D2D communication in cellular networks

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D2D definition and motivation

Wireless networks

- **Wireless Mobile/Cellular Networks:** Licensed spectrum, reliability
- **Wireless Local Area Networks (WLANs):** internet access, local area
- **Mobile/Vehicular Ad-hoc NETwork (MANET/VANET):** self-configuring, independent movement, frequent changes
- **Wireless Sensor Network (WSN):** spatially distributed sensors, cooperate for monitoring purposes
- **Wireless Mesh Network (WMN):** more planned ad-hoc network
- **Delay/Disruption Tolerant Network (DTN):** no end-to-end path, opportunistic networks, store-carry-forward approach
- **Wireless Person Area Networks (WPAN):** data transmission among devices such as computers, telephones and personal digital assistants.
- **Professional/private Mobile Radio networks (PMR):** Push-to-talk, release to listen - VHF or UHF frequency bands

Wireless technologies

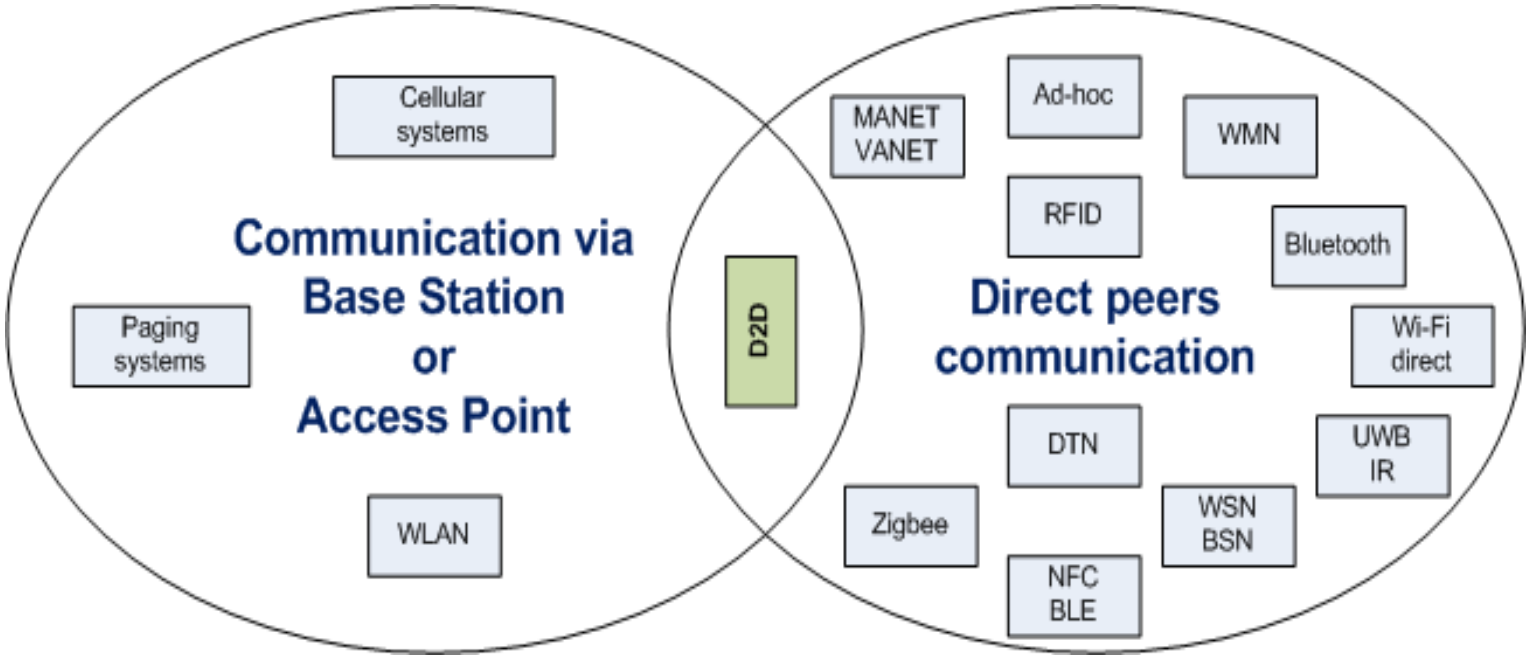
Wireless technologies are applied to different wireless networks:

- **Wireless Mobile/Cellular Networks**
  - **GSM, UMTS, LTE, LTE-A**
- **WLANs**
  - **WiFi, WiFi direct**
- **WSN**
  - **Zegbee, WiFi, Bluetooth**
- **WPAN**
  - **Radio-Frequency IDentification (RFID):** Identify tags attached to objects, one-direction
  - **Near Field Communication (NFC):** Few centimeters range, 2-way communication
  - **Ultra-wideband (UWB):** very low energy level for short range, high bandwidth
  - **Infrared (IR):** short range, line of sight, bidirectional
  - **Bluetooth:** short distances, unlicensed ISM band
- **PMR**
  - **TETRA, TETRAPOL**

Wireless Networks/Technologies

Categorization based on network assistance

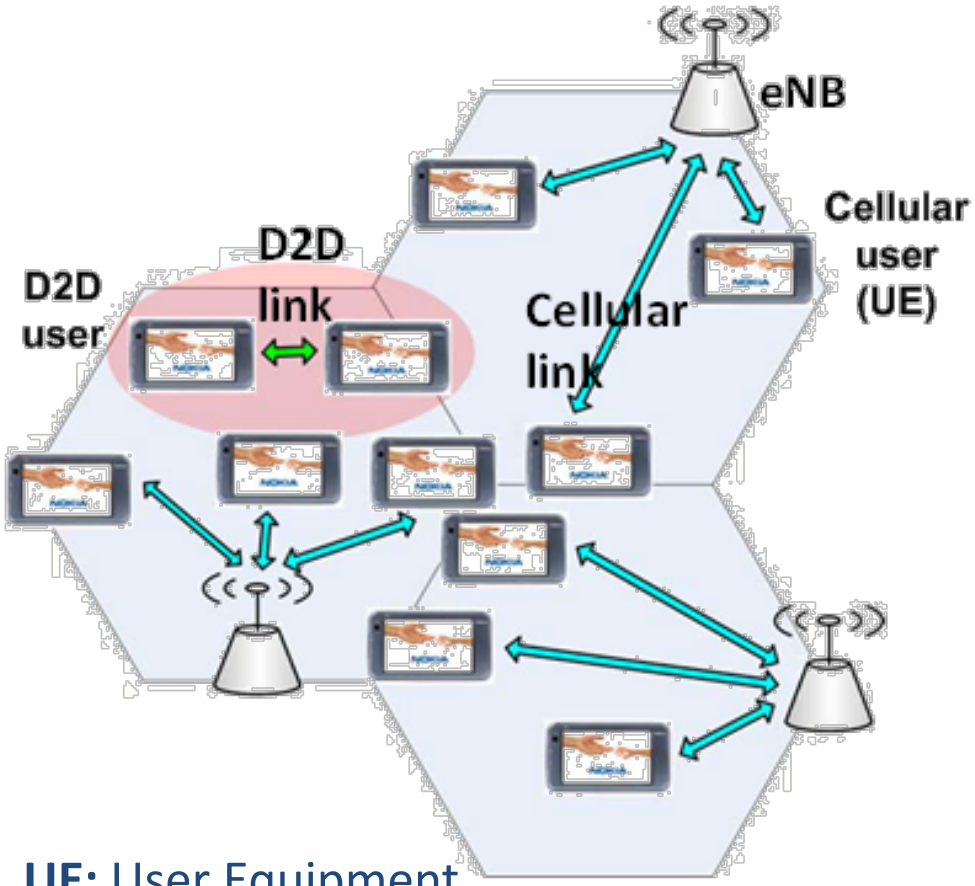
Where D2D lies:



1st perspective → Control

2nd perspective → Data

D2D definition



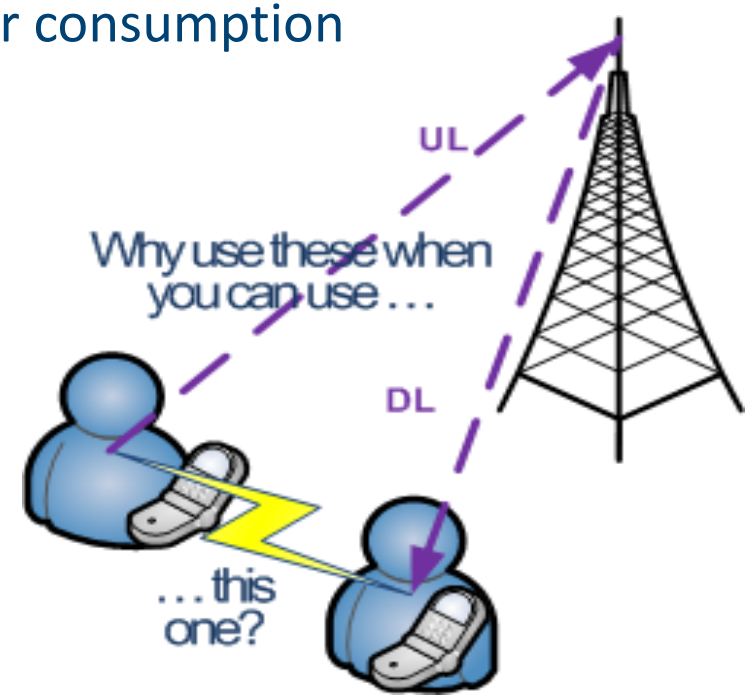
UE: User Equipment
eNB: evolved NodeB

Define D2D as:

- **Direct** pair communication in **licensed** spectrum *(underlay cellular nets)*
- Communication peers are in **physical proximity**
- **Network-assisted** D2D links *(or not in non-coverage areas)*

