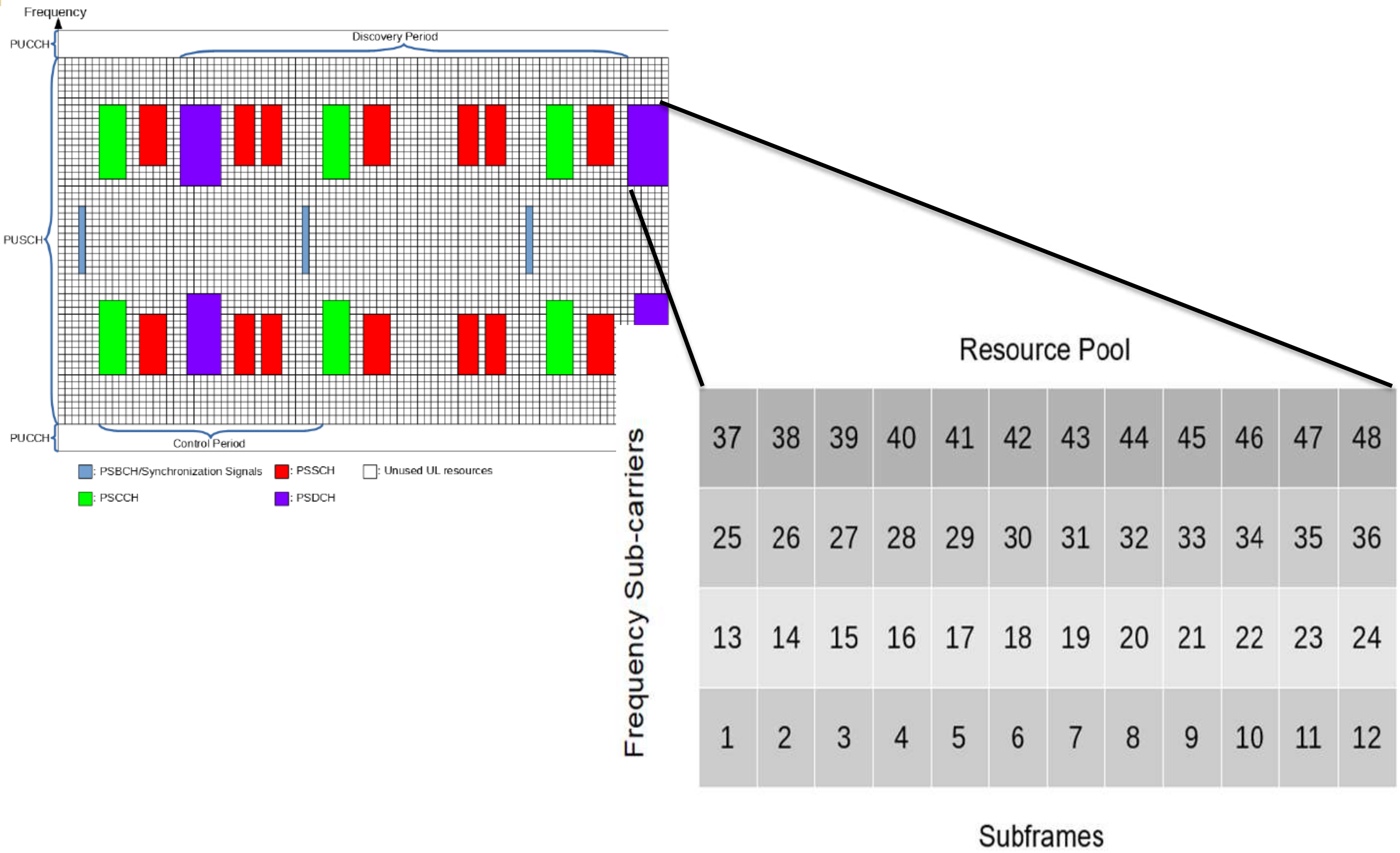

D2D for Network Congestion Relief
D2D for Coverage Extension
D2D for Out of Coverage Communications

D2D Discovery

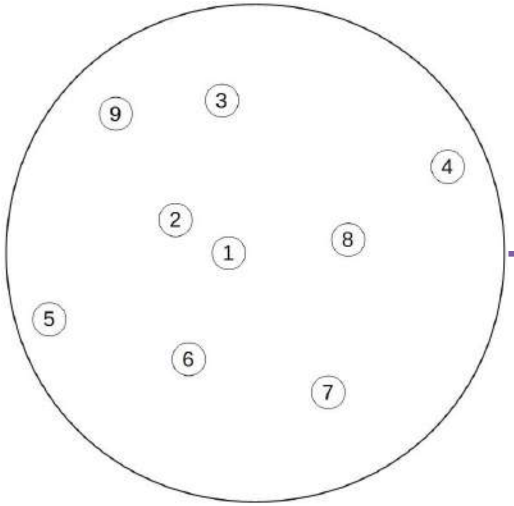
- Discovery is a function that allows UE other UE in their vicinity
- Discovery occurs in two ways:
  - Mode 1: In network
  - Mode 2: out of network
- Discovery messages advertise what each UE is capable of



LTE Physical Sidelink Discovery Channel(PSDCH)



Mode 2 Discovery Process



Single Discovery Period

1) Transmit with probability θ

2) Select one of N_r physical resource blocks to transmit

3) Resolve multiple occupancies

Repeat until discovery is complete

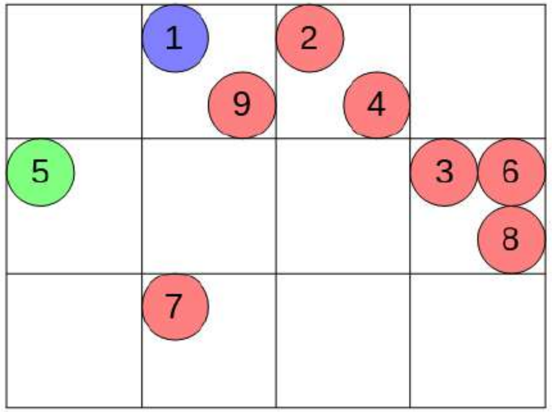
- In practice discovery never stops
- Practically we end discovery once all UE have discovered all other UE

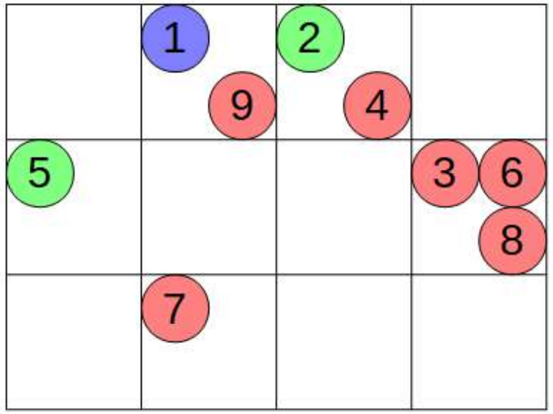
Resolving Multiply Occupied Physical Resource Blocks

