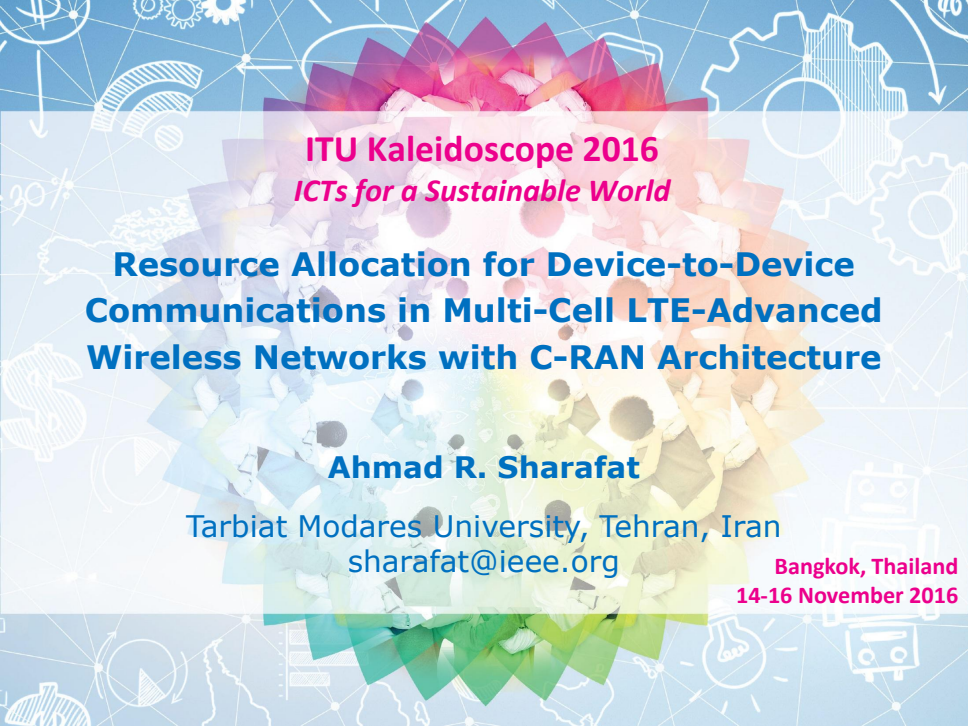




ITU Kaleidoscope 2016
ICTs for a Sustainable World

**Resource Allocation for Device-to-Device
Communications in Multi-Cell LTE-Advanced
Wireless Networks with C-RAN Architecture**

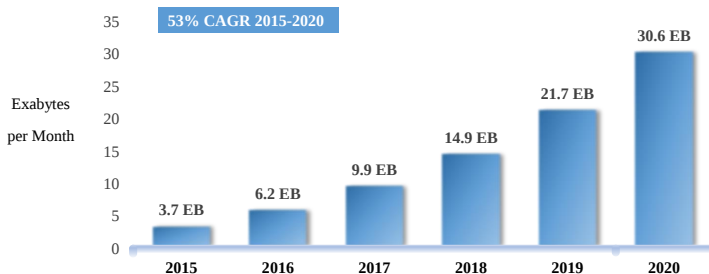
Ahmad R. Sharafat

Tarbiat Modares University, Tehran, Iran
sharafat@ieee.org

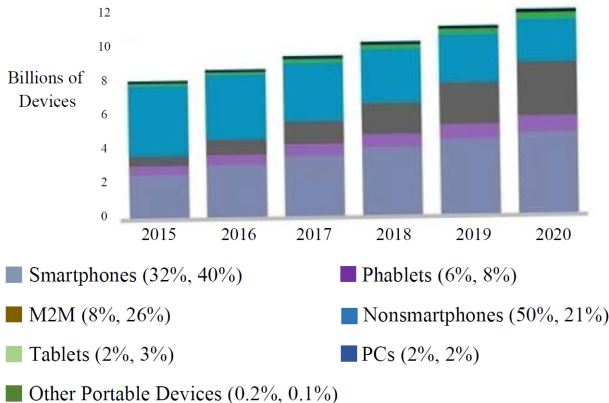
Bangkok, Thailand
14-16 November 2016

- 1 Introduction
- 2 System Model
- 3 Resource Allocation Problem
- 4 Optimal Resource Allocation
- 5 Simulation Results
- 6 Conclusions