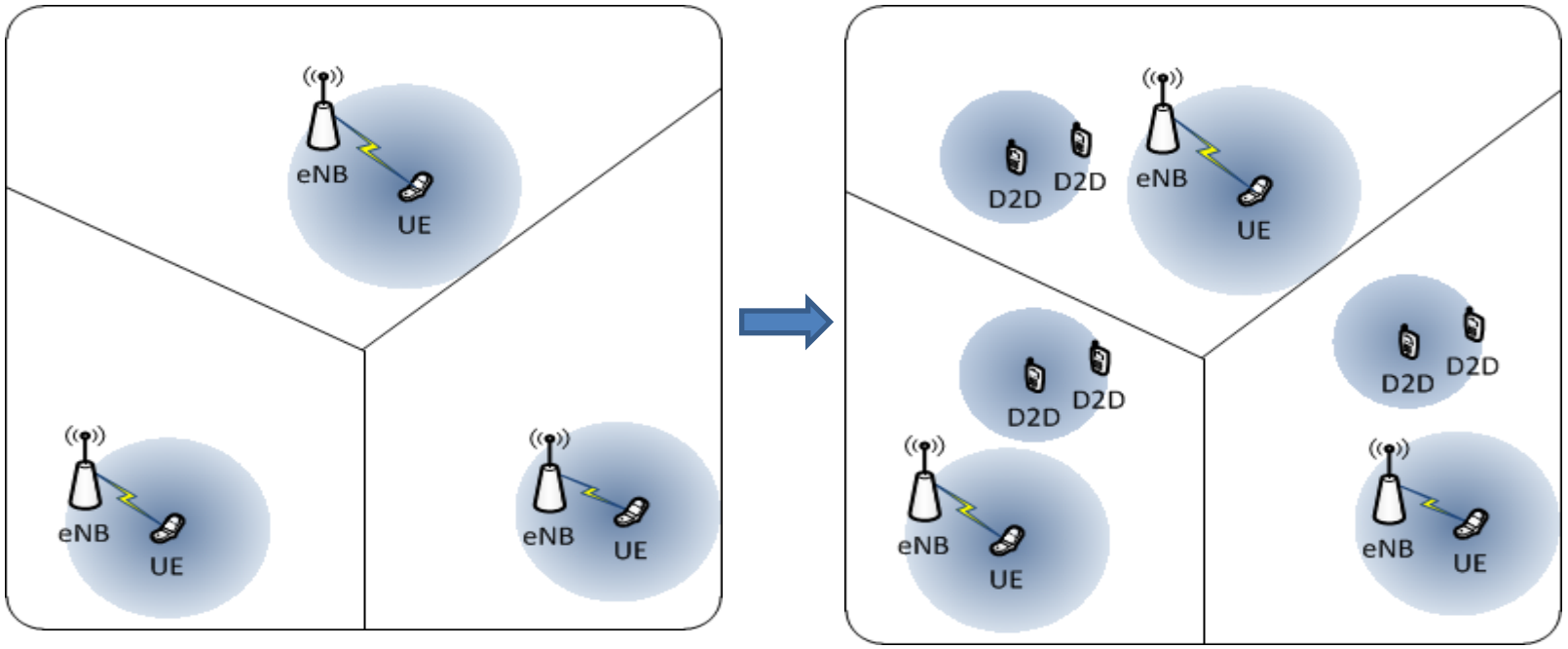
Motivation for D2D (1/6)

- **Proximity gain:**
  - Higher bit rates (throughput)
  - Lower delays (latency)
  - Lower power consumption
- **Hop gain:**
  - single link (not different resource for UL/DL)!



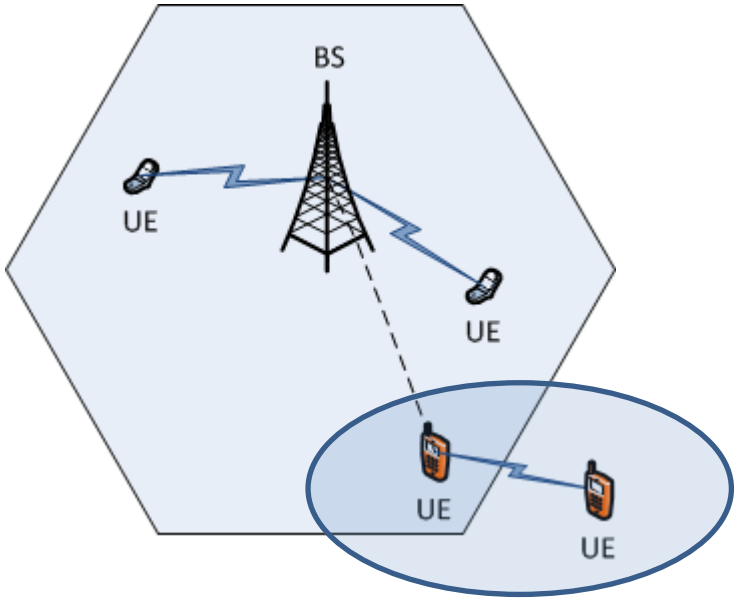
Motivation for D2D (2/6)

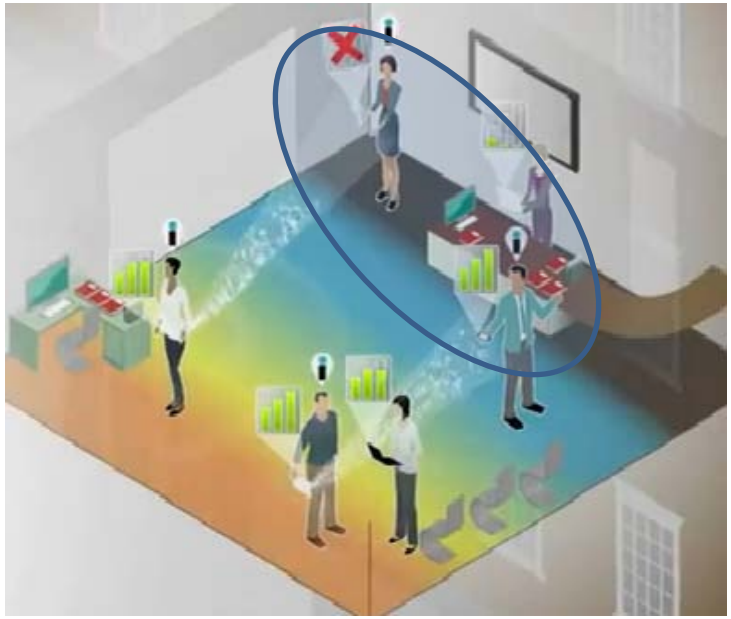
- **Reuse opportunity:**
  - Radio resources utilization: spatial spectral reuse
  - Spectral efficiency increase



Motivation for D2D (3/6)

- **Increased coverage**:
  - UE relaying
  - Handle poor cellular coverage conditions (indoor)





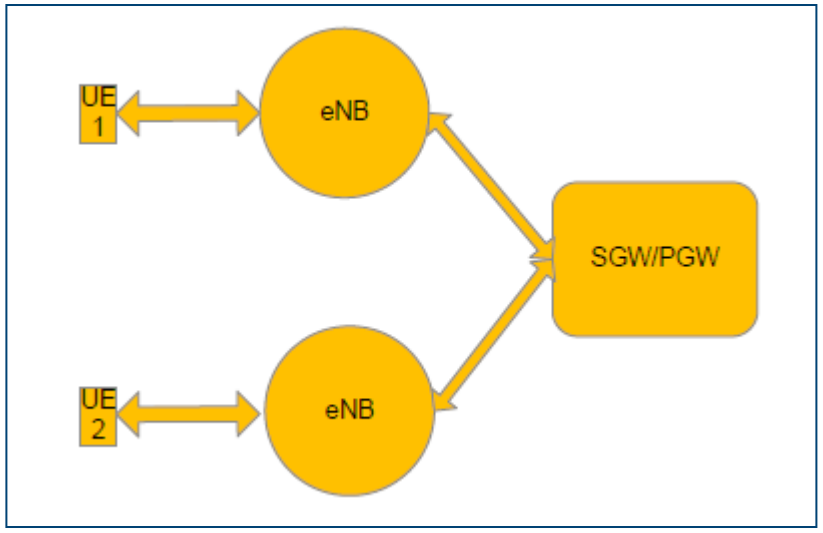
Motivation for D2D (4/6)

- **Public protection and disaster relief:**
  - There are billions of smart cellular devices ! But they can hardly used in emergency situations
  - Direct communication would be vital in scenarios where the network is down

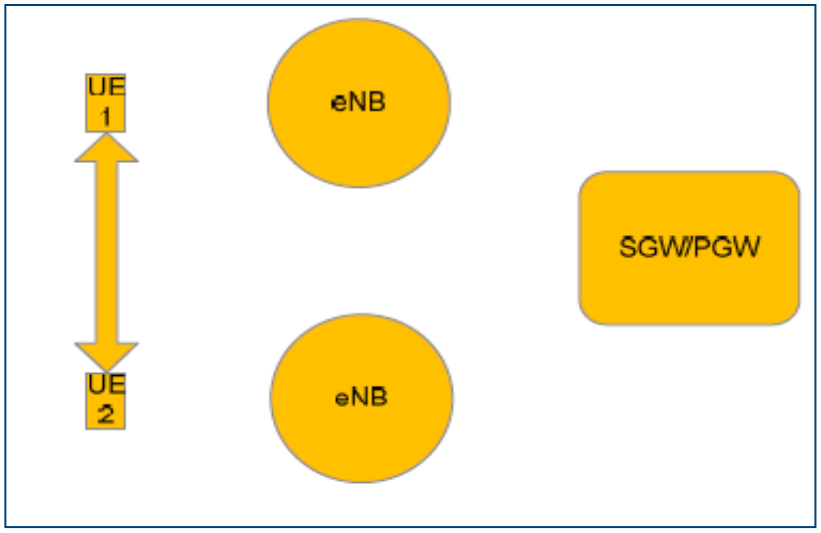
Motivation for D2D (5/6)

