Advanced Topics in Wireless Networks

M. Rasti

Amirkabir University of Technology

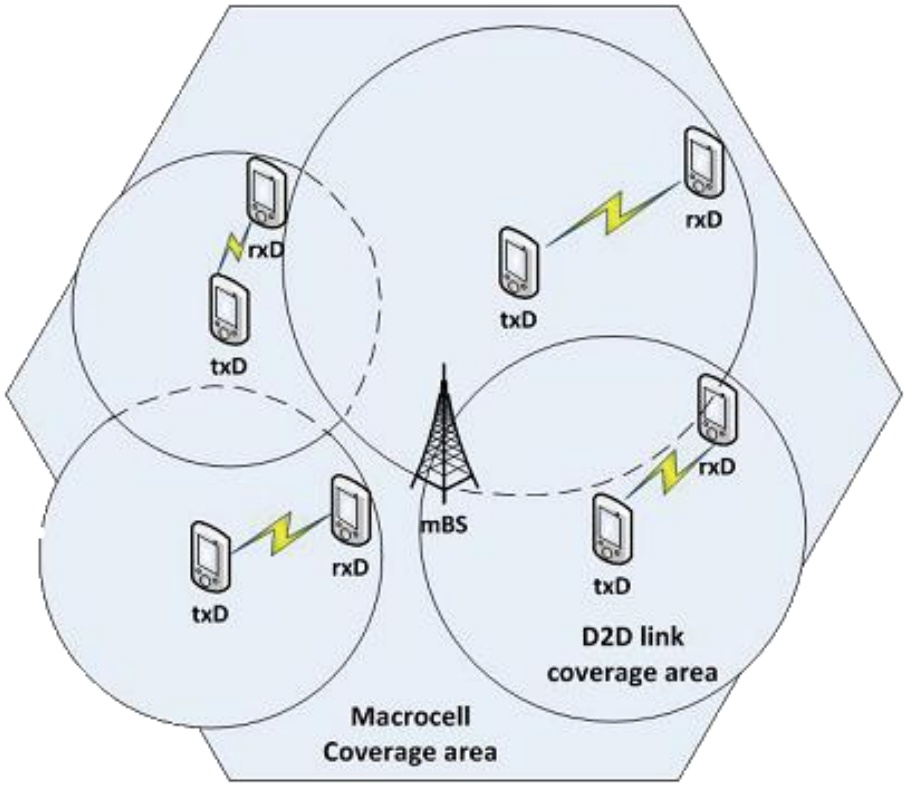
Lecture 5

D2D Communications

Lecture 5 Outline

- Introduction to D2D
- D2D Communication Challenges (Problems)
- A General System Model
- Toward a Taxonomy of D2D Problems

Introduction to D2D



Introduction to D2D

- One of the Third Generation Partnership Project Long Term Evolution commitments is to provide high data rate services for next-generation cellular.

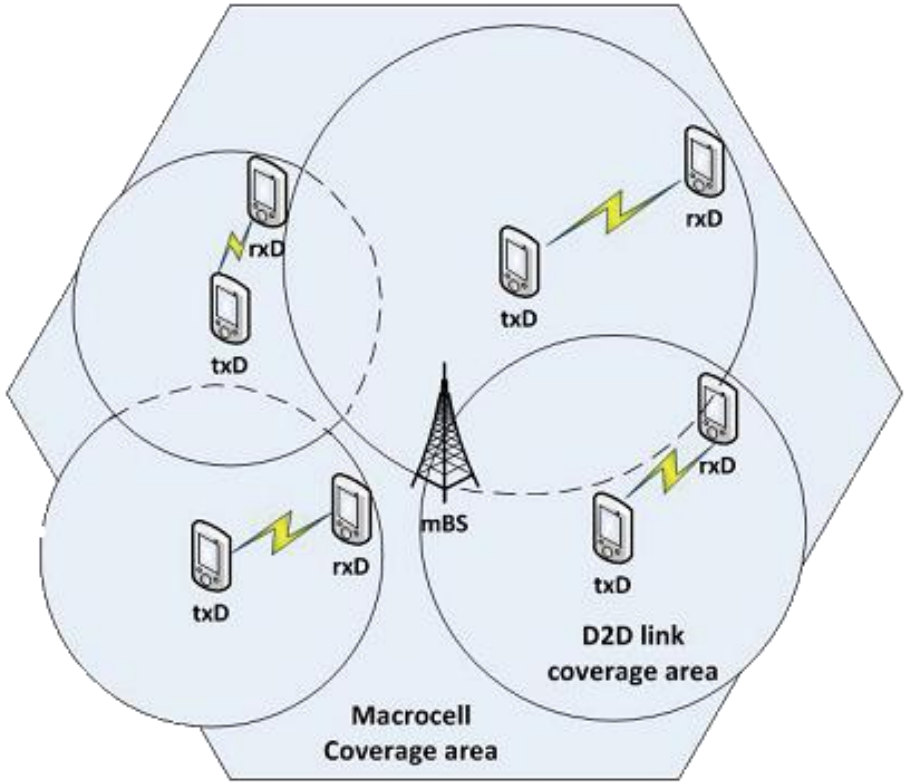
- Local Area Connections, which benefits from short distance communications, was chosen as a way of gaining high data rate