MCM

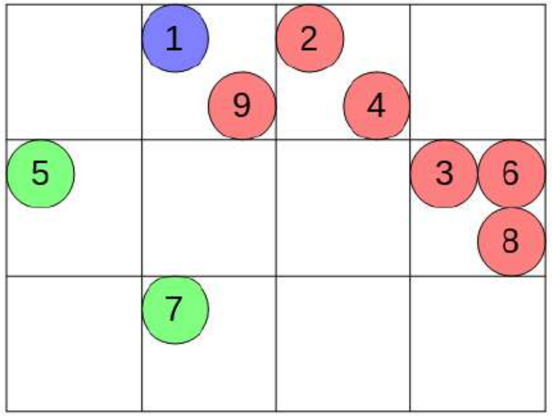
PCM

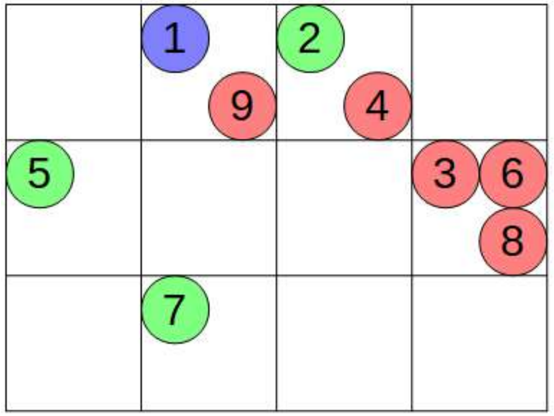
HD





FDD





Section 2:
Mathematical Formulation

Mathematical Model Overview

Split the model into two parts:

Single Round: Model the a discovery period and determine the probability distribution for K discoveries

Whole Process: Use a Markov chain model to model the discovery completion time, the time it takes for one UE to discover all other UE

Single Round Model

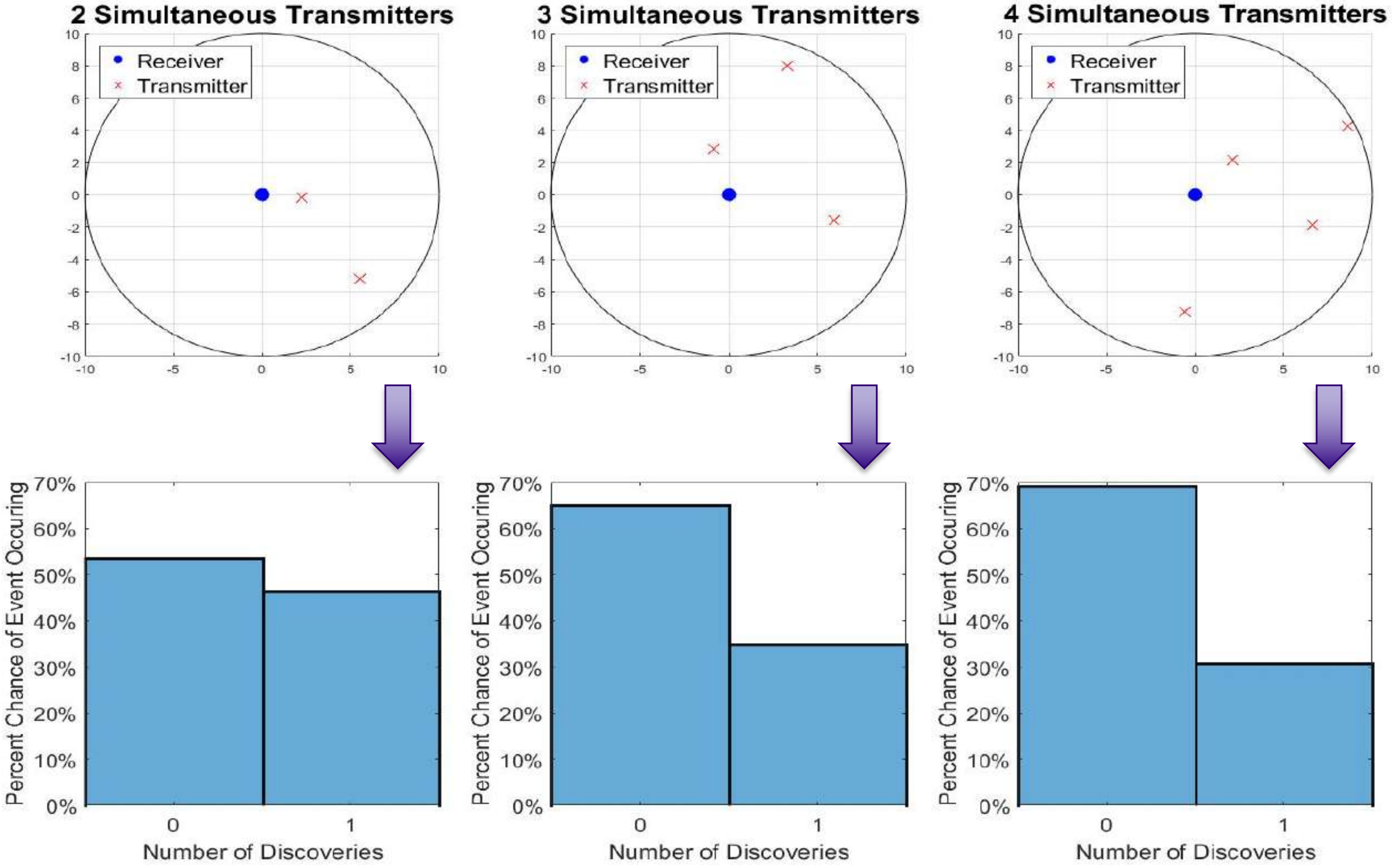
- Define $P_{disc}\left(k \middle| N_p; N_{UE}, N_r, N_t, \theta\right)$
- Conditioning on events:
  - Whether or not a reference UE transmits
    - If it does: The number of transmitting UE who select either the same PRB(FDD) or the same sub-frame(HD) as the reference UE
  - The number of other UE that choose to transmit aside from the reference UE
- Determine the number of discoveries based on only PRB occupancies(MCM) or PRB occupancies and physical distribution(PCM)

UE PRB Choices

UE	Resource selected																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1			X																	
2							X													
3																			X	
4			X																	
5														X						
6									X											
7																			X	
8								O												
9							O													
10			O																	

	Number of users in each PRB																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$X_{u,tx}$	0	0	2	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	2	0
$X_{p,tx}$	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Collision and Capture Probabilities