- **eNB offloading**
- **Core network decongestion**

Conventional - Without D2D

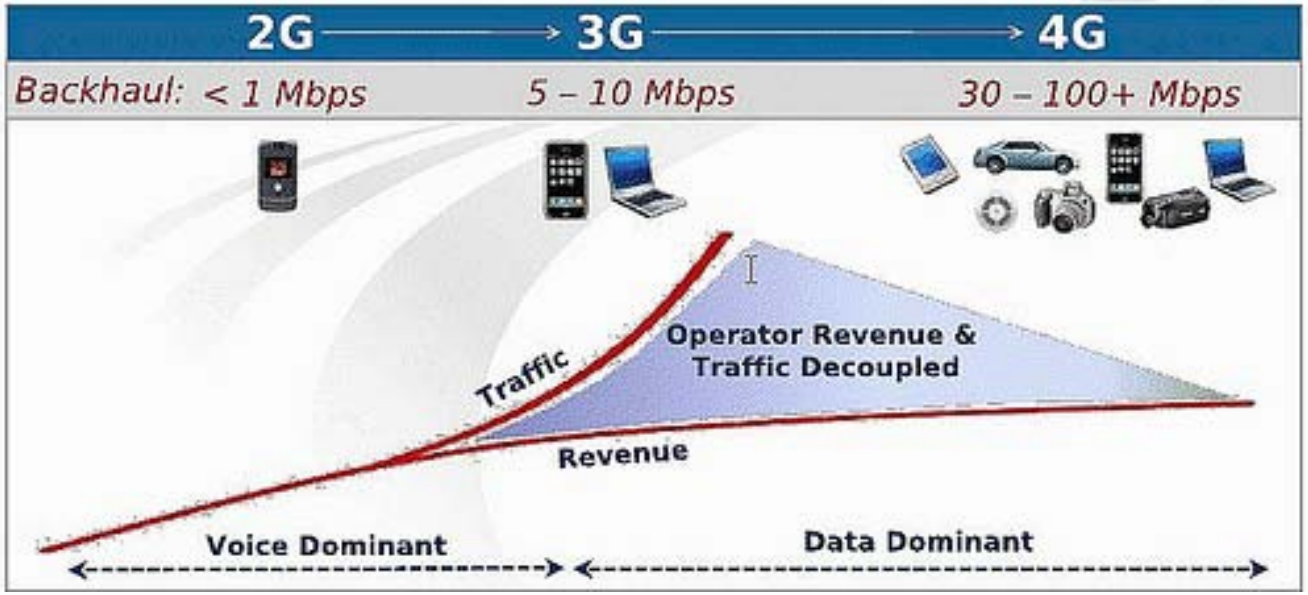


With D2D



Motivation for D2D (6/6)

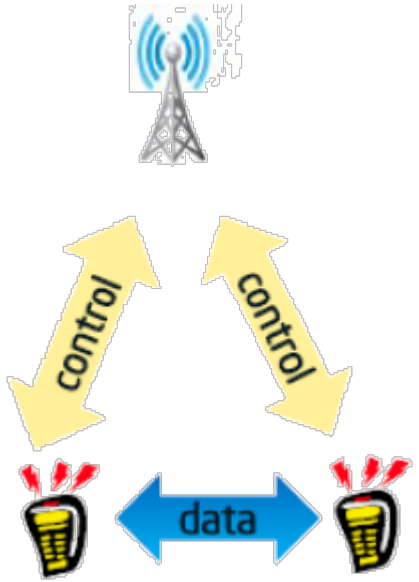
- **Operator profits:**
  - Towards covering the widening gap between network traffic and service revenue



- **New types of P2P services – Proximity Services (ProSe):**
  - Enables communication between consumer devices and cell phones

D2D Vs. Current direct comm. technologies

- **Operator controlled**
- **QoS guarantees**
- **Transparent** to the user
- Increased **security**
- **Mobility** freedom (larger distances)
- **Reliability** – use of licensed band
- eNB assistance



D2D standardization activities

3GPP Features and Study Items Release 12

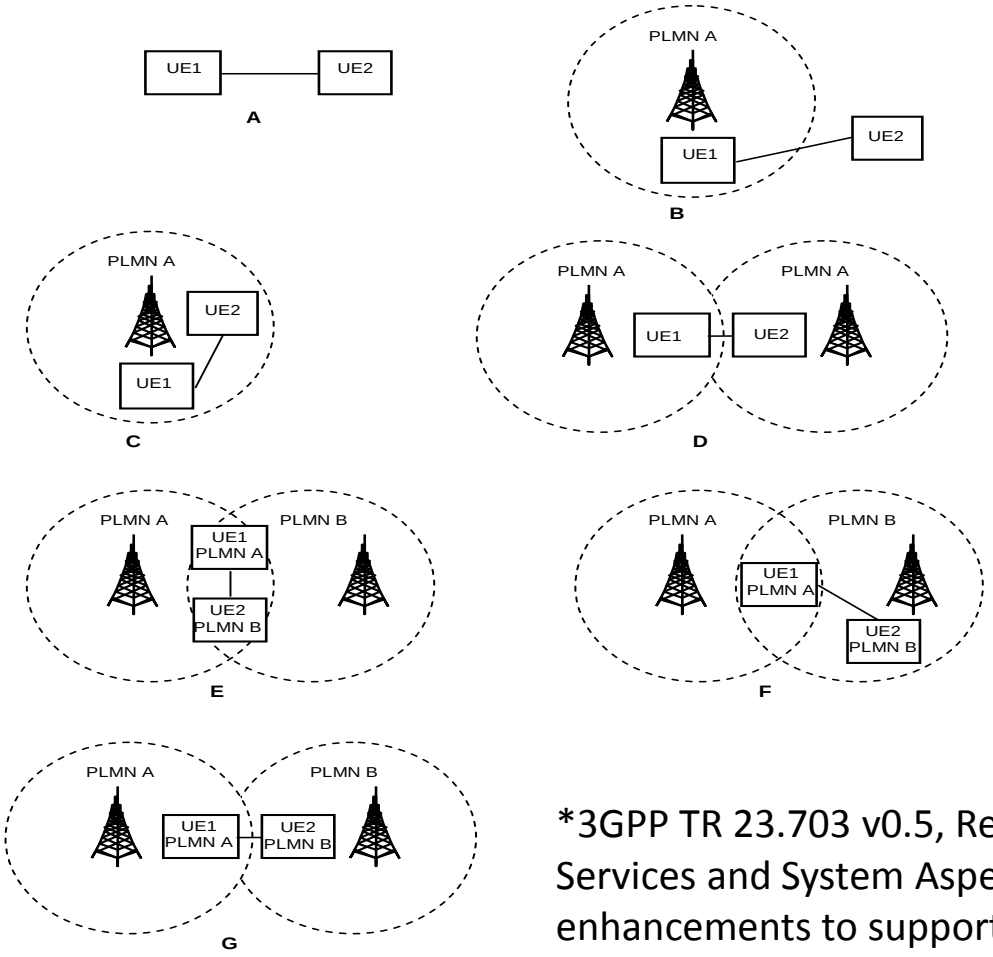
- ✓ **Feasibility study for Proximity Services (ProSe) TR 22.803**
- ✓ **Study on LTE Device-to-Device Proximity Services - Radio Aspects TR36.843**
- ✓ LTE Device to Device Proximity Services; User Equipment (UE) radio transmission and reception TR 36.877
- ✓ Service requirements for the Evolved Packet System (EPS) TS 22.278
- ✓ Group Communication System Enablers for LTE (GCSE_LTE) TS 22.468

Key issues and solutions

- ✓ **Study on architecture enhancements to support Proximity-based Services (ProSe) TR23.703**
- ✓ Study on architecture enhancements to support Group Communication System Enablers for LTE TR23.768

D2D standardization activities

3GPP scenarios for ProSe*

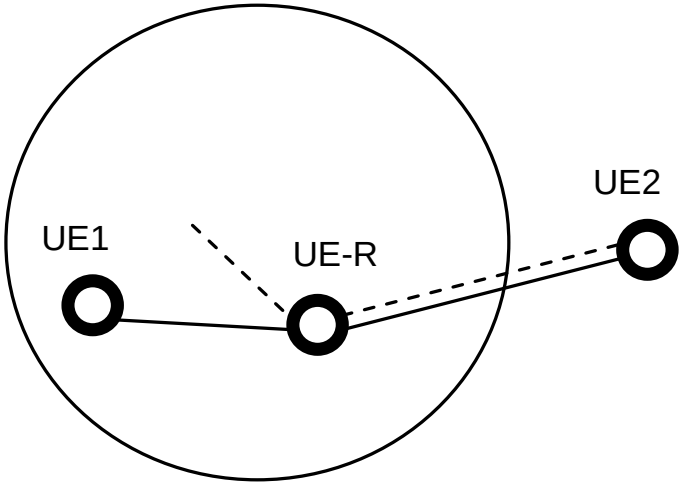


*3GPP TR 23.703 v0.5, Rel 12,"Technical Specification Group Services and System Aspects; Study on architecture enhancements to support Proximity Services (ProSe)", Jun. 2013

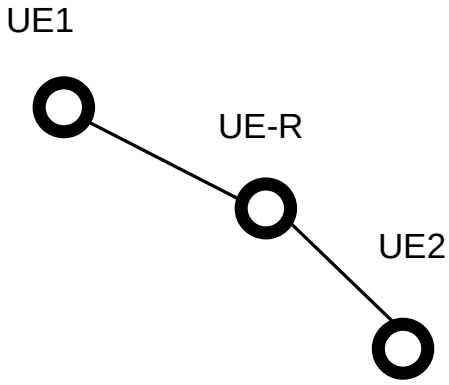
D2D standardization activities

3GPP scenarios 3GPP scenarios for ProSe*

(In the case of Public safety: UE as a relay node)