Introduction



Source: Cisco VNI Mobile, 2016

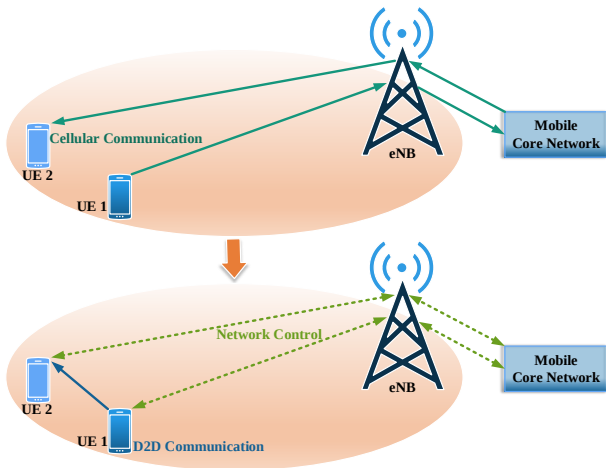


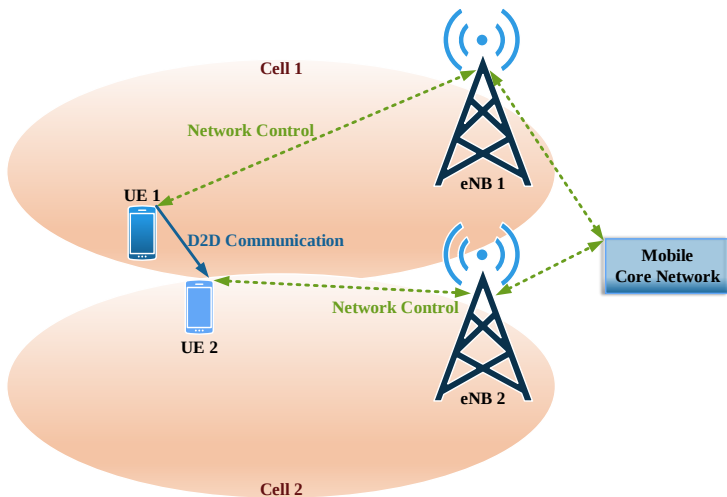
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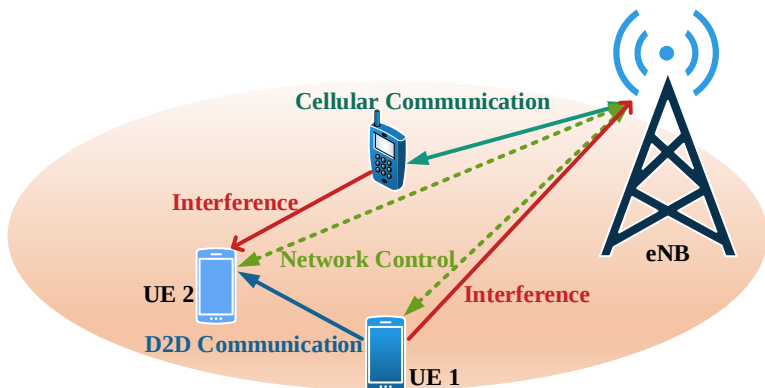
Limitations and Constraints:

1. Frequency spectrum

2. Energy consumption







D2D links reuse cellular channels. Hence, there is a need for interference management and control. In general, existing schemes:

- Assume a single insulated cell
- Ignore inter-cell interference
- Assume each D2D pair is situated in one insulated cell
- Assume each D2D pair uses only one channel
- Consider static power allocation to D2D pairs

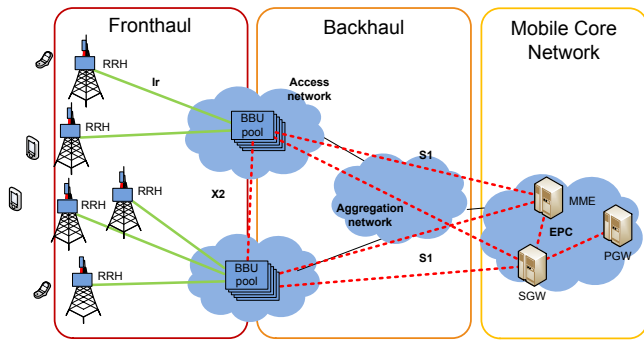
We assume:

- We consider a multi-cell network with inter-cell interferences.
- We assume D2D pairs may be situated in different cells.
- We assign more than one channel at the same time to each pair to the extent possible.
- We assume no high speed movement.