- Device-to-Device (D2D) concept was born.

Introduction to D2D

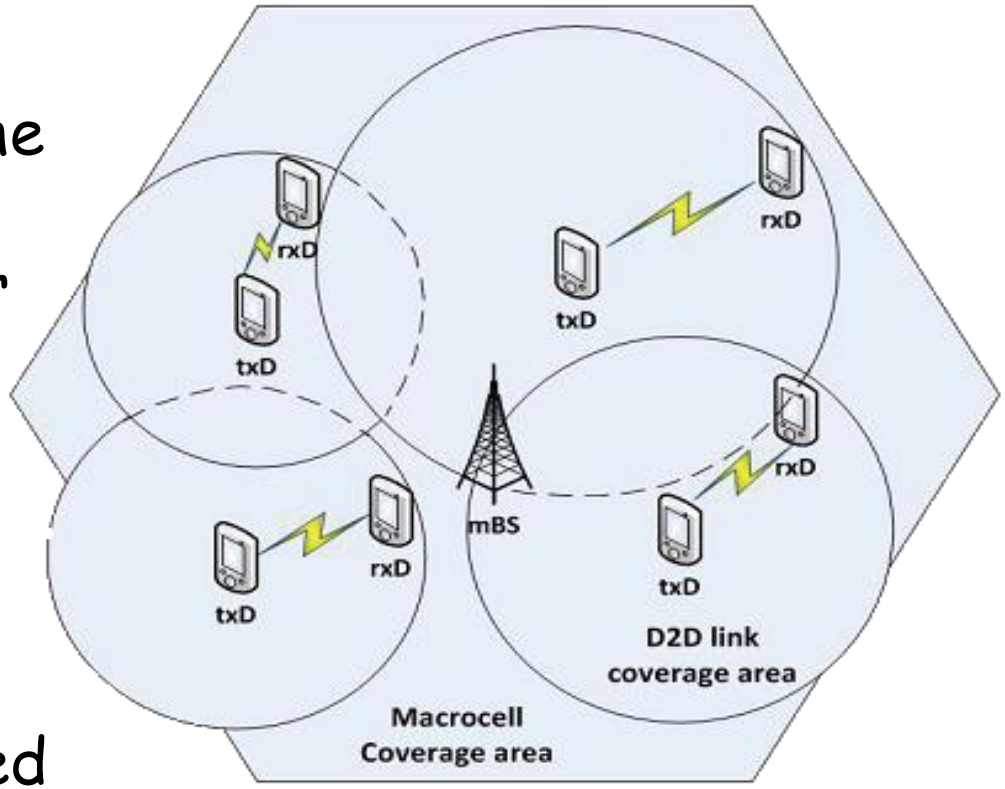
- Throughput enhancement
- Better spatial spectrum reuse
- Energy saving due to possibly lower transmission power
- Extending cellular coverage