A: UE-to-Network or UE-to-UE relay

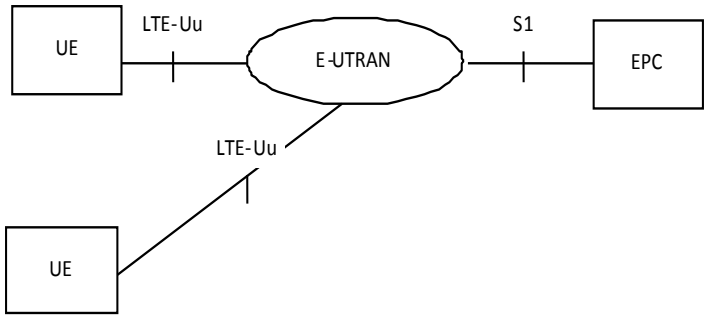


B: UE-to-UE relay

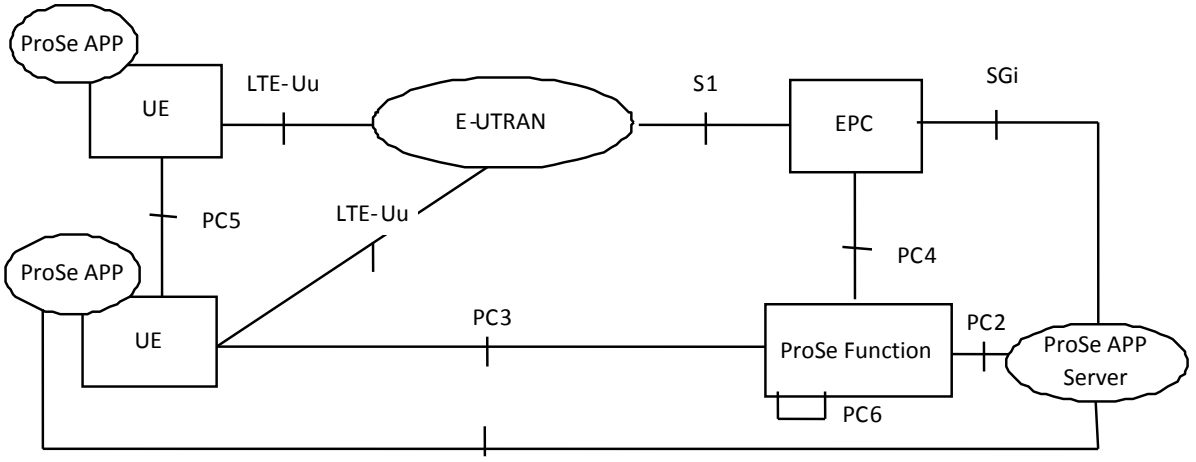
*3GPP TR 23.703 v0.5, Rel 12,"Technical Specification Group Services and System Aspects; Study on architecture enhancements to support Proximity Services (ProSe)", Jun. 2013

D2D standardization activities

- **Conventional Architecture**



- **Architecture with D2D (ProSe)**



D2D challenges

D2D Challenges

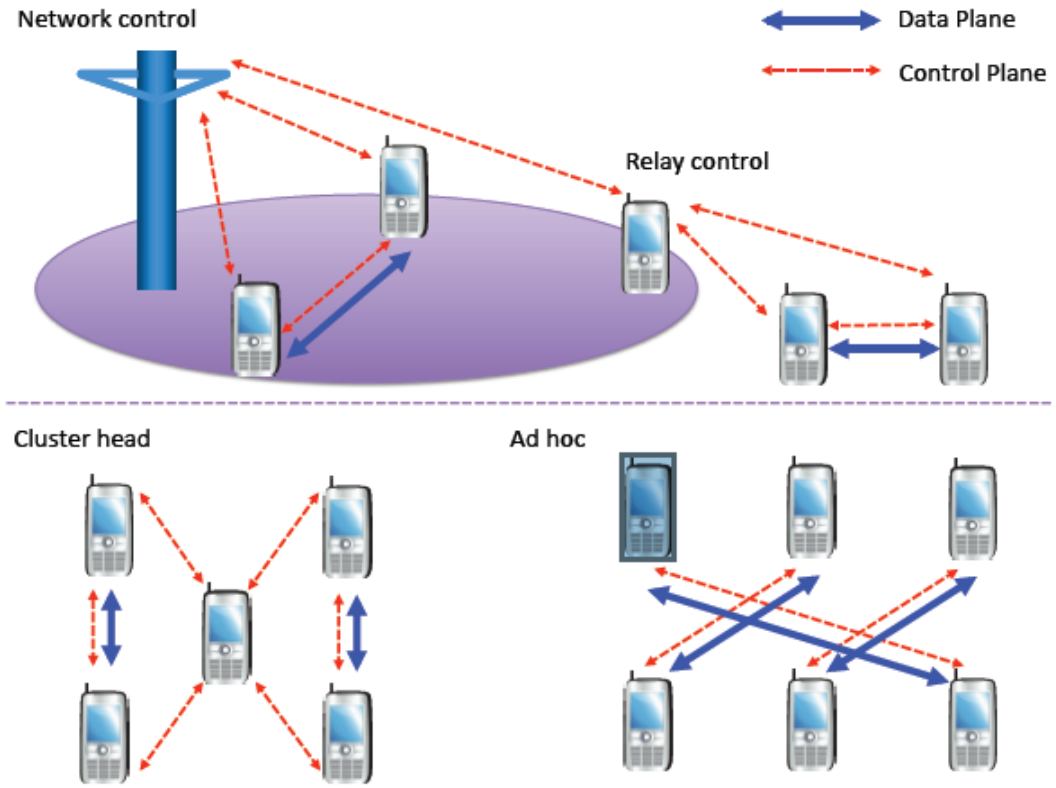
- Higher layer issues:
  - security, authorization, privacy and billing
- **Radio access issues:**
  1. **Design and management challenges**
  2. **Synchronization challenges**
  3. **Direct communication challenges**
  4. **Device discovery challenges**

D2D Challenges

Radio access issues

1. Design and management challenges - Control aspects

- **In coverage**
  - ***Full control by eNB or loose control?***
- **Out of coverage**
  - ***Via a Cluster-head or Ad hoc?***



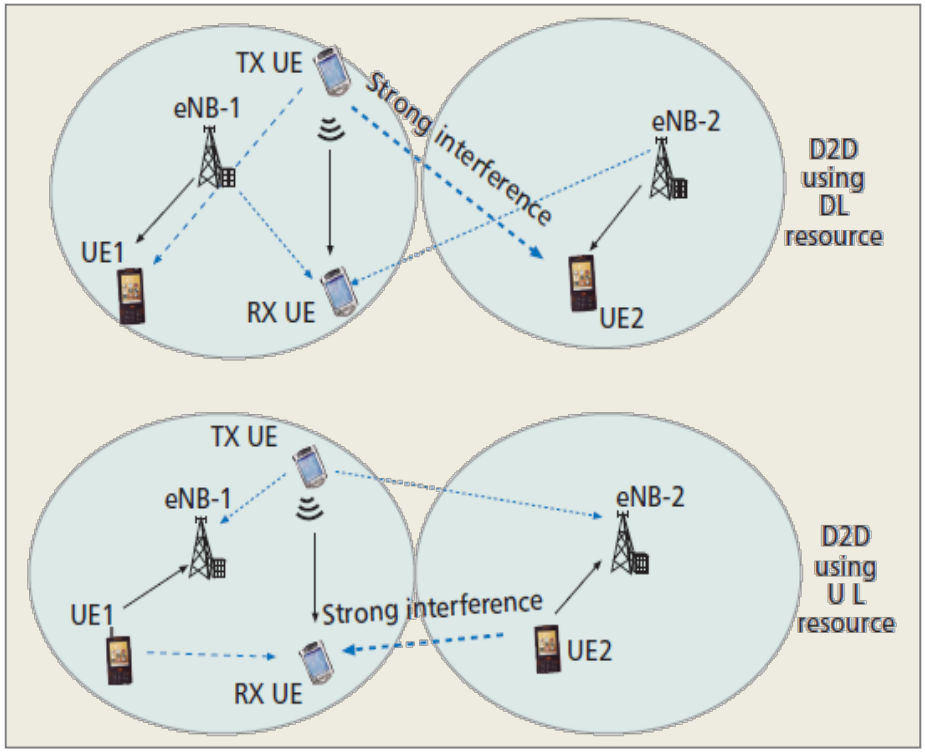
D2D Challenges

Radio access issues

1. Design and management challenges – UL or DL resources

- **Answer: UL** ***Why?***

1. **UL resources are often less utilized**
2. **DL resources contain heavy control signaling**
3. **Interference can be better dealt by eNBs**
4. **Hardware aspects –** Receive in UL or Transmit in DL