- Interference management is performed via proper allocation of resources (e.g., channels, transmit power levels, etc.).
- Resource allocation is an optimization problem that can be solved either in a distributed or a centralized manner.
- Distributed schemes are scalable, require less message passing, but are sub-optimal.
- Centralized schemes have better performance, but require extensive message passing.
- Multi-Cell D2D links require coordination between two cells, i.e., a centralized approach.

Cloud Radio Access Network (C-RAN) is a novel centralized architecture:

- The radio unit, called the remote radio head (RRH), is separated from the baseband unit (BBU),
- BBUs are pooled together in a cloud environment.



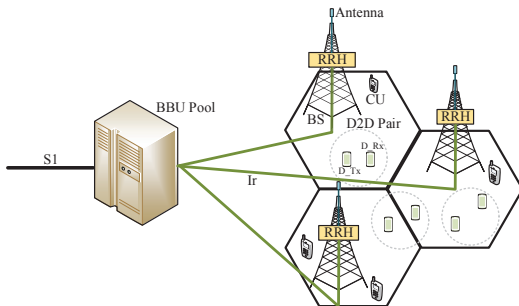
The objective is to allocate channels and transmit power levels:

- Maximize the number of active D2D pairs and reused channels
- Minimize the aggregate system uplink transmit power
- Maintain the QoS and transmit power constraints for all users.

System Model

We consider

- A multi-cell LTE-A network with C-RAN architecture,
- $\mathcal{N} = \{1, \dots, N\}$ as the set of orthogonal uplink channels,
- $\mathcal{C} = \{1, \dots, L\}$ as the set of CUs,
- $\mathcal{D} = \{1, \dots, M\}$ as the set of D2D pairs,
- D2D pairs can reuse cellular uplink channels,
- D_Tx and D_Rx are not required to be in the same cell.



- $\bar{I}_l^c$: Maximum number of channels simultaneously used by CU l .
- $\mathcal{N}_l^c$ ($\mathcal{N}_l^c \subset \mathcal{N}$): Set of channels simultaneously used by CU l .
- $\xi_{l,n}^c, \hat{\xi}_{l,n}^c$: Actual SINR and required SINR of CU l on channel n .
- $P_{l,n}^c, \bar{P}_{l,n}^c$: Actual transmit power and maximum transmit power of CU l on channel n .
- $P_l^c, \bar{P}_l^c$: Actual aggregate transmit power and maximum aggregate transmit power of CU l on all channels.
- $P_l^c = \sum_{n \in \mathcal{N}_l^c} P_{l,n}^c$.
- $\bar{P}_{l,n}^c = \bar{P}_l^c - \sum_{j \in \mathcal{N}_l^c, j \neq n} P_{l,j}^c$.

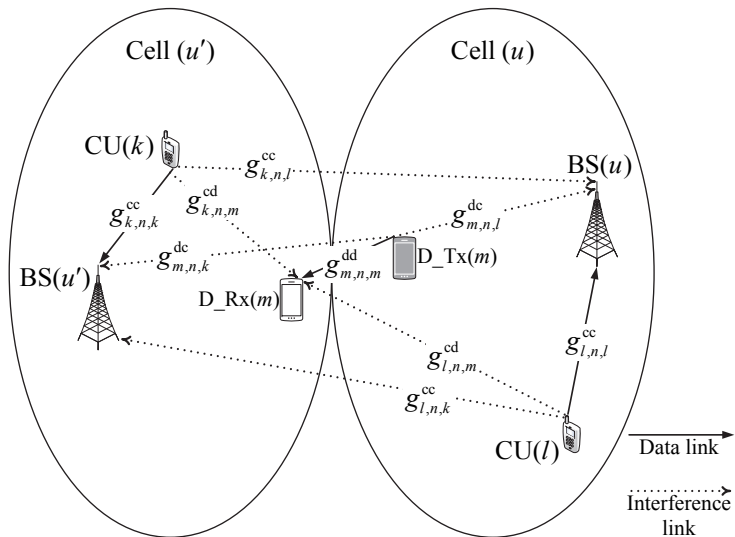
- $\bar{I}_m^d$: Maximum number of channels simultaneously used by D2D pair m .
- $\mathcal{N}_m^d$ ($\mathcal{N}_m^d \subset \mathcal{N}$): Set of uplink channels simultaneously used by D2D pair m .
- $\zeta_{m,n}^d, \hat{\zeta}_{m,n}^d$: Actual SINR and Required SINR of D2D pair m on channel n .
- $P_{m,n}^d, \bar{P}_{m,n}^d$: Actual transmit power and maximum transmit power of D2D pair m on channel n .
- $P_m^d, \bar{P}_m^d$: Actual aggregate transmit power and maximum aggregate transmit power of D2D pair m on all channels.
- $P_m^d = \sum_{n \in \mathcal{N}_m^d} P_{m,n}^d$.
- $\bar{P}_{m,n}^d = \bar{P}_m^d - \sum_{j \in \mathcal{N}_m^d, j \neq n} P_{m,j}^d$.