Single Round Results

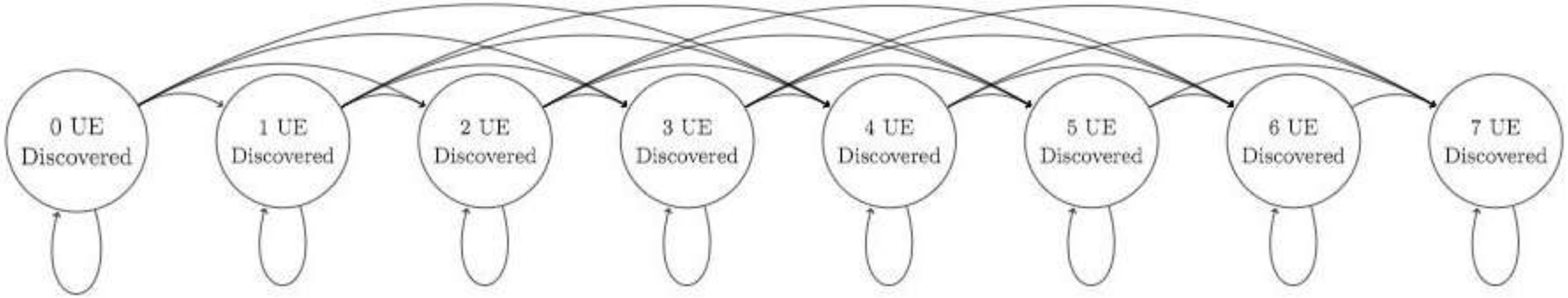
- Final results for $P_{disc}(k|N_p; N_{UE}, N_r, N_t, \theta)$:

$$P_D(k|N_p;\, N_{UE},\, N_r, N_t,\, \theta) = \sum_{n_{u,tx}=0}^{N_{UE}-N_p-1} \sum_{n_{p,tx}=0}^{N_p} P(N_{u,tx} = n_{u,tx}) P(N_{p,tx} = n_{p,tx}) \times$$

$$\Big[\theta \sum_{n_{u,d}=0}^{n_{u,tx}} \sum_{n_{p,d}=0}^{n_{p,tx}} P(N_{u,d} = n_{u,d}) P(N_{p,d} = n_{p,d}) \sum_{\mathbf{X_2}} P(\mathbf{X}_{u,tx}) P(\mathbf{X}_{p,tx}) P(k|\mathbf{X}_{u,tx}, \mathbf{X}_{p,tx})$$

$$+ (1-\theta) \sum_{\mathbf{X_1}} P(\mathbf{X}_{u,tx}) P(\mathbf{X}_{p,tx}) P(k|\mathbf{X}_{u,tx}, \mathbf{X}_{p,tx})\Big]$$

Multiple Round Model



- Entire discovery process is an absorbing Markov chain with transition probabilities from the single round model
- In this case entering the absorbing state is the same as completing discovery

Multiple Round Results

$$\mathbf{T} = \begin{bmatrix} P_D(0|\,0;\,N_{UE},\,N_r,\,N_t,\,\theta) & P_D(1|\,0;\,N_{UE},\,N_r,\,N_t,\,\theta) & P_D(2|\,0;\,N_{UE},\,N_r,\,N_t,\,\theta) \\ 0 & P_D(0|\,1;\,N_{UE},\,N_r,\,N_t,\,\theta) & P_D(1|\,1;\,N_{UE},\,N_r,\,N_t,\,\theta) \\ 0 & 0 & 1 \end{bmatrix}$$

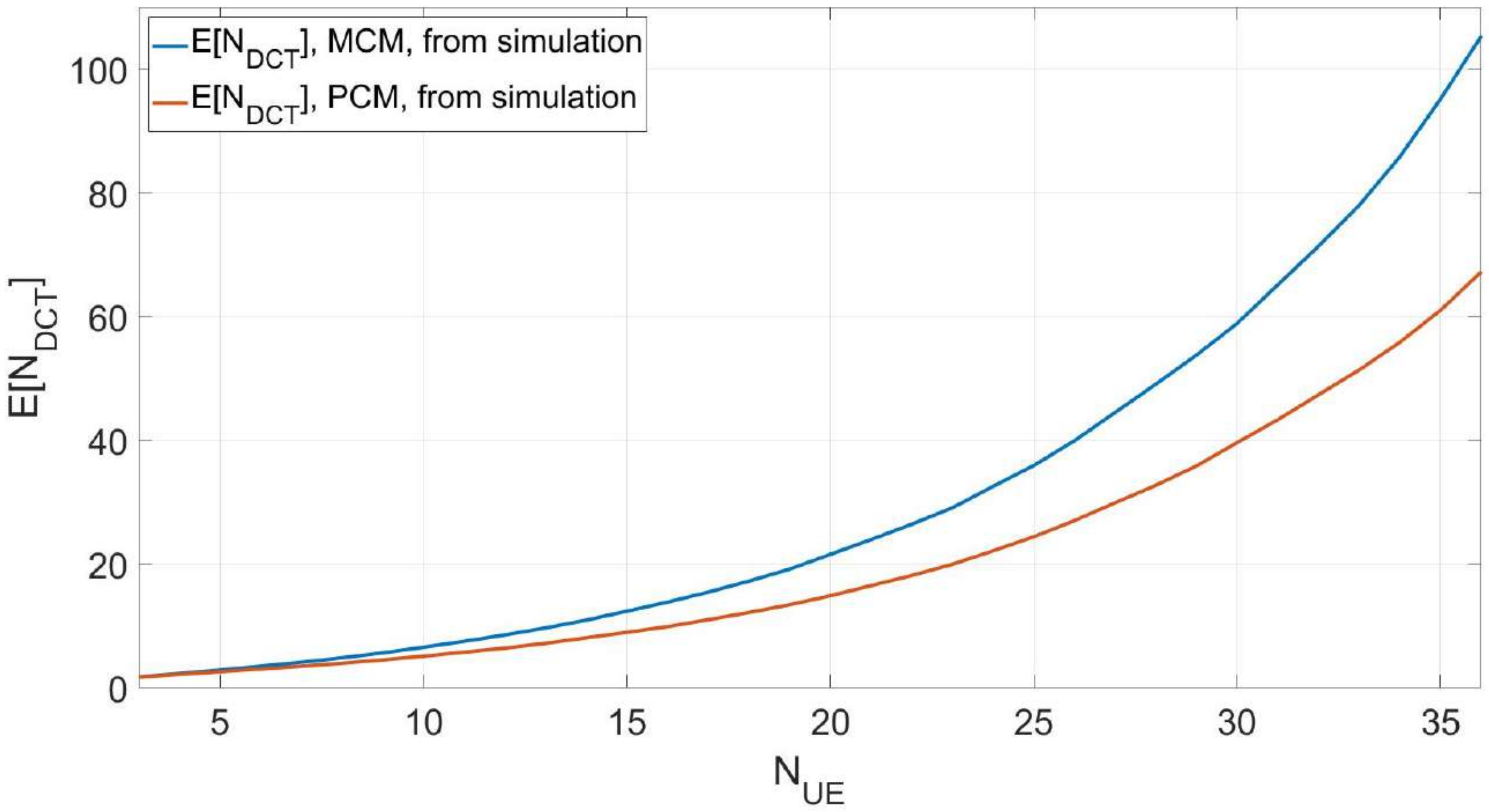
- Key discovery statistic is rounds until discovery completion time N_{DCT}
- We can use the transition matrix T to form the fundamental matrix N which can be used to determine the absorption statistics, which double as the discovery statistics