Introduction to D2D



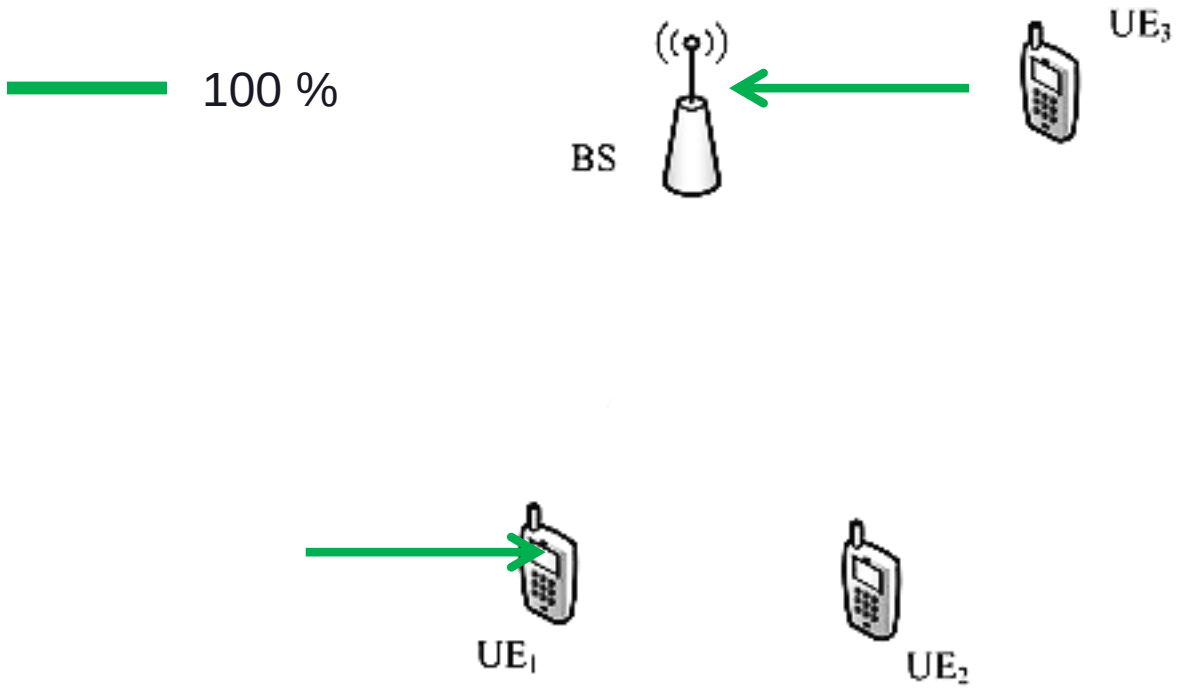
Introduction to D2D

- D2D Communication Classification:
  - Inband D2D: Using the cellular spectrum for both D2D and cellular links
    - Overlay
    - Underlay
  - Outband D2D: D2D links exploit unlicensed spectrum