- Channel gain between CU k and the receiver of CU l (i.e., the base station to which CU l is communicating) on channel n is

$$g_{k,n,l}^{\text{cc}} = K\beta_{k,n,l}\zeta_{k,n,l}L_{k,n,l}^{-\alpha}.$$

where

- K is a constant that depends on system parameters,
 - $\beta_{k,n,l}$ is the fast fading gain with exponential distribution,
 - $\zeta_{k,n,l}$ is the slow fading gain with log-normal distribution,
 - α is the path loss exponent,
 - $L_{k,n,l}$ is the distance between CU k and the receiver of CU l .
- We assume AWGN noise in each channel.
 - $\sigma_{l,n}^{\text{c}}$: Noise power at the receiver of CU l in channel n ,
 - $\sigma_{m,n}^{\text{d}}$: Noise power at the receiver of D2D pair m in channel n .



Resource Allocation Problem

- Two basic definitions:
 - ① An admissible D2D pair
 - ② A candidate reuse channel
- Let
 - ① $\mathcal{D}'$ ($\mathcal{D}' \subseteq \mathcal{D}$) be the set of all admissible D2D pairs.
 - ② $\mathcal{R}_m$ be the set of candidate reuse channels for the D2D pair m .
 - ③ $\mathcal{N}'$ be the union of all candidate reuse channels for all D2D pairs, i.e., $\mathcal{N}' = \mathcal{R}_1 \cup \mathcal{R}_2 \cup \dots \cup \mathcal{R}_M$.
- Each uplink channel is reused by at most one D2D pair.
- If D2D pair m reuses channel n , then $\rho_{m,n}^d$ is 1, otherwise it is 0.
- We wish to
 - ① Maximize the number of admissible D2D pairs and reused channels.
 - ② Minimize the total transmit power for all users.
 - ③ Maintain the QoS and transmit power constraints for all users.

Problem Formulation I

$$\text{Determine } \begin{cases} \rho_{m,n}^d, & \forall m \in \mathcal{D}, \forall n \in \mathcal{N}, \\ P_{m,n}^d, & \forall m \in \mathcal{D}, \forall n \in \mathcal{N}, \\ P_{l,n}^c, & \forall l \in \mathcal{C}, \forall n \in \mathcal{N}, \end{cases} \quad (1a)$$

$$\text{To Maximize } \sum_{m \in \mathcal{D}} \sum_{n \in \mathcal{N}} \rho_{m,n}^d \quad (1b)$$

$$\text{To Minimize } \sum_{l \in \mathcal{C}} \sum_{m \in \mathcal{D}} \sum_{n \in \mathcal{N}} (P_{l,n}^c + \rho_{m,n}^d P_{m,n}^d), \quad (1c)$$

Subject to:

$$\zeta_{l,n}^c = \frac{g_{l,n,l}^{cc} P_{l,n}^c}{\sigma_{l,n}^c + \sum_{\substack{k \in \mathcal{C} \\ k \neq l}} g_{k,n,l}^{cc} P_{k,n}^c + \sum_{m \in \mathcal{D}} \rho_{m,n}^d g_{m,n,l}^{dc} P_{m,n}^d} \geq \hat{\zeta}_{l,n}^c, \forall l \in \mathcal{C}, \forall n \in \mathcal{N}, \quad (1d)$$

$$\zeta_{m,n}^d = \frac{g_{m,n,m}^{dd} P_{m,n}^d}{\sigma_{m,n}^d + \sum_{k \in \mathcal{C}} g_{k,n,m}^{cd} P_{k,n}^c} \geq \hat{\zeta}_{m,n}^d, \quad \forall m \in \mathcal{D}', \forall n \in \mathcal{N}, \quad (1e)$$

$$\rho_{m,n}^d \in \{0, 1\}, \quad \forall m \in \mathcal{D}, \forall n \in \mathcal{N}, \quad (1f)$$