Section 3:
Results

Sim Setup/problem statement

- Two key questions:
  - How does the choice of modeling assumptions affect the time taken to complete discovery?
  - If UE transmit at a fixed probability θ what is the best resource pool size N_r for a given θ and number of UE N_{UE}?
- Metric used: rounds until discovery completion time, N_{DCT}, the number of rounds taken for one randomly chosen UE to discover all other UE

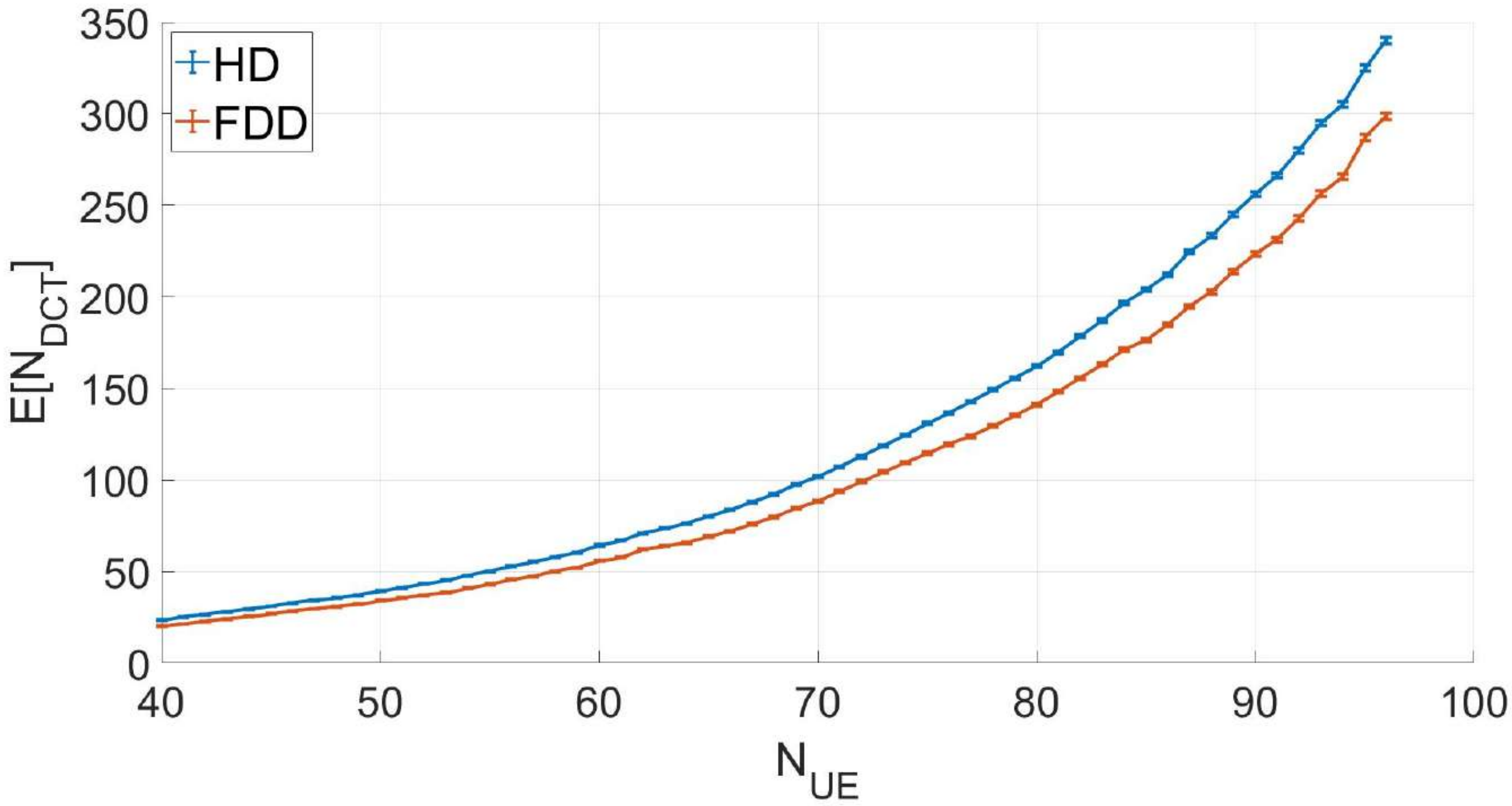
Average Rounds Until Discovery Completion Time, $E[N_{DCT}]$, MAC vs PHY Collisions, HD UE



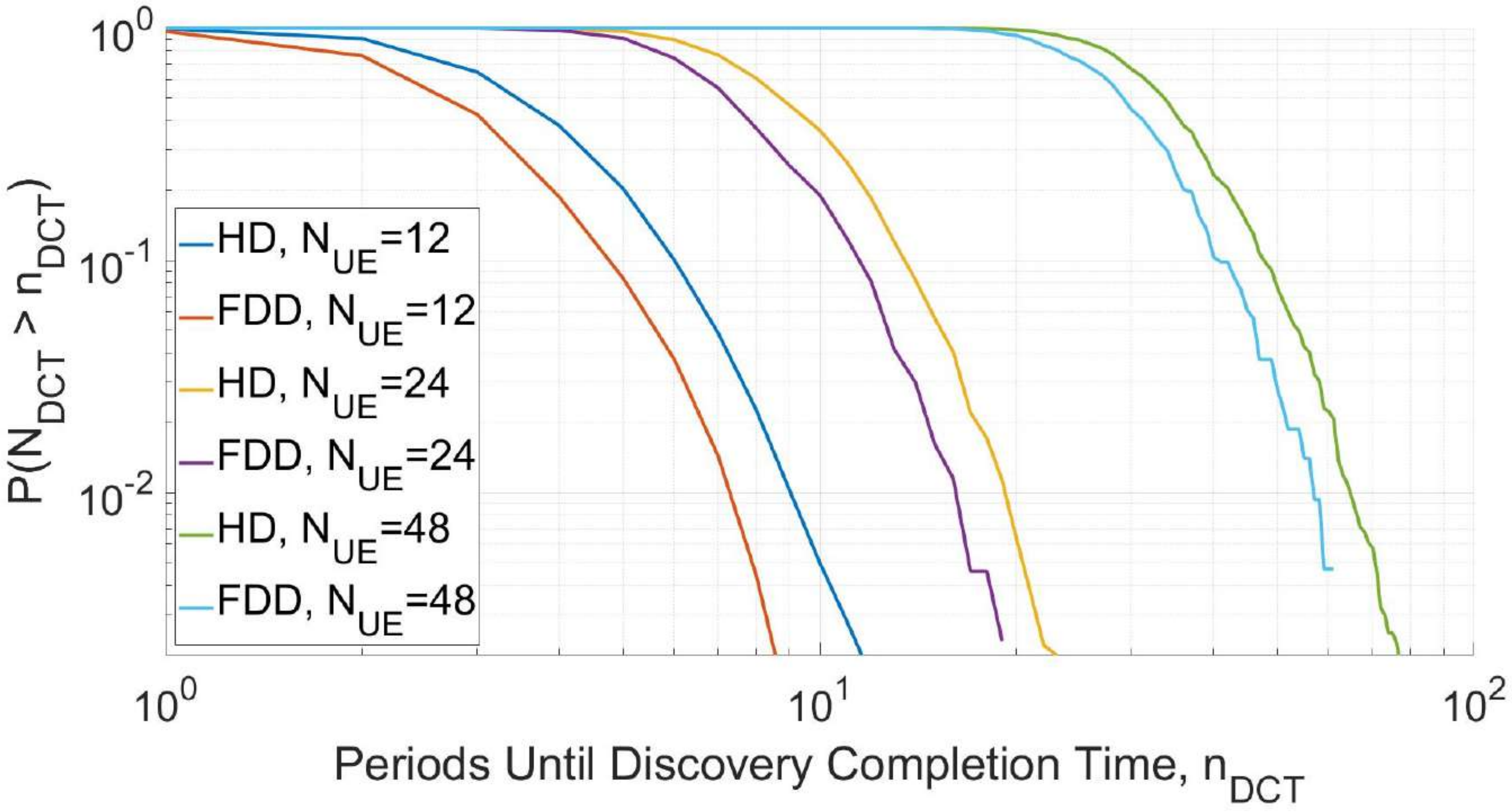
Difference Between $E[N_{DCT}]$, MAC vs PHY Collisions, HD UE