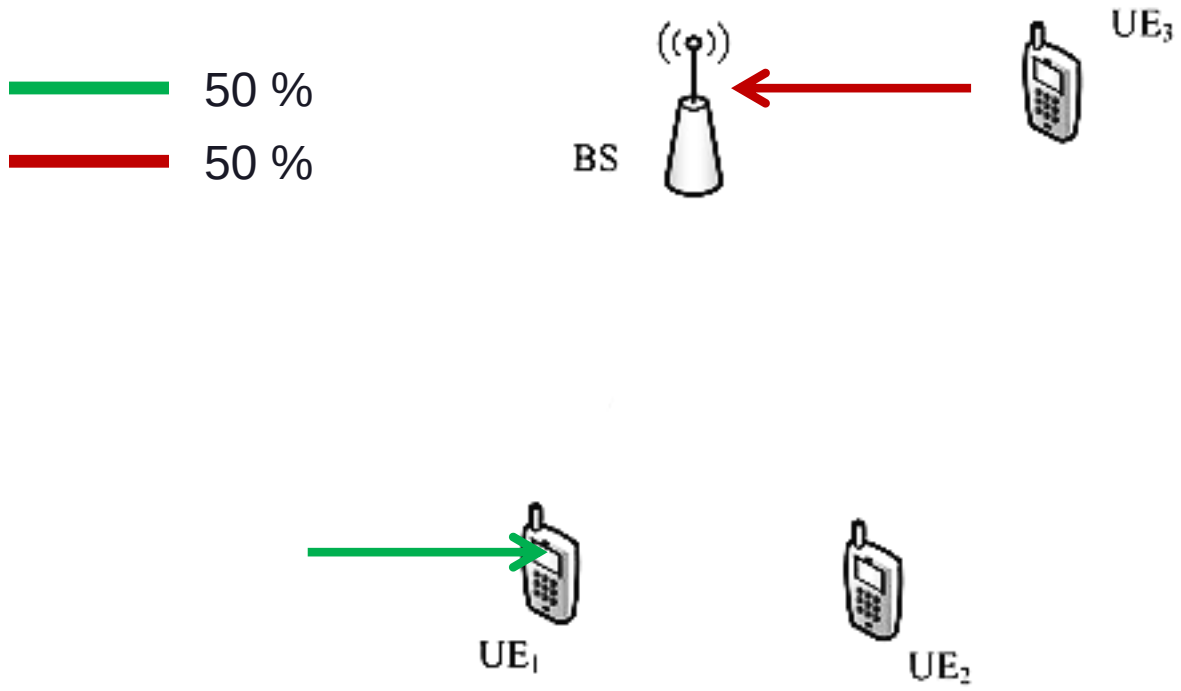
Introduction to D2D

- Underlay Inband D2D



Introduction to D2D

- Overlay Inband D2D (or Outband D2D)



D2D Communication Challenges (Problems)

- Node/peer Discovery
- Scheduling: Carrier (resource blocks) Allocation
- Power Control
- Mode Selection

D2D Communication Challenges (Problems)

- Node/peer Discovery:
  - The first phase of a D2D communication in which UEs and/or BSs discover the device pairs that would potentially benefit from D2D communication
  - Distributed and centralized algorithms are proposed in [1] and [2]

[1] K.Doppler, C.Ribeiro, and J.Kneckt, "Advances in D2D communications: Energy efficient service and device discovery radio,"

[2] F. Baccelli, N. Khude, R. Laroia, J. Li, T. Richardson, S. Shakkottai, S. Tavildar, and X. Wu, "On the design of device-to-device autonomous discovery,"

D2D Communication Challenges (Problems)

- Scheduling
  - Allocating the available carriers (block resources) to D2D pairs and cellular users
- Mode Selection
  - Choosing to connect to BS or to its D2D pair
- Power Control
  - Interference management between D2D and cellular users (in either UL or DL)

System Model

- System is considered to be a single-cell LTE-A cellular system
- In a single-cell a fixed-number of RBs are available for allocating to users
- Three phases are considered to be happened
  - Peer Discovery
  - Scheduling
  - Power control
  - Mode selection

System Model

- In an LTE network there are the following constraints [11] :

1. A RB is assigned to at most one cellular user
2. Aggregate power for each user on all of it's RBs must be less than the maximum level
3. Power allocated on each RB should be less than a peak-level
4. Farther Limitations (which could be removed!)
   - RB allocated to a users must be adjacent (In LTE-A, this limitation has been removed)
   - Transmit Power levels for a given user on all of its allocated and used RBs are the same

[11] XU Quan-sheng, "Resource allocation algorithm in LTE uplink SC-FDMA system for time-varying channel with imperfect channel state information ", The Journal of China Universities of Posts and Telecommunications

System Model

- For underlaying D2D (underlay inband) in an LTE-A, additional assumption/limitations appear as follows :

6. A given RB is assigned to only one cellular user (and no more), although it may be assigned to many D2D users regardless of being assigned to a cellular user or not

7. When a RB is assigned to a cellular user, no D2D user may choose the 'indirect' mode on that RB

8. When a RB is occupied by no cellular user, at most one D2D user may choose the 'indirect' mode on that RB.

System Model

- **Notations :**

C : set of indices of 'Cellular' users

D : set of indices of 'D2D' users

$D(j)$: pair of D2D device j whom j is potentially found to be able to send to (in discovery phase)

l_i : Number of RBs assigned to user i

N : number of all users

i : index of users ($1 \leq i \leq N$)