Problem Formulation II

$$\sum_{m \in \mathcal{D}} \rho_{m,n}^d \leq 1, \quad \forall n \in \mathcal{N}, \quad (1g)$$

$$1 \leq \sum_{n \in \mathcal{N}} \rho_{m,n}^d \leq I_m^d, \quad \forall m \in \mathcal{D}', \quad (1h)$$

$$0 \leq P_{l,n}^c \leq \bar{P}_{l,n}^c, \quad \forall l \in \mathcal{C}, \forall n \in \mathcal{N}, \quad (1i)$$

$$0 \leq P_{m,n}^d \leq \bar{P}_{m,n}^d, \quad \forall m \in \mathcal{D}, \forall n \in \mathcal{N}, \quad (1j)$$

$$0 \leq P_l^c \leq \bar{P}_l^c, \quad \forall l \in \mathcal{C}, \quad (1k)$$

$$0 \leq P_m^d \leq \bar{P}_m^d, \quad \forall m \in \mathcal{D}. \quad (1l)$$

Optimal Resource Allocation

- This problem is a mixed integer linear programming (MILP) problem, which is difficult to solve directly.
- We divide the optimization problem into two sub-problems:
 - 1 D2D Admissibility and Optimal Power Control
 - 2 Resource Allocation for Admissible D2D Pairs
- We solve each sub-problem separately, and combine the results via our proposed algorithm.

- The D2D pair m can reuse channel n if

$$\begin{aligned}
 & \textcircled{1} \left\{ \begin{aligned} \zeta_{l,n}^c &= \frac{g_{l,n,l}^{cc} P_{l,n}^c}{\sigma_{l,n}^c + \sum_{\substack{k \in \mathcal{C} \\ k \neq l}} g_{k,n,l}^{cc} P_{k,n}^c + g_{m,n,l}^{dc} P_{m,n}^d} \geq \hat{\zeta}_{l,n}^c, \forall l \in \mathcal{C}, \\ \zeta_{m,n}^d &= \frac{g_{m,n,m}^{dd} P_{m,n}^d}{\sigma_{m,n}^d + \sum_{k \in \mathcal{C}} g_{k,n,m}^{cd} P_{k,n}^c} \geq \hat{\zeta}_{m,n}^d, \end{aligned} \right. \\
 & \textcircled{2} \left\{ \begin{aligned} 0 &\leq P_{l,n}^c \leq \bar{P}_{l,n}^c, \forall l \in \mathcal{C}, \\ 0 &\leq P_{m,n}^d \leq \bar{P}_{m,n}^d. \end{aligned} \right.
 \end{aligned}$$

- In matrix form, the power constraints can be reformulated as

$$\mathbf{0} \leq \mathbf{p}_{m,n} \leq \bar{\mathbf{p}}_{m,n},$$

where

$$\bar{\mathbf{p}}_{m,n} = [\bar{P}_{1,n}^c \quad \bar{P}_{2,n}^c \quad \dots \quad \bar{P}_{L,n}^c \quad \bar{P}_{m,n}^d]^T.$$

- SINR constraints can be reformulated as

$$\left\{ \begin{array}{l} (g_{l,n,l}^{cc} P_{l,n}^c - \sum_{\substack{k \in \mathcal{C} \\ k \neq l}} \hat{\xi}_{l,n}^c g_{k,n,l}^{cc} P_{k,n}^c) - \hat{\xi}_{l,n}^c g_{m,n,l}^{dc} P_{m,n}^d \geq \hat{\xi}_{l,n}^c \sigma_{l,n}^c, \forall l \in \mathcal{C}, \\ - \sum_{k \in \mathcal{C}} \hat{\xi}_{m,n}^d g_{k,n,m}^{cd} P_{k,n}^c + g_{m,n,m}^{dd} P_{m,n}^d \geq \hat{\xi}_{m,n}^d \sigma_{m,n}^d. \end{array} \right.$$

