Modelling D2D Communications in Cellular Access Networks via Coupled Processors

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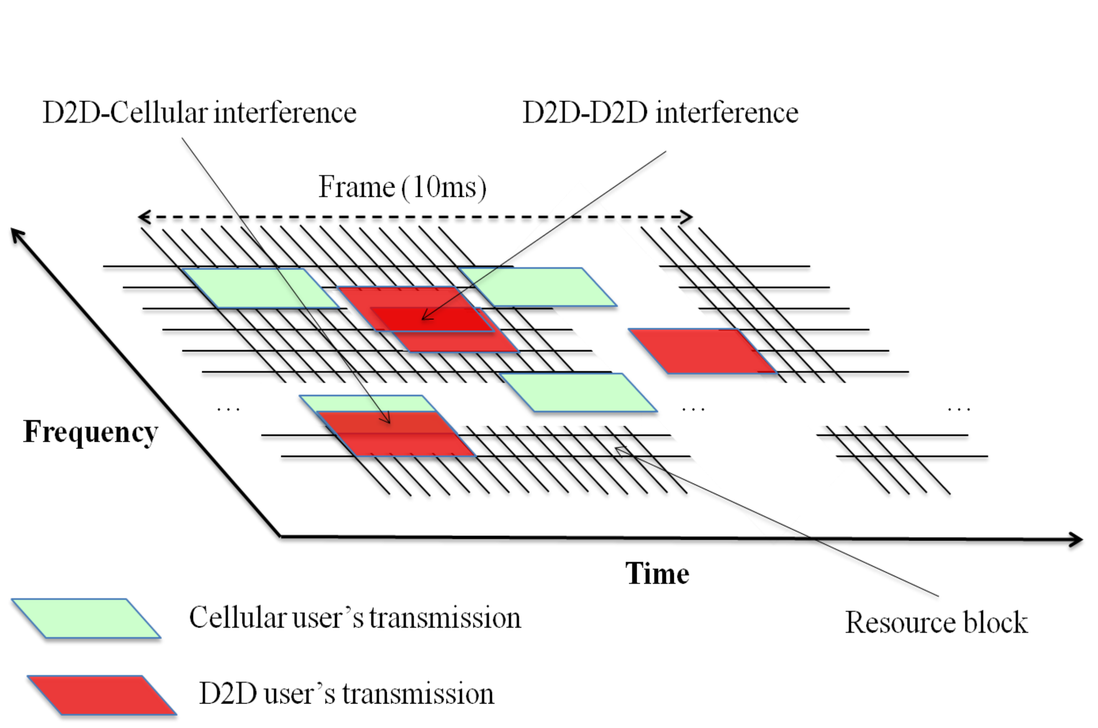
Developing the Science of Networks

Abstract

Also in cellular networks, D2D communications provide numerous advantages. Nevertheless, modelling D2D systems remains a complex and unsolved task. In this work, *we present the first analytical study on D2D system performance*. Our approach models interdependencies among D2D and cellular transmitters in details and achieves a conservative estimation of the stability region of D2D systems, as well as evaluates the effects of D2D transmissions on cellular users. Furthermore, the proposed approach can easily trade-off performances for less complexity in a realistic application, i.e., in a proportional fairness optimization.

D2D transmissions, interesting but challenging



We study the D2D in-band underlay scheduling case, where cellular and D2D transmitters share the same resources [1].

Transmissions are strongly coupled each other by mutual interference.