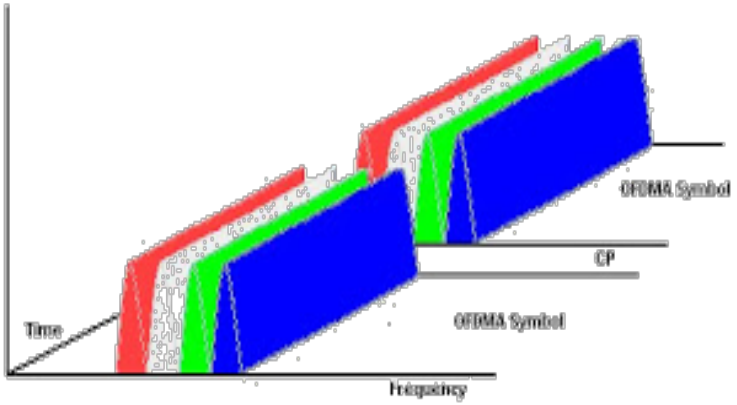


D2D Challenges

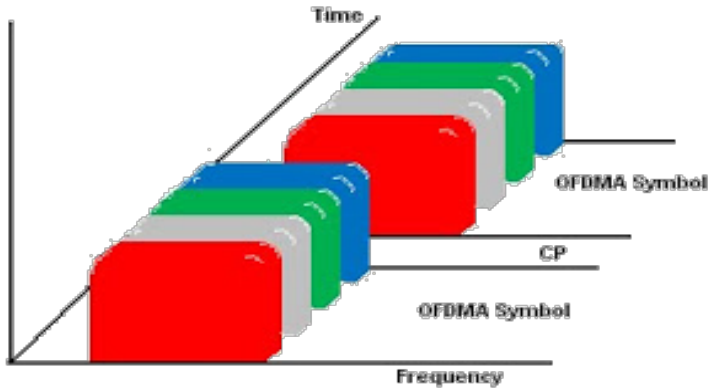
Radio access issues

1. Design and management challenges – modulation format

LTE-A PHY



DL: OFDMA



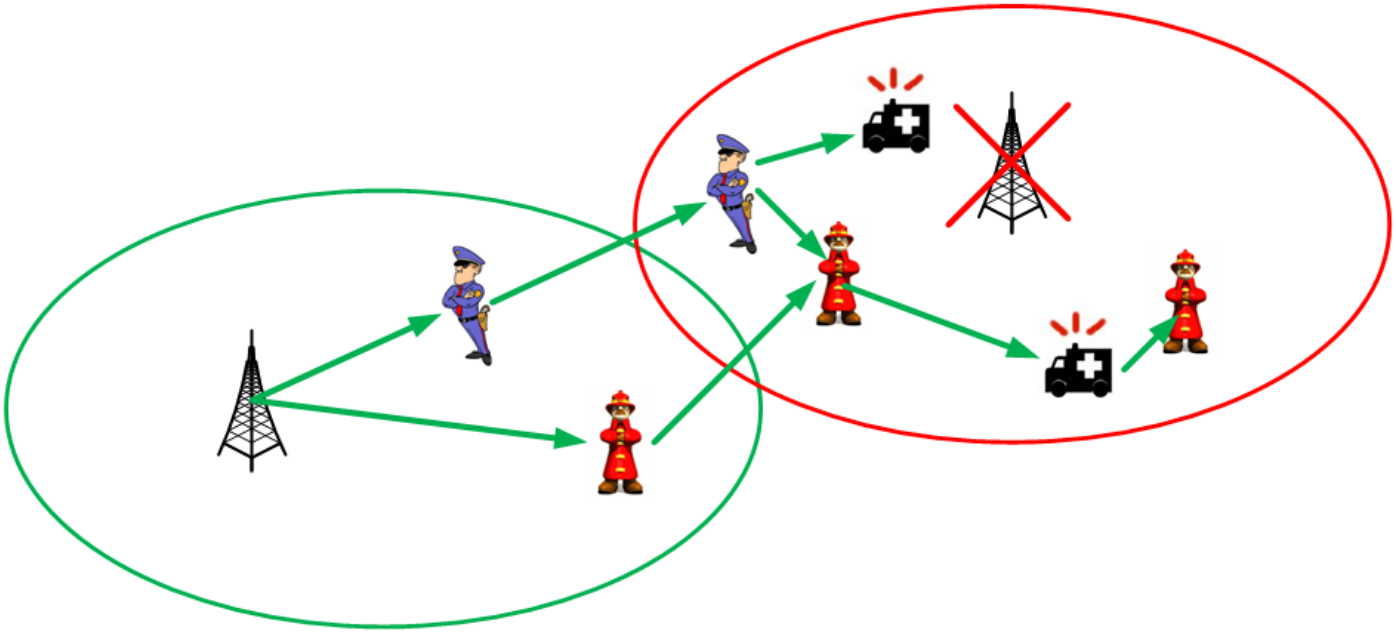
UL: SC-FDMA

D2D Challenges

Radio access issues

1. Design and management challenges – D2D operation modes

- unicast / multicast, broadcast , relay



D2D Challenges

Radio access issues

2. Synchronization challenges

- **UEs in coverage – Synchronization is hard to be achieved**
- UEs may be associated with different eNBs
- UEs may have different distances to the eNB and different Timing advance adjustments may be applied

- **UEs out-of-coverage – Synchronization in much more difficult**
- periodic transmission of synchronization signals from UEs may be needed (PSS/SSS sequences)

D2D Challenges

Radio access issues

3. Direct communication challenges

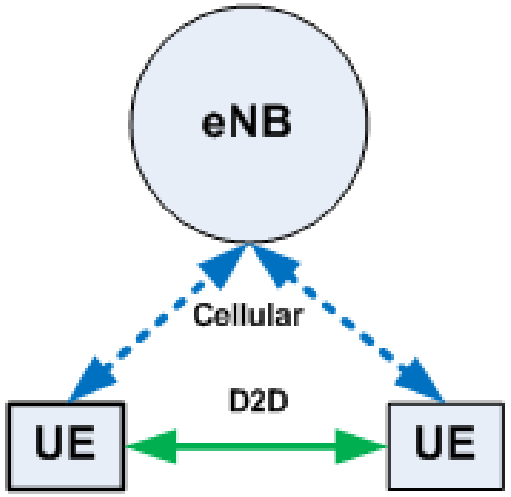
- **Cellular/Direct mode selection**
- **Radio management:** Interference management/ Resource allocation/Power control

D2D Challenges

Radio access issues

3. Direct communication challenges

Cellular/Direct mode selection



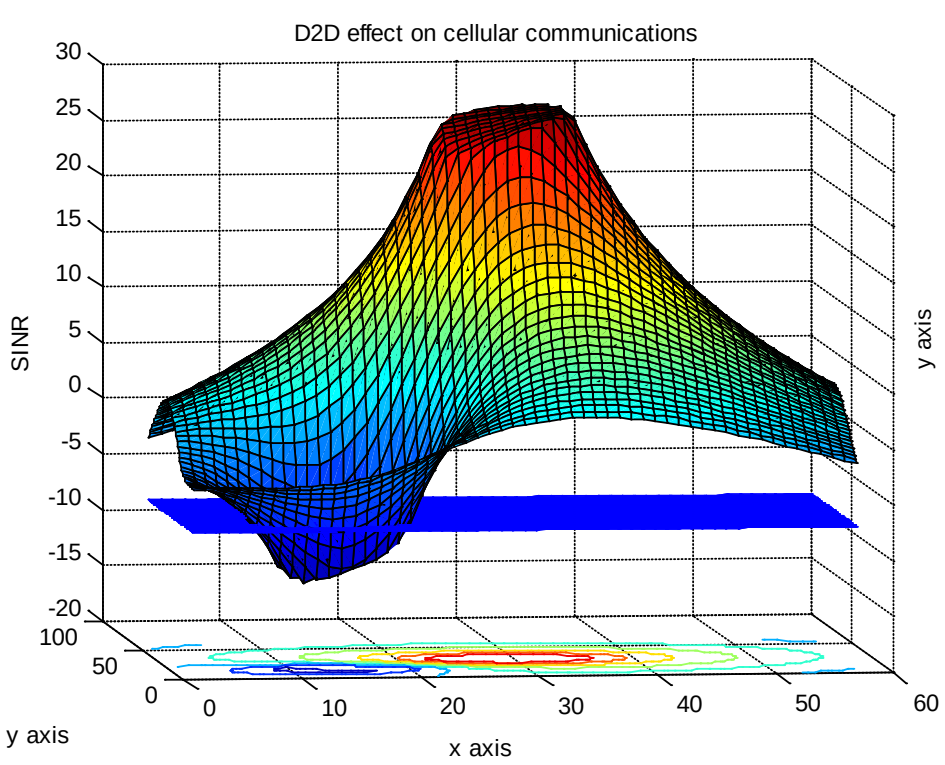
- At what **timescale** should:
  - The eNB perform mode selection? (1ms/100ms?)
  - The UEs CQI do estimation and reporting?
  - Network signaling & processing overhead **vs.** up-to-date decisions
- When deciding **consider**:
  - D2D link quality and cellular link quality (**QoE?**)
  - Instantaneous load situation of the cell, buffer status of users and QoS
  - Received Signal Strength or distance between 2 nodes