			N_f			
			3	4	5	6
$N_{UE} = N_r/3$	N_t	4	5.7587%	7.2764%	8.5255%	12.0759%
		5	7.1351%	8.1554%	11.0580%	13.3772%
		6	9.1953%	11.8130%	13.0653%	13.0220%
		7	9.9499%	11.2445%	12.6151%	14.7483%
		8	11.6489%	11.8835%	14.0518%	15.1387%
$N_{UE} = N_r$		4	28.4771%	28.3651%	28.5989%	28.2968%
		5	29.3388%	28.6559%	27.8643%	27.3561%
		6	27.4905%	28.1402%	27.5246%	27.4780%
		7	28.0072%	27.5328%	27.3186%	27.2798%
		8	28.5935%	28.1443%	26.7310%	28.9047%
$N_{UE} = 3N_r$		4	44.1521%	41.3964%	40.7018%	39.0537%
		5	41.2771%	40.3887%	38.9329%	37.5133%
		6	41.5595%	39.0805%	37.0505%	37.5430%
		7	40.5951%	38.8632%	36.4775%	38.2926%
		8	39.7468%	40.0578%	36.1925%	34.9795%

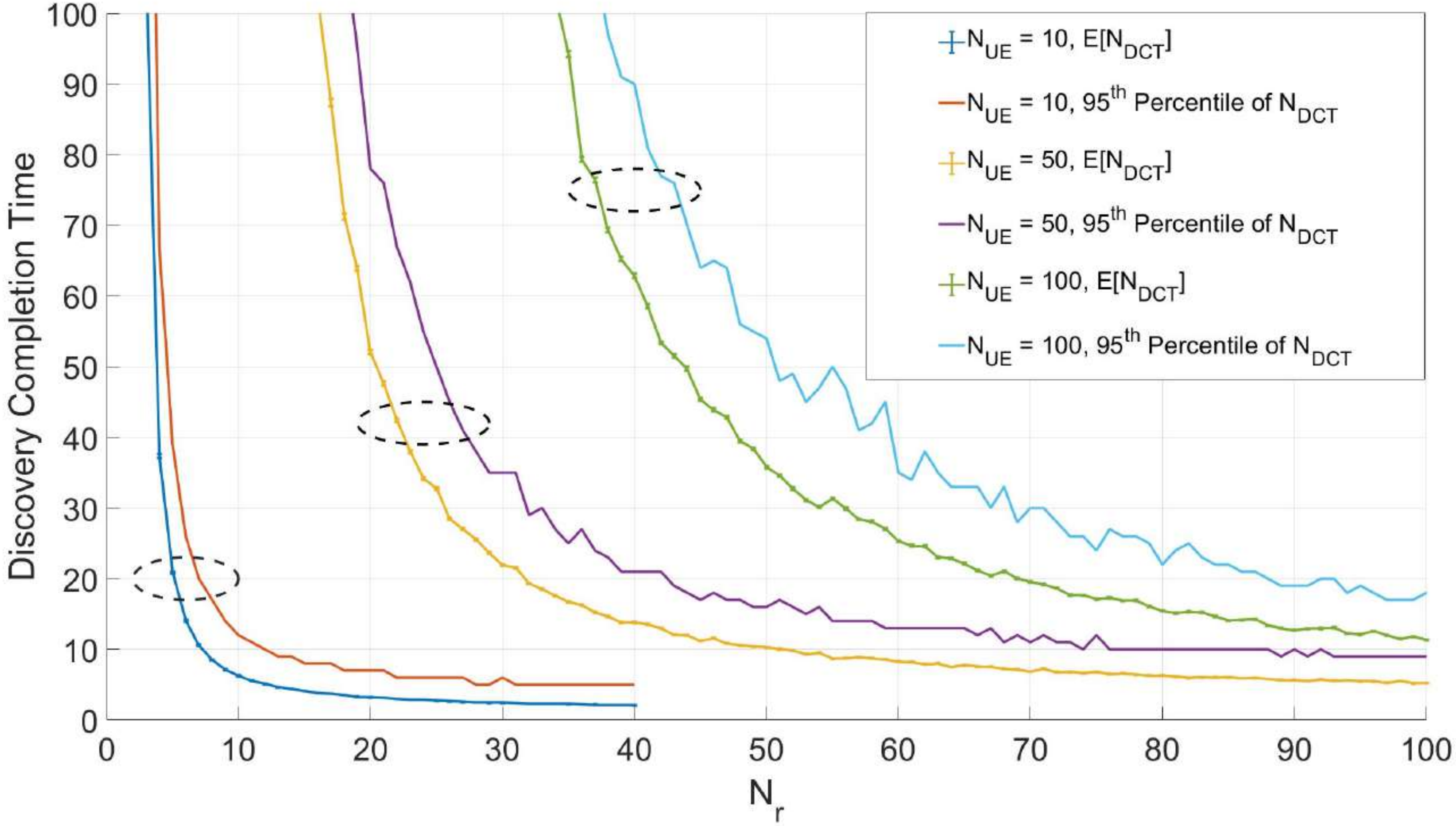
Average Rounds until Discovery Completion Time, $E[N_{DCT}]$, HD vs FDD UE, MCM