- In matrix form SINR constraints can be reformulated as

$$\mathbf{A}_{m,n} \mathbf{p}_{m,n} \geq \boldsymbol{\mu}_{m,n},$$

Where

$$\mathbf{A}_{m,n} = \begin{bmatrix} g_{1,n,1}^{cc} & \cdots & -\hat{\zeta}_{1,n}^{cc} g_{L,n,1}^{cc} & -\hat{\zeta}_{1,n}^{cc} g_{m,n,1}^{dc} \\ \vdots & \ddots & \vdots & \vdots \\ -\hat{\zeta}_{L,n}^{cc} g_{1,n,L}^{cc} & \cdots & g_{L,n,L}^{cc} & -\hat{\zeta}_{L,n}^{cc} g_{m,n,L}^{dc} \\ -\hat{\zeta}_{m,n}^{cd} g_{1,n,m}^{cd} & \cdots & -\hat{\zeta}_{m,n}^{cd} g_{L,n,m}^{cd} & g_{m,n,m}^{dd} \end{bmatrix},$$

$$\mathbf{p}_{m,n} = [P_{1,n}^c \quad P_{2,n}^c \quad \cdots \quad P_{L,n}^c \quad P_{m,n}^d]^T,$$

$$\boldsymbol{\mu}_{m,n} = [\hat{\zeta}_{1,n}^c \sigma_{1,n}^c \quad \cdots \quad \hat{\zeta}_{L,n}^c \sigma_{L,n}^c \quad \hat{\zeta}_{m,n}^d \sigma_{m,n}^d]^T.$$

- The first sub-problem is

$$\begin{aligned} & \text{Minimize } \mathbf{1}_{L+1}^T \mathbf{p}_{m,n}, \\ & \text{Subject to } \begin{cases} \mathbf{A}_{m,n} \mathbf{p}_{m,n} \geq \boldsymbol{\mu}_{m,n}, \\ \mathbf{0} \leq \mathbf{p}_{m,n} \leq \bar{\mathbf{p}}_{m,n}. \end{cases} \end{aligned}$$

- This is a linear programming (LP) problem, and can be solved by the Simplex, the Active-Set or the Interior-Point algorithm.
- If this sub-problem has a solution, we denote it by

$$\mathbf{p}_{m,n}^* = \begin{bmatrix} P_{1,n}^{c*} & P_{2,n}^{c*} & \dots & P_{L,n}^{c*} & P_{m,n}^{c*} \end{bmatrix}^T.$$

- In this situation
 - D2D pair m is admissible,
 - Channel n is a candidate reuse channel for D2D pair m ,
 - The minimum total transmit power of D2D pair m and CUs on channel n is

$$P_{m,n}^{\text{sum}} = \mathbf{1}_{L+1}^T \mathbf{p}_{m,n}^*.$$

- When only CUs use channel n and no D2D pair reuses it, the power control problem for CUs is a similar LP problem.
- In this case, the minimum aggregate transmit power of CUs in channel n is the sum of elements in vector $\mathbf{p}_{0,n}^*$, i.e.,

$$P_{0,n}^{\text{sum}} = \mathbf{1}_{L+1}^T \mathbf{p}_{0,n}^*.$$

- When the D2D pair m reuses channel n already in use by CUs, the increase in the aggregate transmit power of CUs and the transmitter of D2D pair m on channel n is

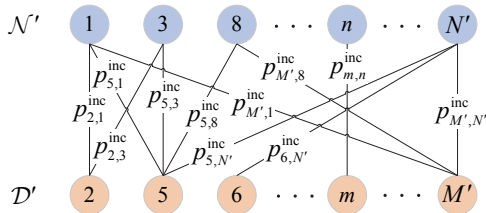
$$P_{m,n}^{\text{inc}} = P_{m,n}^{\text{sum}} - P_{0,n}^{\text{sum}}.$$

- When there is only one admissible D2D pair m in all cells, its optimal reuse channel can be found via

$$n_m^* = \arg \min_{n \in \mathcal{R}_m} P_{m,n}^{\text{inc}}.$$

- When there are multiple admissible D2D pairs, the problem of finding the optimal reuse channel for each admissible D2D pair is an assignment problem. This is our second sub-problem, formulated as

$$\begin{aligned} \min_{\rho_{m,n}^d} & \left\{ \sum_{n \in \mathcal{N}'} \sum_{m \in \mathcal{D}'} \rho_{m,n}^d P_{m,n}^{\text{inc}} \right\}, \\ \text{subject to} & \begin{cases} \rho_{m,n}^d \in \{0, 1\}, \\ \sum_{m \in \mathcal{D}'} \rho_{m,n}^d \leq 1, \forall n \in \mathcal{N}', \\ \sum_{n \in \mathcal{N}'} \rho_{m,n}^d = 1, \forall m \in \mathcal{D}'. \end{cases} \end{aligned}$$



A bipartite graph for channel assignment problem.