L : number of RBs

System Model

Notations :

k : index of RBs ($1 \leq k \leq L$)

$$S_{ik} = \begin{cases} 0, & if\ RB\ k\ is\ not\ assigned\ to\ user\ i \\ 1, & if\ RB\ k\ is\ assigned\ to\ user\ i \end{cases}$$

p_{ik}: power of device *i* on Resource Block *k*

p_{max}: maximum aggregate power of each device on all of its RBs

p_{peak} : maximum power of each device on each of its RBs

γ_{ik}: SINR of user *i* on RB *k*

r_{ik} : throughput of user *i* on RB *k*

System Model

Notations :

$\hat{r}_i$: target aggregate throughput of device i

mode of D2D device i: m_{ik}

$$= \begin{cases} 0, & \text{if link on RB } k \text{ is indirect (to BS)} \\ 1, & \text{if link on RB } k \text{ is direct (to D2D} \end{cases} :$$

H_{iB} : path gain between user i and Base Station

$H_{iD(j)}$: path gain between user i and receiver pair of D2D user j

W = bandwidth of each RB in Hz

N_o = background noise

System Model

- SINR:

$$\gamma_{ik} = \begin{cases} \left(\dfrac{p_{ik} H_{iD(i)} m_{ik}}{\sum_{j \epsilon C} p_{jk} H_{jD(i)} S_{jk} + \sum_{j \epsilon D} p_{jk} (1 - m_{jk}) H_{jD(i)} S_{jk} + \sum_{j \epsilon D} p_{jk} m_{jk} H_{jD(i)} S_{jk} + N_0} + \dfrac{p_{ik} H_{iB} (1 - m_{ik})}{\sum_{j \epsilon D} p_{jk} m_{jk} H_{jB} S_{jk} + N_0} \right) S_{ik}, & i \epsilon D \\ \left(\dfrac{p_{ik} H_{iB}}{\sum_{j \epsilon D} p_{jk} m_{jk} H_{jB} S_{jk} + N_0} \right) S_{ik}, & i \epsilon C \end{cases}$$

- Achievable data rate of user i on RB k:

$$r_{ik} = W \log_2 (1 + \gamma_{ik})$$

Toward a Taxonomy of D2D Problems

- Variables
  - Resource blocks assignment (Scheduling): S_{ik}
  - Transmit Power levels of devices (power control): p_{ik}
  - Mode of communication (mode selection): m_{ik}

- Objectives
  - Maximizing aggregate throughput
  - Minimizing aggregate power
  - Fairness
  - Minimizing outage ratio

Toward a Taxonomy of D2D Problems

- Constraints
  - Maximum allocable resources to D2D users
  - Maximum transmit power by UE devices,
  - Guaranteeing a minimum SINR for D2D and/or cellular users

Toward a Taxonomy of D2D Problems

- **Constraints :**

C1. Power of each user on all of its RBs is the same

C2. Aggregate power of a user on all of its RBs is below a maximum power level (which a UE device can send). Also power allocated on each RB should be less than a peak-level.

C3. A minimum throughput for D2D users and cellular users

C4. In a RB where there is a cellular user occupying it, no D2D user may send in 'indirect' modes. Also in RB where there is no cellular user occupying it, at most one D2D user may send data in 'indirect' modes.

Toward a Taxonomy of D2D Problems

Problem 1:

$$\min_{p_{ik}, m_{ik}} \sum_{k=1}^{L} \sum_{i=1}^{N} p_{ik}$$

Such that:

$$p_{ik} = p_i \ , \forall i, k \qquad (C1)$$

$$p_{ik} \leq \min\left(p_{max}/l_i \, , p_{peak}\right) \ , \forall i, k \qquad (C2)$$

$$\sum_{k=1}^{L} r_{ik} \geq \hat{r}_i \ , \forall i \qquad (C3)$$

$$\sum_{i \in c} S_{ik} + \sum_{j \in D} (1 - m_{ik}) \leq 1 \ , \forall k \qquad (C4)$$

Variables: s_{ik}, p_{ik}, m_{ik}

Toward a Taxonomy of D2D Problems

Problem 2:

$$\max_{\{s_{ik}\},\{p_{ik}\},\{m_{ik}\}} \sum_{k=1}^{L} \sum_{i=1}^{N} r_{ik}$$

Such that:

$$p_{ik} = p_i \ , \forall i,k \qquad (C1)$$

$$p_{ik} \leq \min\left(p_{max}/l_i \ , p_{peak}\right) \ , \forall i,k \qquad (C2)$$

$$\sum_{k=1}^{L} r_{ik} \geq \hat{r}_i \ , \forall i \qquad (C3)$$

$$\sum_{i \in c} S_{ik} + \sum_{j \in D} (1 - m_{ik}) \leq 1 \ , \forall k \qquad (C4)$$