CCDF of N_{DCT}, HD vs FDD UE, MCM



Effects of Varying N_r on N_{DCT}



N_r Recommendations for MCM and FDD UE

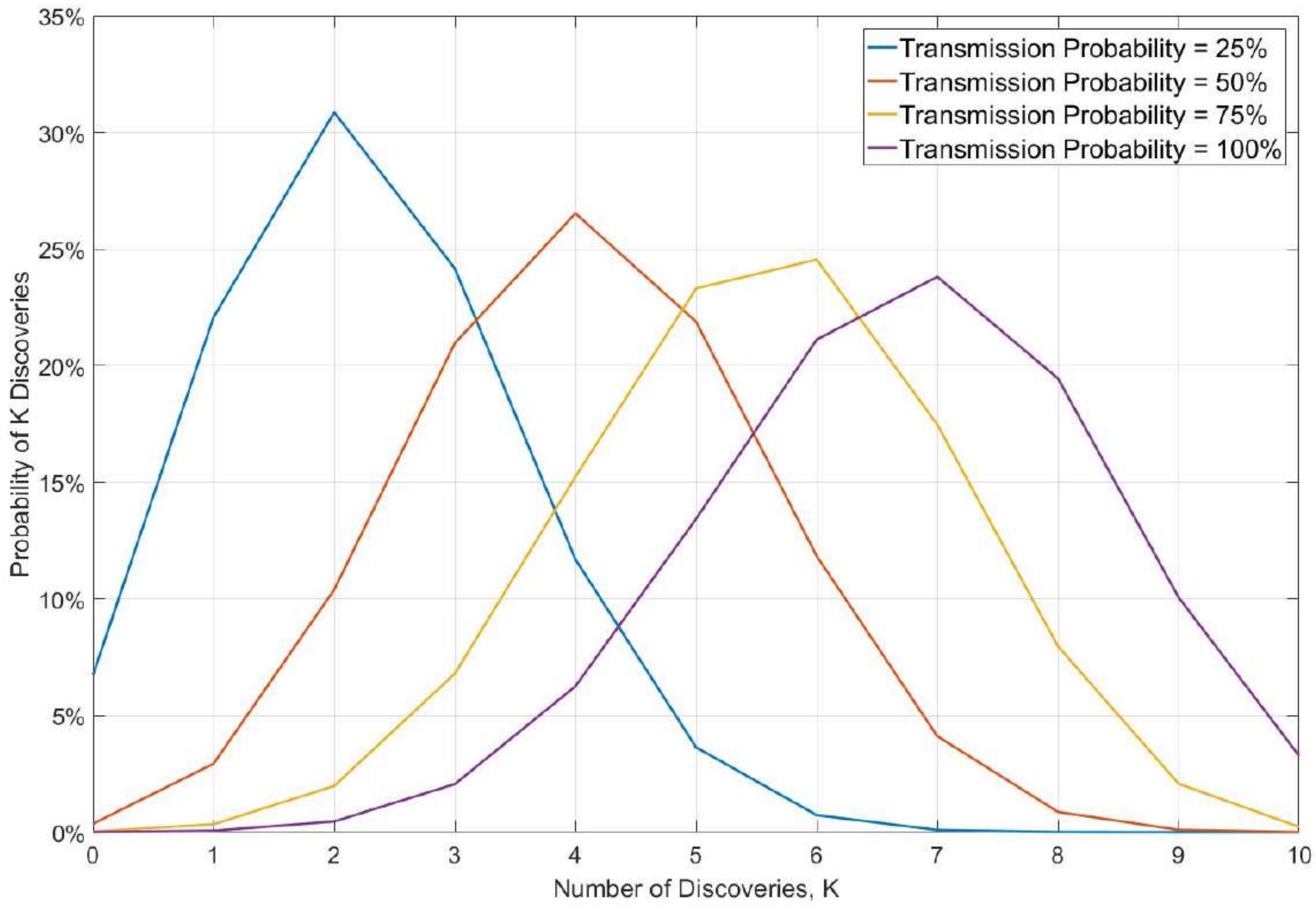
N_{UE}	<3 s on average	<10 s on average	<3 s 95% of the time	<10 s 95 % of the time
10	8	5	13	6
20	18	10	31	12
30	29	15	49	18
40	42	20	72	25
50	55	26	89	32
60	68	31	116	39
70	81	37	132	45
80	94	43	160	53
90	110	48	185	59
100	112	53	210	67

Section 4:
Future Work

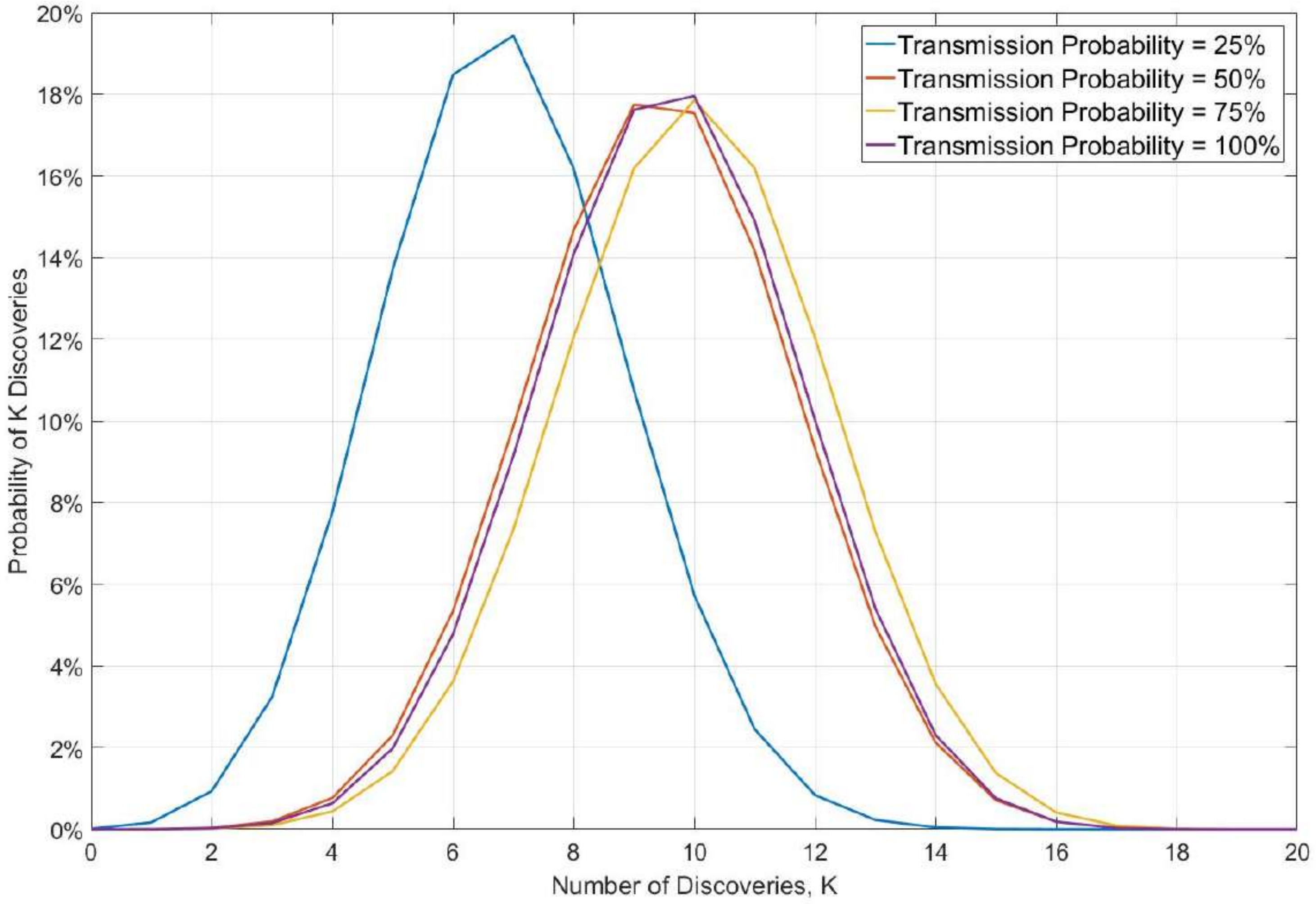
New Problem

- If a network provider has set an N_r appropriate for some number of UE, N_{UE}, make use of the off network sidelink how do we mitigate the negative effects?
- Although the standards contain no mechanism to modify transmission probability θ during discovery nothing prevents UE from modifying their own transmission probability