- The Hungarian algorithm can be used to solve the second subproblem efficiently.
- In this way, one cellular channel is assigned to each admissible D2D pair.
- When assigning more than one channel to each D2D pair is desired, the following algorithm is used.

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1:  $\mathcal{C}$ : The set of active CUs
2:  $\mathcal{D}$ : The set of D2D pairs
3:  $\mathcal{R}_m$ : The set of candidate reuse channels for D2D pair  $m$ 
4:  $\mathcal{N}$ : The set of uplink channels
5:  $\mathcal{N}_m^d$ : The set of assigned channels to D2D pair  $m$ 
6: Initialization:  $\begin{cases} \rho_{m,n}^d = 0, \forall n \in \mathcal{N}, \forall m \in \mathcal{D}, \\ \mathcal{N}_m^d = \emptyset, \forall m \in \mathcal{D}, \\ \mathcal{R}_m = \emptyset, \forall m \in \mathcal{D}. \end{cases}$ 
7: while  $\mathcal{N} \neq \emptyset$  &  $\mathcal{D} \neq \emptyset$  do
8:   Calculate  $\bar{P}_{l,n}^c, \forall n \in \mathcal{N}, \forall l \in \mathcal{C}$ ,
9:   Calculate  $\bar{P}_{m,n}^d, \forall n \in \mathcal{N}, \forall m \in \mathcal{D}$ ,
10: Step 1
11:   for  $\forall m \in \mathcal{D}$  do
12:     for  $\forall n \in \mathcal{N}$  do
13:       Calculate  $\mathbf{p}_{m,n}^*$  by solving 1st sub-problem
14:       if 1st sub-problem has a solution then
15:          $n \in \mathcal{R}_m$ 
16:       end if
17:     end for
18:     if  $\mathcal{R}_m = \emptyset$  then  $\mathcal{D} = \mathcal{D} - m$ 
19:     end if
20:   end for
21:    $\mathcal{N} = \mathcal{R}_1 \cup \mathcal{R}_2 \cup \dots \cup \mathcal{R}_M$ 
22: end Step 1

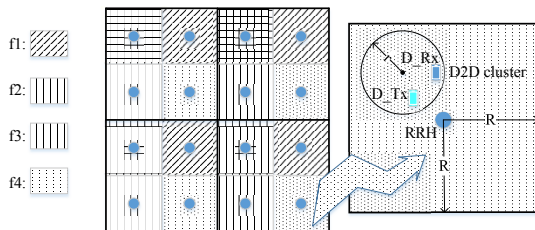
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23: Step 2
24: for  $\forall m \in \mathcal{D}$  do
25:   for  $\forall n \in \mathcal{R}_m$  do
26:     Calculate  $P_{m,n}^{\text{inc}}$ 
27:   end for
28: end for
29: if  $|\mathcal{D}| = 1$  then  $\begin{cases} n_m^* = \arg \min_{n \in \mathcal{R}_m} P_{m,n}^{\text{inc}} \\ \rho_{m,n_m^*}^d = 1 \\ \mathcal{N}_m^d = \mathcal{N}_m^d + n_m^* \end{cases}$ 
30: else Use the Hungarian algorithm
    to get  $n_m^*, \forall m \in \mathcal{D}$ , & then
     $\begin{cases} \rho_{m,n_m^*}^d = 1, \forall m \in \mathcal{D} \\ \mathcal{N}_m^d = \mathcal{N}_m^d + n_m^*, \forall m \in \mathcal{D} \end{cases}$ 
31: end if
32: end Step 2
33: for  $\forall m \in \mathcal{D}$  do
34:    $\mathcal{R}_m = \emptyset$ ,
35:    $\mathcal{N} = \mathcal{N} - n_m^*$ ,
36:   if  $\sum_{n \in \mathcal{N}_m^d} \rho_{m,n}^d = \bar{I}_m^d$  then  $\mathcal{D} = \mathcal{D} - m$ 
37:   end if
38: end for
39: end while