A model to evaluate D2D performance is missing

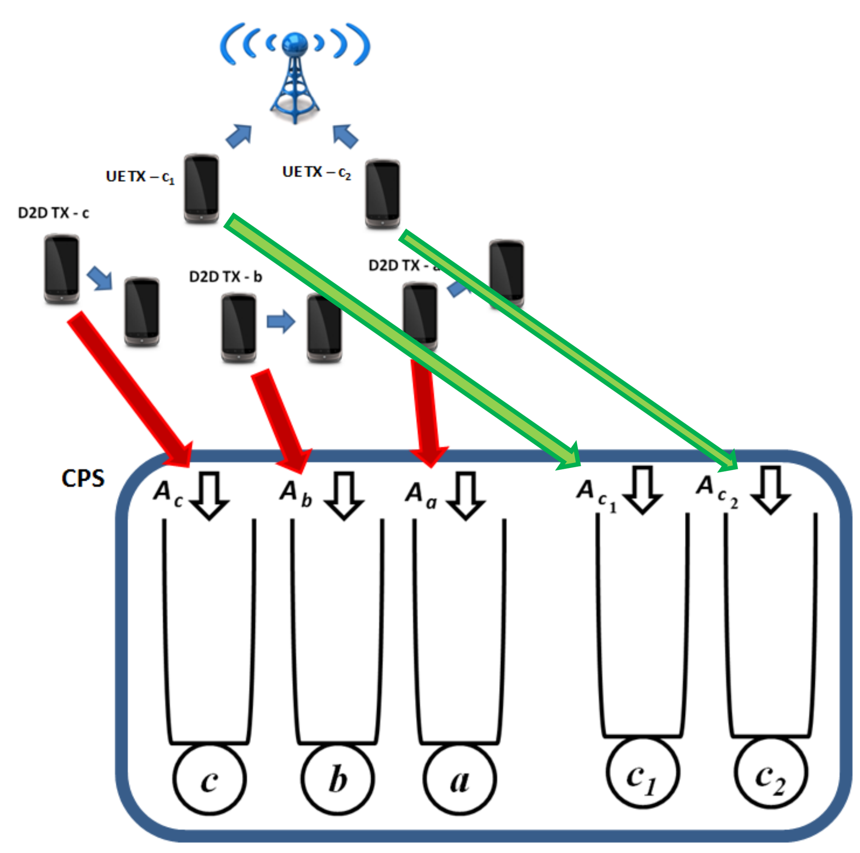
Goals:
- optimizations of D2D operations;
- efficient coexistence of cellular and D2D users.

Previous work:
- D2D system are evaluated by simulations,
- assuming the system in saturation, i.e., all transmitters have always traffic to transmit;
- and assuming simple and underperforming scheduling.

What's missing:
- full knowledge of D2D achievable rates (stability region);
- performance bounds.

System Model and Analysis

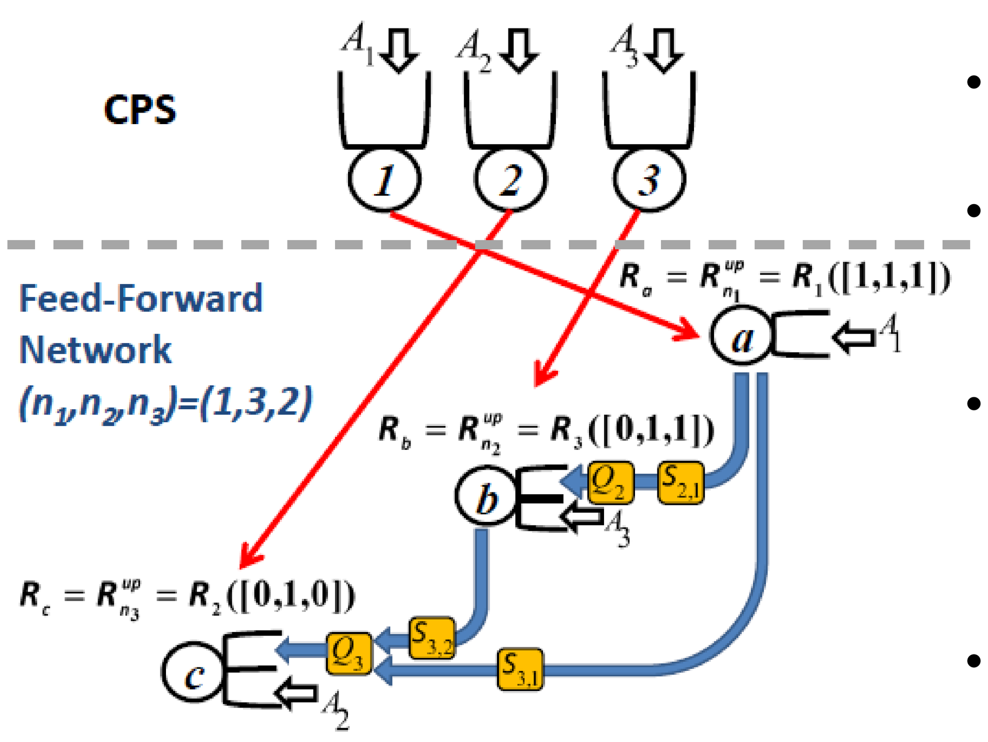
We model the D2D system through a queueing system with Coupled Processors (CP) [2].