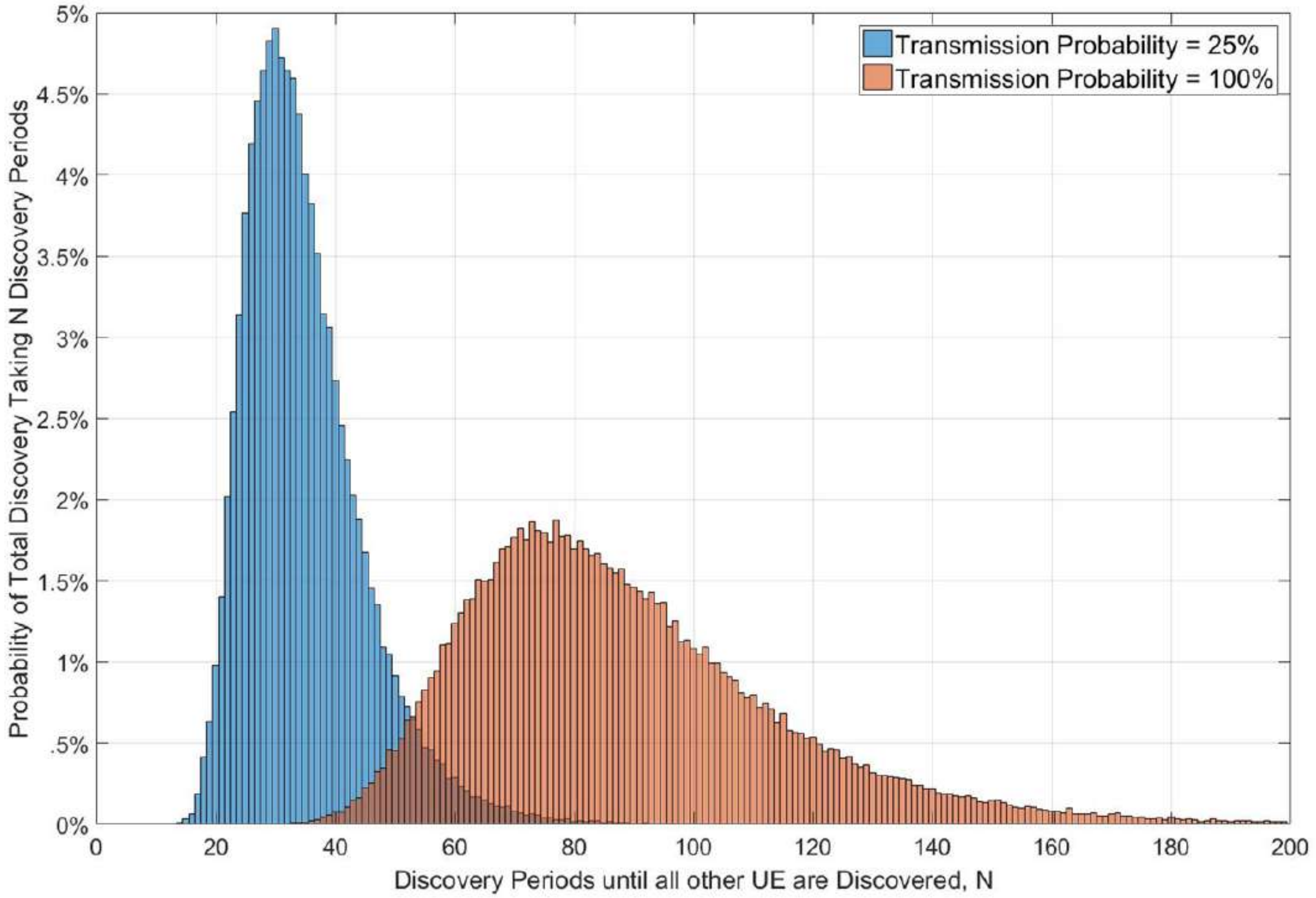
Single Round Discoveries, Uncongested Channel



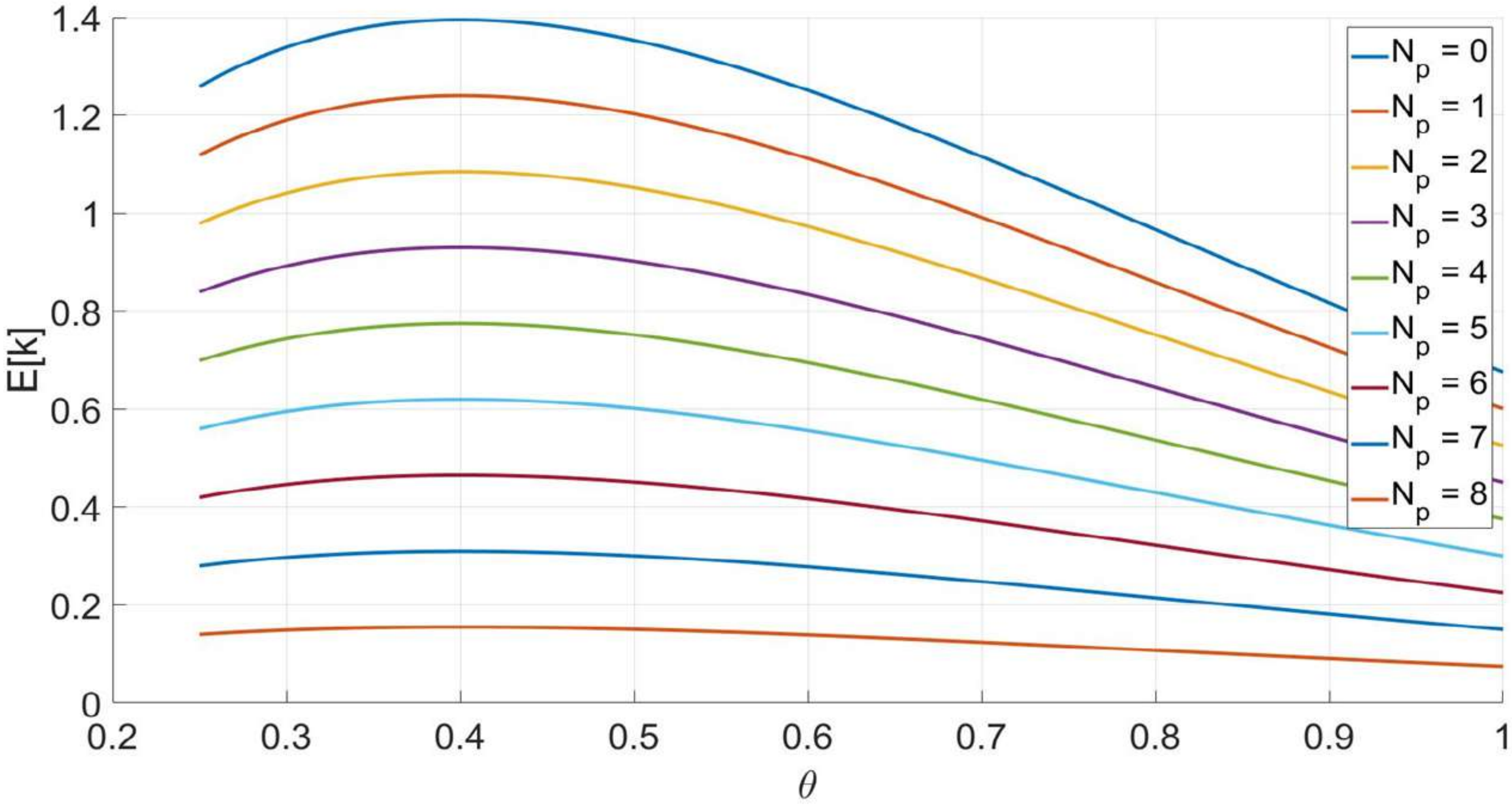
Single Round Discoveries, Congested Channel