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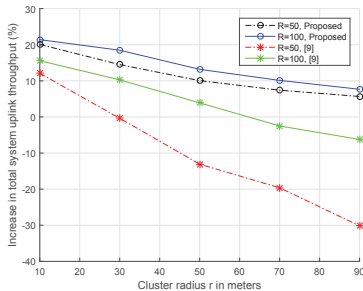
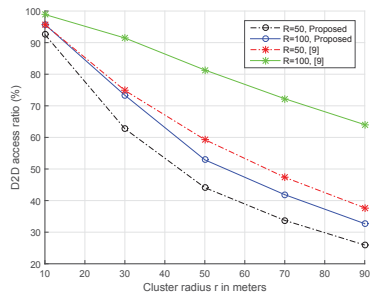
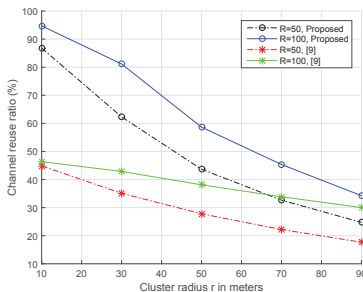
Simulation Results

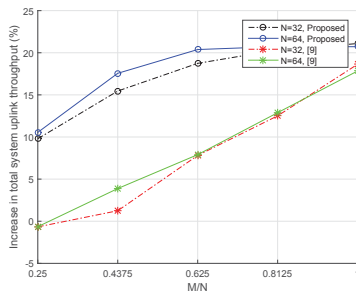
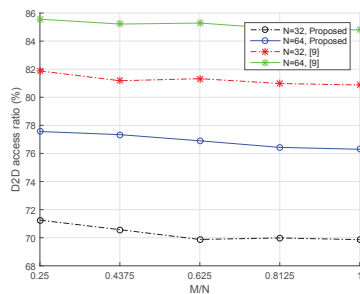
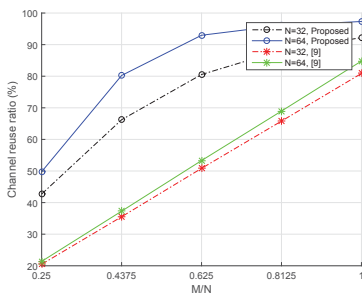


- We consider CUs are uniformly distributed in a fully loaded cellular network and each D2D pair is located in a uniformly distributed cluster with radius r .
- we compare the performance of our proposed scheme with that in [9] which assumes a margin k in each CU's required SINR to take into account the interference caused by D2D transmitters.

Parameter	Value
Cell radius (R)	50, 100 m
Channel bandwidth	1 MHz
AWGN power (σ)	-114 dBm
Pathloss exponent (α)	3
Pathloss constant (K)	10^{-2}
Max. CU aggregate power ($\bar{P}_l^c$)	20 dBm
Max. D_Tx aggregate power ($\bar{P}_m^d$)	20 dBm
Req. SINR for a CU ($\hat{\xi}_{l,n}^c$)	Uniform distribution in [0,20] dB
Req. SINR for a D2D pair ($\hat{\xi}_{m,n}^d$)	Uniform distribution in [0,20] dB
Max. number of a CU's channels ($\bar{I}_l^c$)	1
Max. number of a D2D pair's channels ($\bar{I}_m^d$)	3
D2D cluster radius (r)	10, 30, 50, $\dots$, 90 m
Number of cellular channels (N)	32, 64
Number of cellular users (L)	32, 64
No. of D2D pairs (M)	0.25, 0.4375, $\dots$, 1 of N
Fast fading gain (β)	Exponential distribution with unit mean
Slow fading gain (ζ)	Log-normal distribution with unit mean and standard deviation of 8 dB
SINR margin (k)	2 dB

- Simulation metrics, each averaged for 200 realizations are:
 - ① **Channel reuse ratio:** The number of channels reused by D2D pairs divided by the total number of channels.
 - ② **D2D access ratio:** The number of admissible D2D pairs divided by the total number of D2D pairs.
 - ③ **The increase in the total system uplink throughput** when D2D links are allowed as compared to the case in which D2D links are not permitted.





Conclusions

- We proposed a novel optimal resource allocation scheme for D2D users in a multi-cell LTE-A network with C-RAN architecture that
 - Increases the total capacity of the system,
 - Maintains the required QoS in terms of SINR for all users,
 - Considers both intracell and intercell interference,
 - Permits the D2D transmitter and its receiver to be situated in different cells,
 - Allows each D2D pair to simultaneously utilize multiple channels.
- We divided the optimization problem into two sub-problems, solved each sub-problem separately, and combined the results via our proposed algorithm.
- Simulation results demonstrate significant improvements in system performance.

Thank You