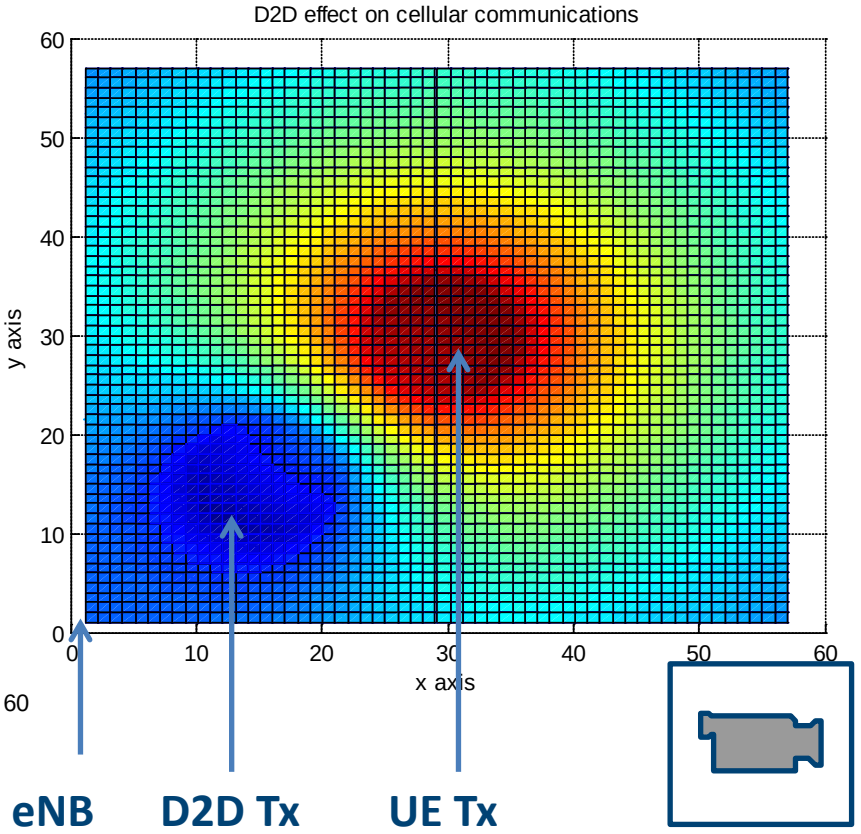
D2D Challenges

Radio access issues

3. Direct communication challenges

Interference management for Spatial spectrum reuse



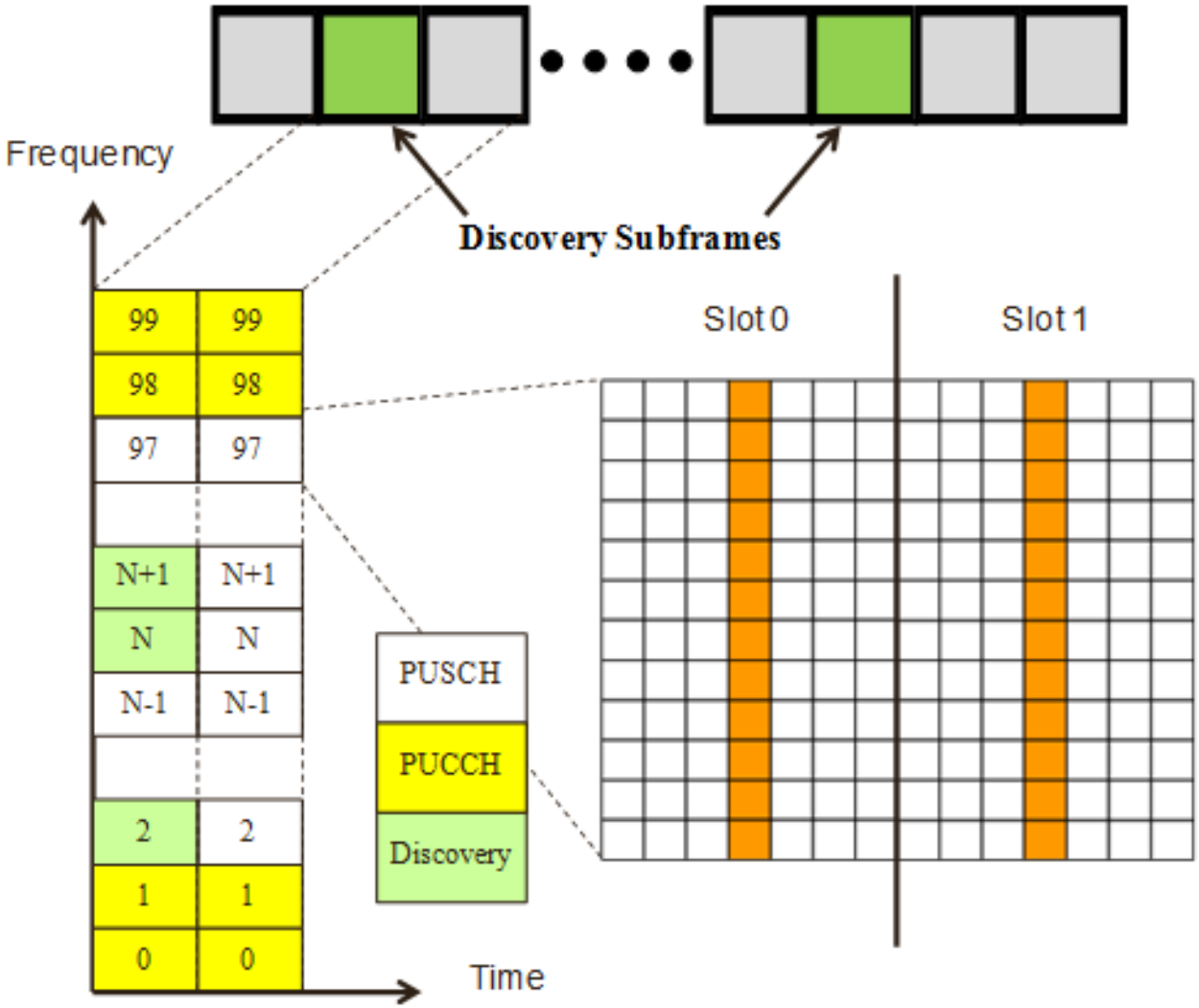


D2D Challenges

Radio access issues

4. Device discovery challenges

- **Discovery approach**
  - **push mechanism** where UE broadcasts its presence
  - **pull mechanism** where UE requests information regarding discoverable UEs
- **Resources**
  - **Static allocation**
  - **Dynamic allocation**
- **Signal design**
  - **Rich information or**
  - **discovery sequences such as the PSS/SSS**


Frequency
Discovery Subframes
99
98
97
N+1
N
N-1
2
1
0
Slot 0
Slot 1
PUSCH
PUCCH
Discovery
Time

Specific solutions for enabling D2D communication in cellular networks

Solution 1: Direct communication

Interference-aware resource allocation for D2D communication

Proposed graph-coloring D2D resource allocation scheme

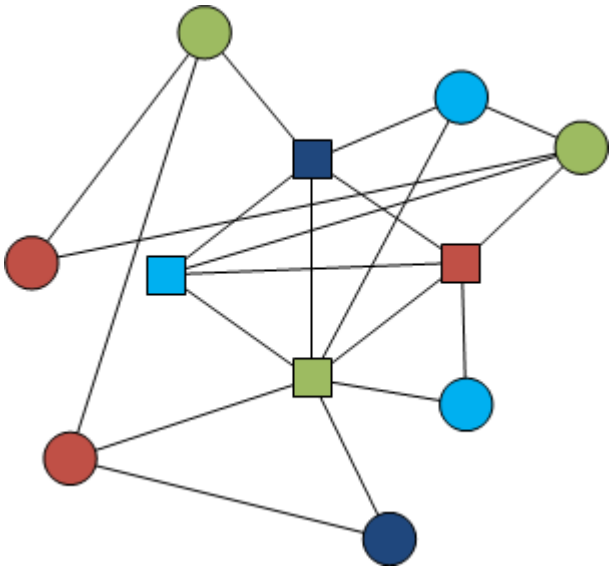
- **Assumptions**:
  - D2D pairs available
  - Interference/topology information available at eNB
  - eNB responsible for the spectrum allocation/sharing
- **Proposed scheme:**
  - Target: maximize spatial spectrum reuse
  - D2D resource allocation exploits:
    1. UL resource allocation
    2. Interference information

Proposed graph-coloring D2D resource allocation scheme

Graph building method:

- Colors=UL allocated resources,
- Edges/lines = interference between nodes

Nodes: □ UE ○ D2D pair,



- High complexity
- Graph-coloring algorithms
  1. *Greedy Algorithm*
  2. *Random Sequential Algorithm (RS)*
  3. *Repeat Random Sequential Algorithm (RRS)*

Proposed graph-coloring D2D resource allocation scheme

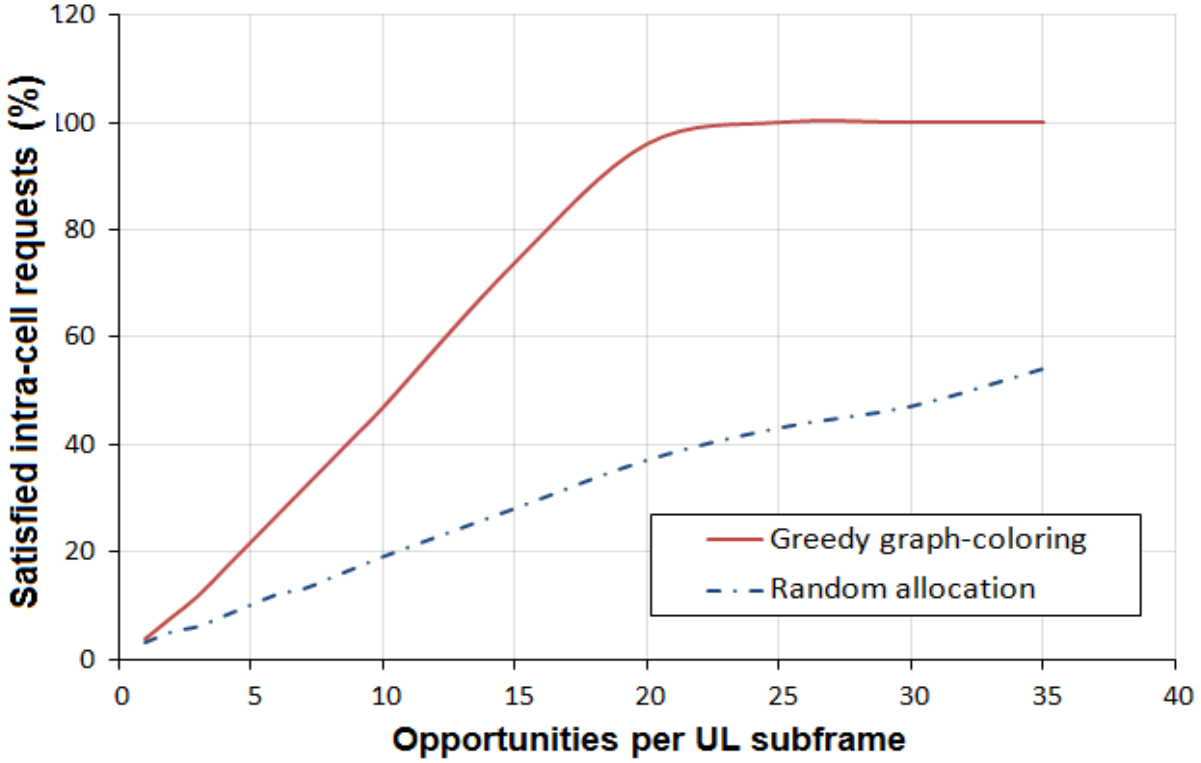
- Link level Simulations

Parameter	Value
Cell radius	1.5 km
Frame structure	Type 2 (TDD)
Frame duration	10ms
UL/DL configuration	0
UL duration	3 ms
CP length	7 symbols/slot
Available bandwidth	20 MHz
Number of available RB	100
Quiet Period (QP)	285.7 μs (4 symbols)
Standard Scheduler	Round Robin
UEs' distribution	Uniform
UE class	Cat. 3
Modulation	16QAM

UL opportunity =1 color= a number of RB allocated to a specific UE for UL transmission