Effects of Choosing a Suboptimal θ



Showing that there exists only 1 optimal theta



Outline of Solution and Future Work

- Each round UE transmit with probability θ and receive N_m discovery messages, new and old
- The "optimal" θ doesn't change as a function of N_p
  - N_m is distributed the same as $P_{disc}(k|0; N_{UE}, N_r, N_t, \theta)$
- Use the (θ, N_m) pair from each round to learn the θ vs $E[k]$ curve, stochastic gradient descent
- Determine the "optimal" θ from the learned curve

Sources and Acknowledgements

[1]: D. Griffith and F. Lyons, "Optimizing the UE Transmission Probability for D2D Direct Discovery," *2016 IEEE Global Communications Conference (GLOBECOM)*, Washington, DC, 2016, pp. 1-6.

[2]: A. Ben Mosbah, D. Griffith and R. Rouil, "A novel adaptive transmission algorithm for Device-to-Device Direct Discovery," *2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC)*, Valencia, 2017, pp. 177-182.

[3]: D. Griffith, A. Ben Mosbah and R. Rouil, "Group discovery time in device-to-device (D2D) proximity services (ProSe) networks," *IEEE INFOCOM 2017,* 2017.

This work was supported in part under NIST PSIAP Program via Coop. Agreement # 70NANB17H170.

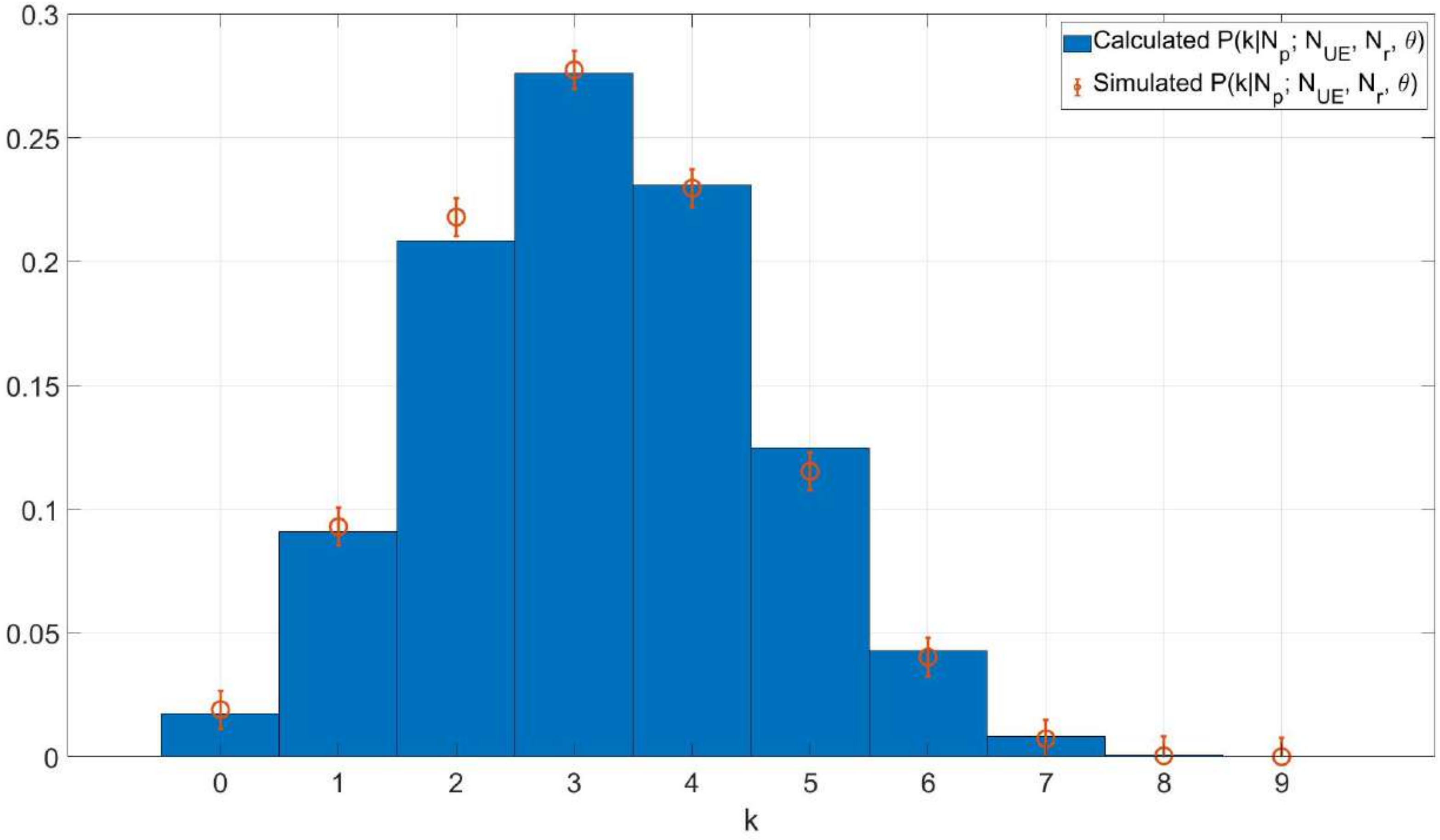
#PSCR2019

Come back for the

Next Session

Backup

PDF validation



CCDF validation