Variables: s_{ik}, p_{ik}, m_{ik}

Toward a Taxonomy of D2D Problems

- [5] Doppler, K.; Chia-Hao Yu; Ribeiro, C.B.; Janis, P., "Mode Selection for Device-To-Device Communication Underlaying an LTE-Advanced Network," Wireless Communications and Networking Conference (WCNC), 2010 IEEE , vol., no., pp.1,6, 18-21 April 2010

- [6] Chia-Hao Yu; Tirkkonen, O.; Doppler, K.; Ribeiro, C., "Power Optimization of Device-to-Device Communication Underlaying Cellular Communication," Communications, 2009. ICC '09. IEEE International Conference on , vol., no., pp.1,5, 14-18 June 2009

- [7] Yongsheng Cheng; Yuantao Gu; Xiaokang Lin, "Combined power control and link selection in deviceto-device enabled cellular systems," Communications, IET , vol.7, no.12, pp.1221,1230, Aug. 13 2013

- [8] Hakola, S.; Tao Chen; Lehtomaki, J.; Koskela, T., "Device-To-Device (D2D) Communication in Cellular Network - Performance Analysis of Optimum and Practical Communication Mode Selection," *Wireless Communications and Networking Conference (WCNC), 2010 IEEE* , vol., no., pp.1,6, 18-21 April 2010

Toward a Taxonomy of D2D Problems

- [9] Si Wen; Xiaoyue Zhu; Xin Zhang; Dacheng Yang, "QoS-aware mode selection and resource allocation scheme for Device-to-Device (D2D) communication in cellular networks," Communications Workshops (ICC), 2013 IEEE International Conference on , vol., no., pp.101,105, 9-13 June 2013

- [10] S. Ali, N. Rajatheva, and M. Latva-aho, "Full Duplex Device-to-Device Communication in Cellular Networks".

- [11] X. Cai, J. Zheng, Y. Zhang, and H. Murata, "A Capacity Oriented Resource Allocation algorithm for device-to-device communication in mobile cellular networks," in Communications (ICC), 2014 IEEE International Conference on, 2014, pp. 2233-2238.

- [12] X. Chen, L. Chen, M. Zeng, X. Zhang, and D. Yang, "Downlink resource allocation for Device-to-Device communication underlaying cellular networks," in Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on, 2012, pp. 232-237.

- [13] Y. Li, D. Jin, J. Yuan, and Z. Han, "Coalitional Games for Resource Allocation in the Device-to-Device Uplink Underlaying Cellular Networks." 2014.

روش	فرضیات										متغیر ها					هدف					محدودیت ها					نوع راه حل (در صورت ارائه)
	منابع سلولی استفاده شده		تک سلولی	چند سلولی	duplexing	تعداد جفت گره D2D		حداکثر تعداد کانال قابل تخصیص به یک جفت D2D		امکان اشتراک گذاری هر کانالِ کاربر سلولی توسط		توان کاربران	توان BS	حالت D2D	BS	تخصیص RB ها	حداقل مجموع توان ارسالی	حداکثر گذر دهی یک لینک	حداقل outage	حداکثر گذر دهی همه کاربران	حداکثر گذر دهی همه کاربران و انصاف	حداکثر توان ارسالی محدود	تضمین حداقل SINR		محدود کردن حداکثر SINR		
	UL	DL				یک جفت	چند جفت	یک کانال	چند کانال	یک کاربر D2D	چند کاربر D2D											برای کاربران سلولی	برای کاربران D2D	برای کاربران سلولی	برای کاربران D2D	نا متمرکز	متمرکز
[5]	✓	✓	✓	✓			✓		✓		✓			✓				✓				✓	✓				✓
[6]	✓	✓	✓				✓	-	-	-	-	✓		✓				✓				✓	✓		✓	✓		✓
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