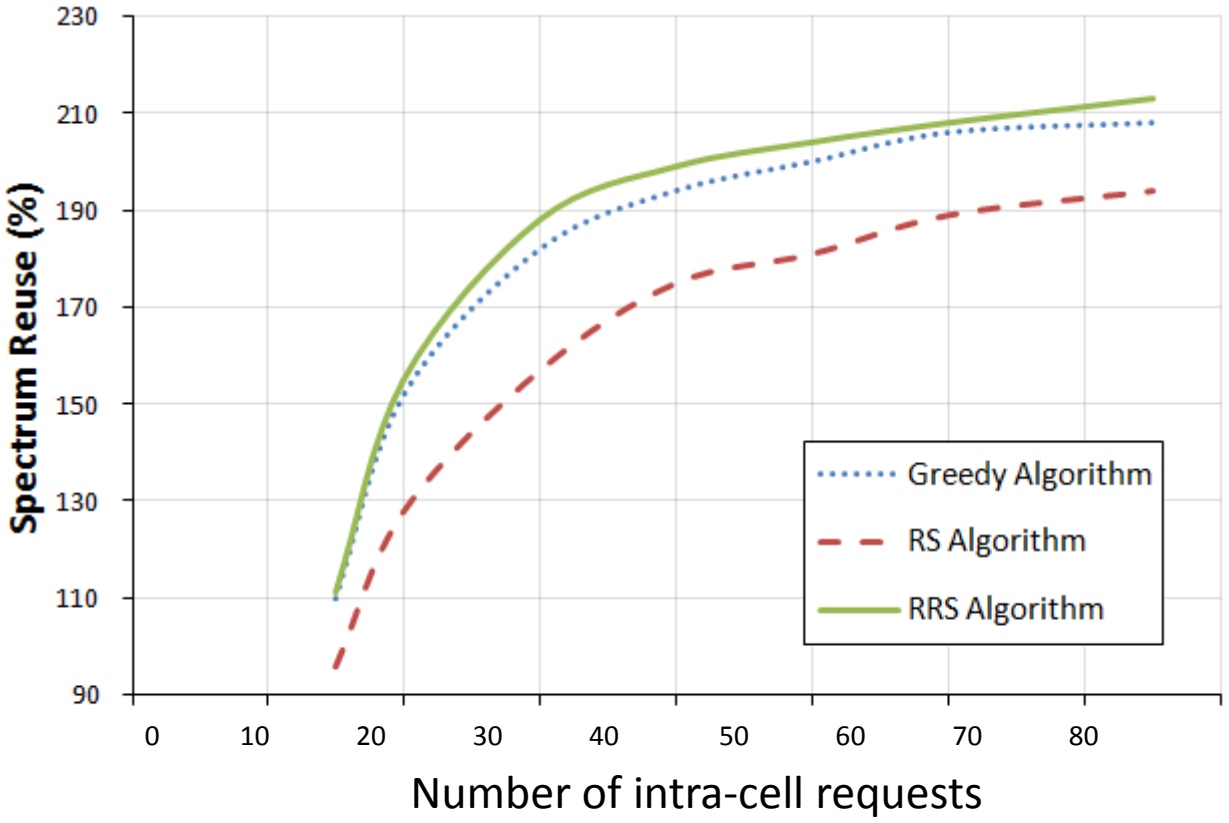
Proposed graph-coloring D2D resource allocation scheme

- Result: satisfaction of intra-cell communication requests
  - 50 UEs uniformly distributed around eNB, requesting for intra-cell communication (50 potential D2D communications)



Proposed graph-coloring D2D resource allocation scheme

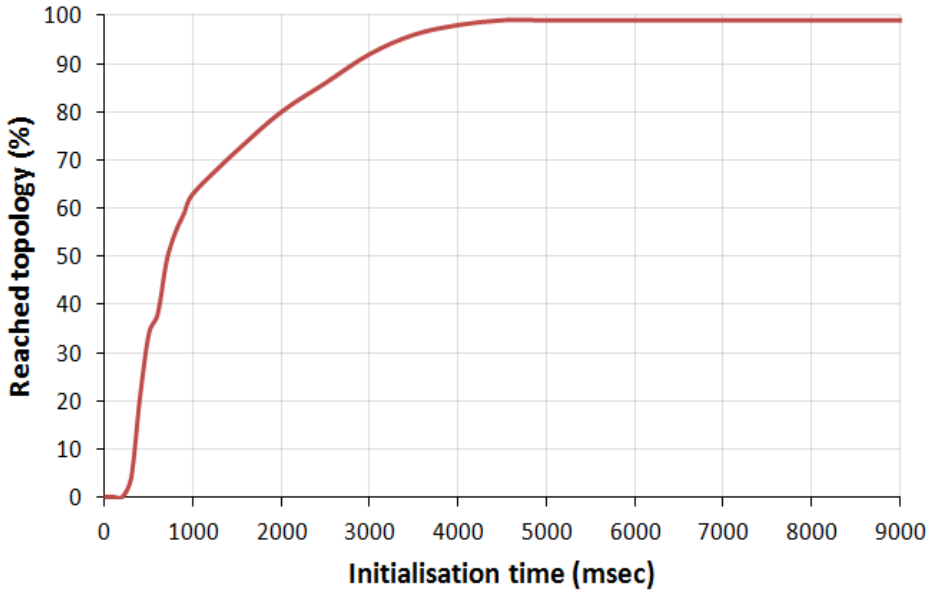
- Result: Spatial spectrum reuse
  - 20 UL opportunities (the available RBs have been allocated to 20 UEs)



Proposed graph-coloring D2D resource allocation scheme

- An interference information collection mechanism is needed

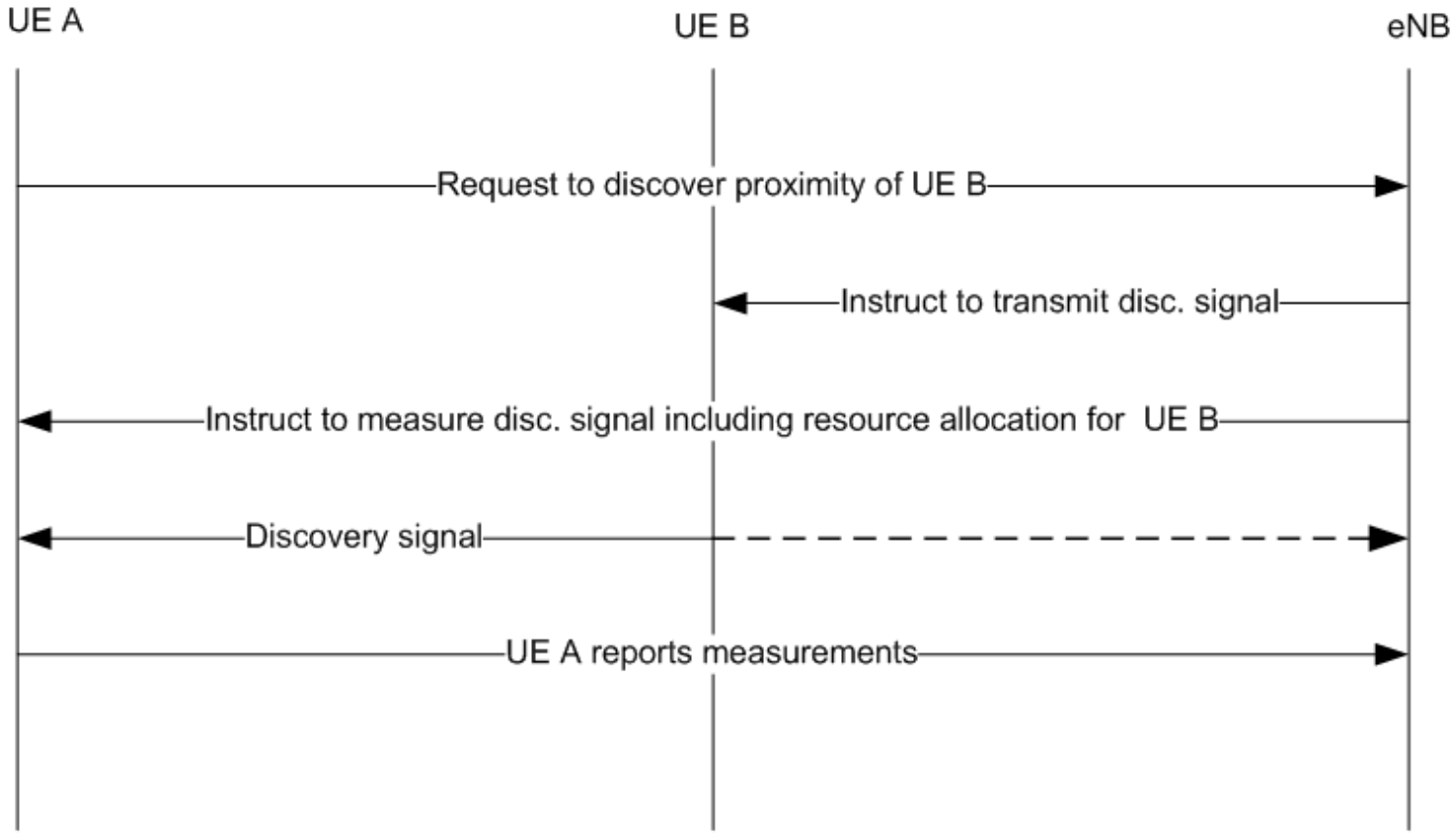
Reduce the need for interference information collection