In D2D, interferences (and throughputs) are univocally determined by the set of simultaneous transmitters.

With CP, the service rate of queues is univocally determined by the set of active queues.

Our method: untangle the net of interdependencies.
Model interdependencies through feed forward networks [3].



- CP queues are mapped onto GPS nodes (same arrivals);
- when active, GPS nodes propagate traffic to following nodes, absorbing capacity;
- at each epoch *t*, GPS nodes serve traffic at slower rate than the corresponding CP node (conservative);
- one network per sorting.

Stability of feed forward networks implies stability of CP.

Reducing the complexity: Proportional Fairness

The CP analysis can be simplified depending on the goal.

PROPORTIONAL FAIRNESS

$$\underset{\rho^*}{\text{maximize}} \sum_{j=1}^{D} w_j \log\left(\rho_j^*\right),$$

subject to: $\forall j = 1, \ldots, D,$

STABILITY REGION

$$\rho_j^* \le \min\left(R_j^{min}, R_j^{up} - \sum_{k=1}^{j-1} S_{j,k}\rho_k^*\right),$$

$$\rho_j^* \le \rho_j$$

ARRIVALS LIMIT

Optimization can be performed on a small set of sortings carefully chosen:

- **Exploiting stability region fairness improves considerably**

TABLE IV: Optimization vs. Saturation: Utility

D2D transmitters	Mean Sat.	95% Conf. Interval	Mean Opt.	95% Conf. Interval
3	2.3289	2.11-2.54	2.5303	2.37-2.68
4	2.2870	2.06-2.50	2.5750	2.44-2.70
5	1.9881	1.80-2.17	2.3424	2.21-2.47
6	1.7460	1.39-2.09	2.2153	2.01-2.41
8	1.5185	1.25-1.77	2.0537	1.91-2.19

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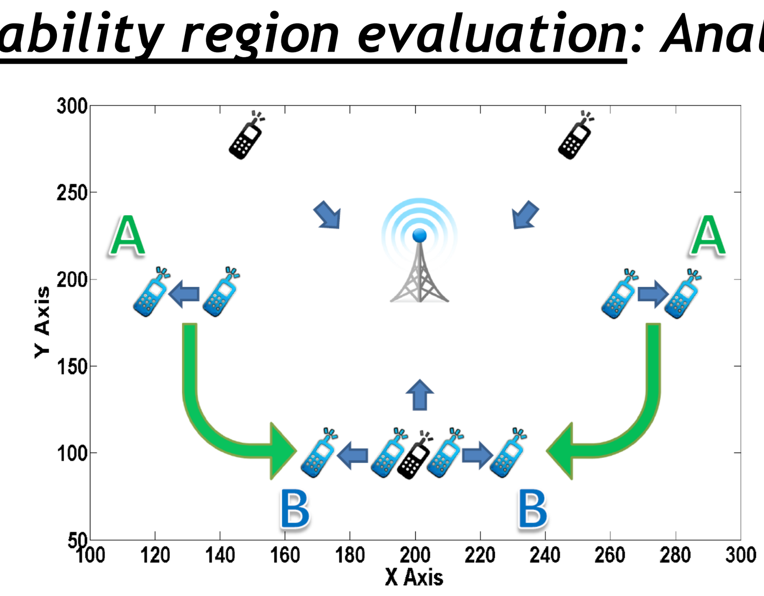
TABLE III: Heuristic vs. Brute Force: Complexity

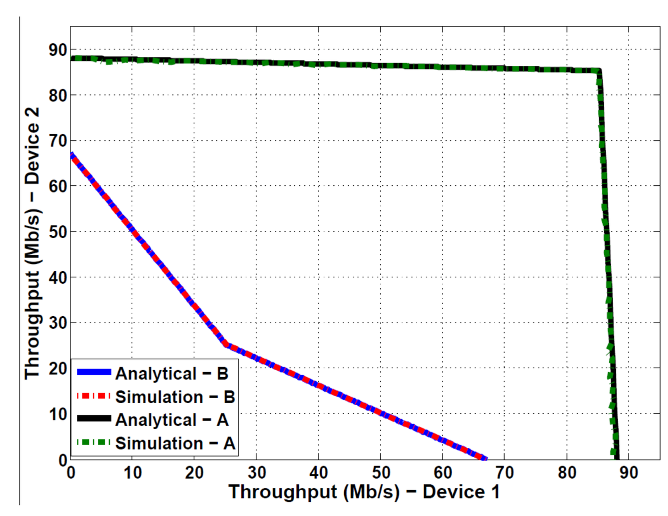
D2D transmitters	Mean # of Networks (Heuristic)	95% Confidence Interval	Networks Available
3	3.44	3.36-3.52	6
4	4.60	4.36-4.84	24
5	9.56	8.95-10.18	120
6	11.70	10.49-12.92	720
8	22.70	20.52-24.88	40320

COMPLEXITY

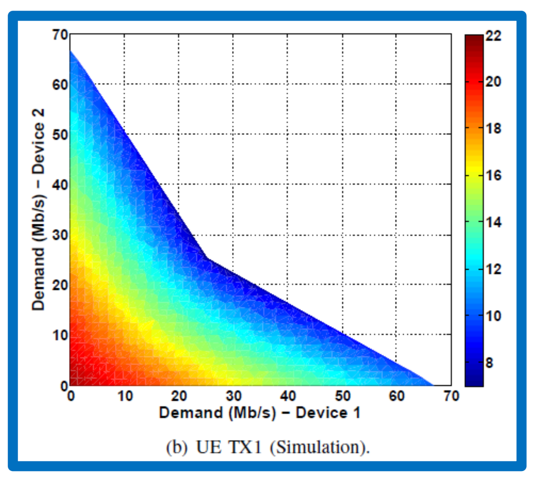
Numerical Evaluation

***Stability region evaluation**: Analytical vs. Packet-Level Simulation*

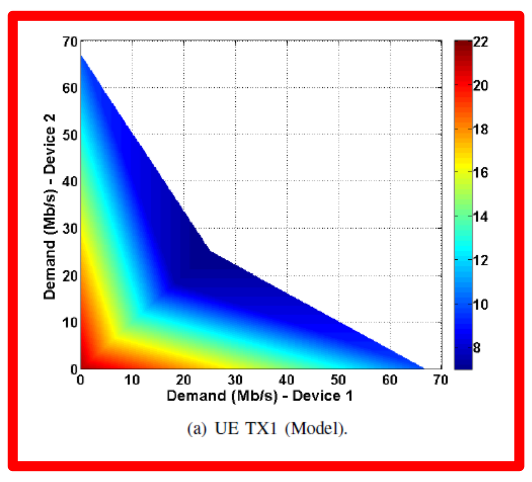




Simulation



(b) UE TX1 (Simulation).



(a) UE TX1 (Model).

Analysis

Analytical results model accurately the D2D stability region.
Model slightly underestimates cellular throughputs (Max. diff: 11.18%).

References

[1] Wu, Xinzhou, et al. "FlashLinQ: A synchronous distributed scheduler for peer-to-peer ad hoc networks." IEEE/ACM Transactions on Networking (TON) 21.4 (2013): 1215-1228.
[2] S. C. Borst, M. Jonckheere, and L. Leskelä. "Stability of parallel queueing systems with coupled service rates. Discrete Event Dynamic Systems", 18(4):447-472, 2008.
[3] C.Vitale, G.Rizzo, B.Rengarajan and V.Mancuso. "An Analytical Approach to Performance Analysis of Coupled Processor Systems". International Teletraffic Congress (ITC) 2015.