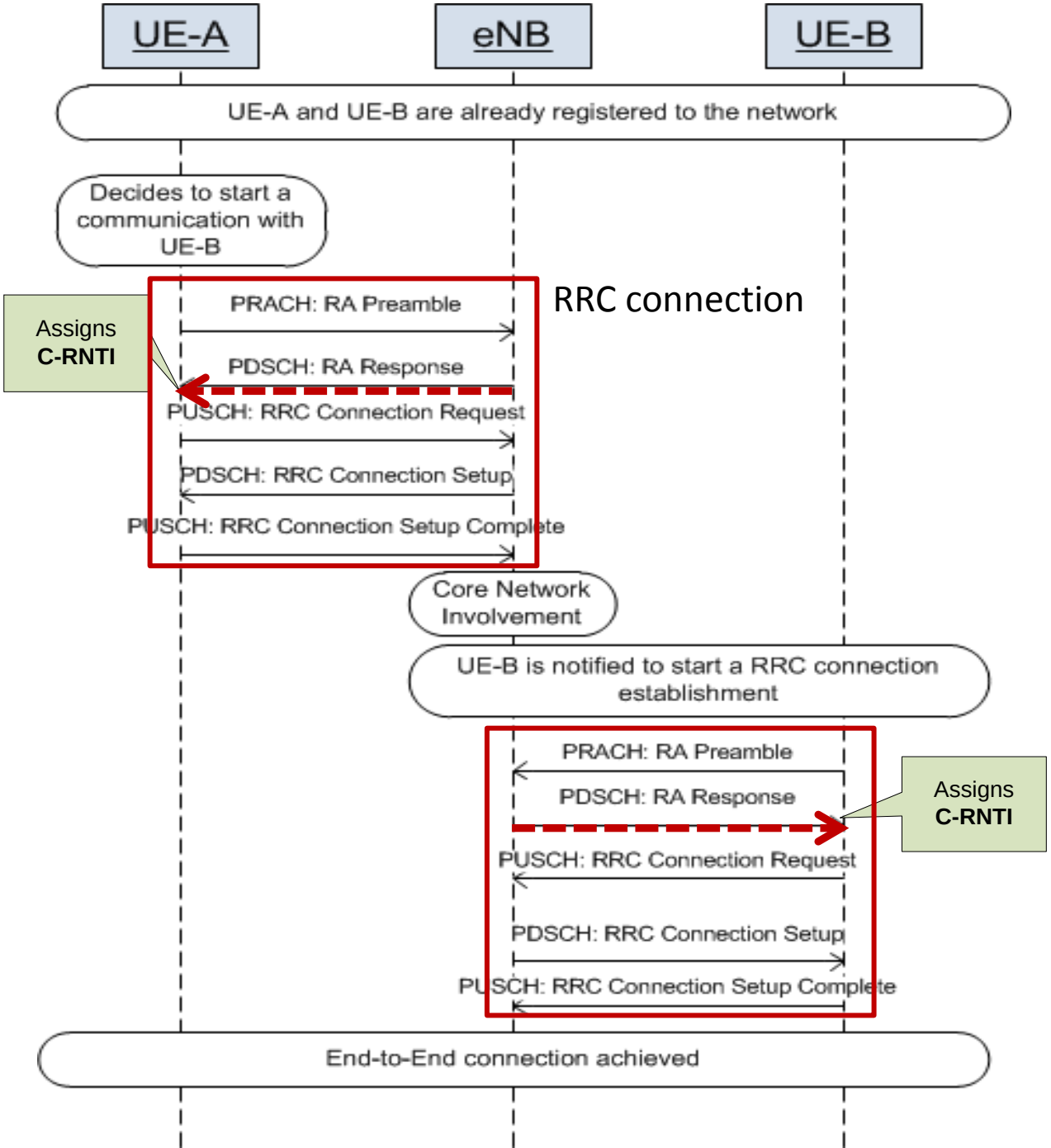


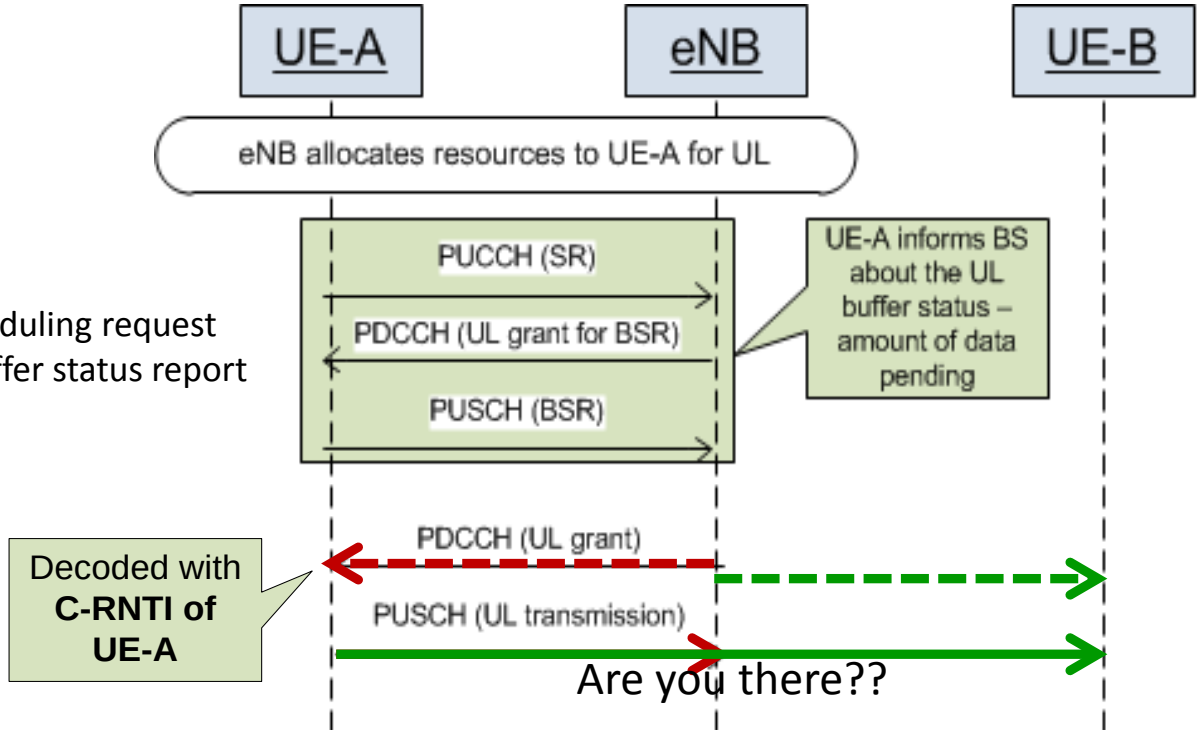
Solution 2: Device discovery

Radio access network enhancements for device discovery transmissions

eNB directed discovery can achieve extremely fast discovery, and should be considered as a first step before establishing D2D communication

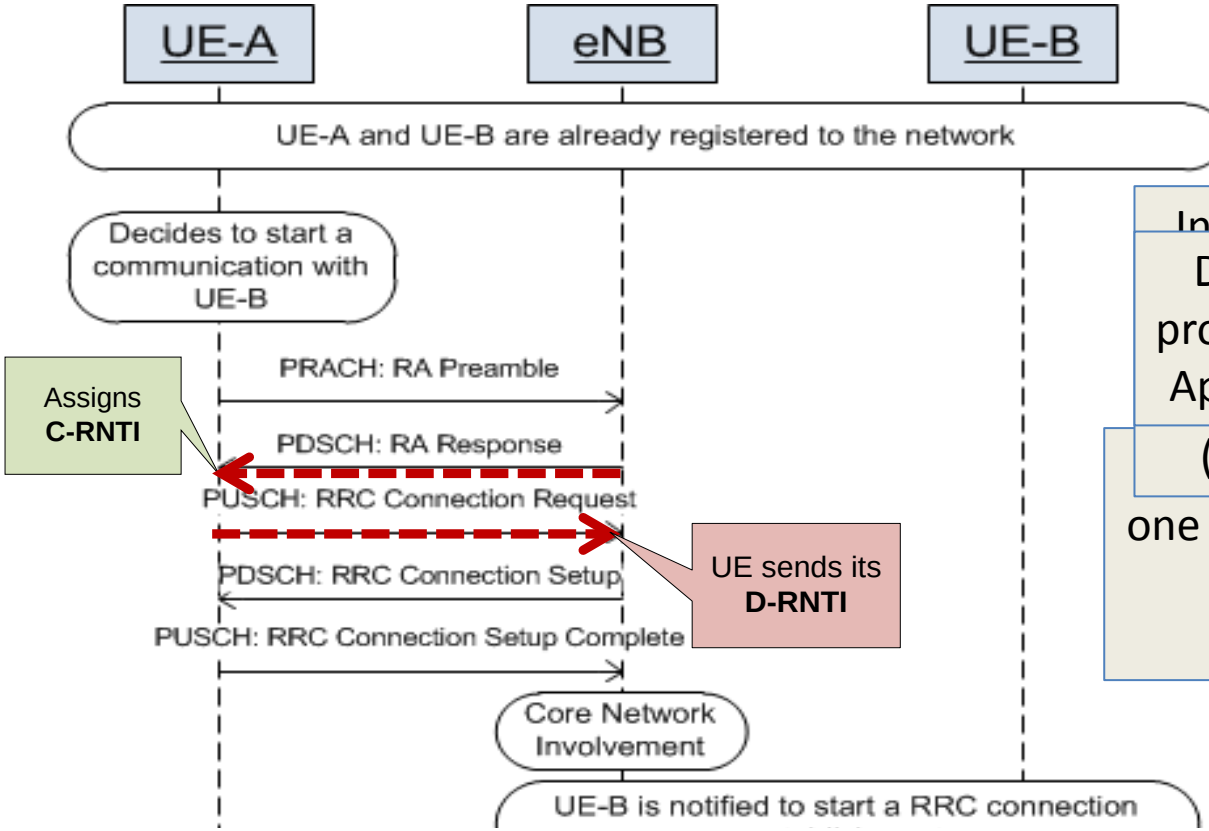



UE-A
eNB
UE-B
UE-A and UE-B are already registered to the network
Decides to start a communication with UE-B
RRC connection
Assigns C-RNTI
PRACH: RA Preamble
PDSCH: RA Response
PUSCH: RRC Connection Request
PDSCH: RRC Connection Setup
PUSCH: RRC Connection Setup Complete
Core Network Involvement
UE-B is notified to start a RRC connection establishment
PRACH: RA Preamble
PDSCH: RA Response
Assigns C-RNTI
PUSCH: RRC Connection Request
PDSCH: RRC Connection Setup
PUSCH: RRC Connection Setup Complete
End-to-End connection achieved



*SR: scheduling request
*BSR: Buffer status report

eNB does not know the identity of target UE-B to inform for receiving data



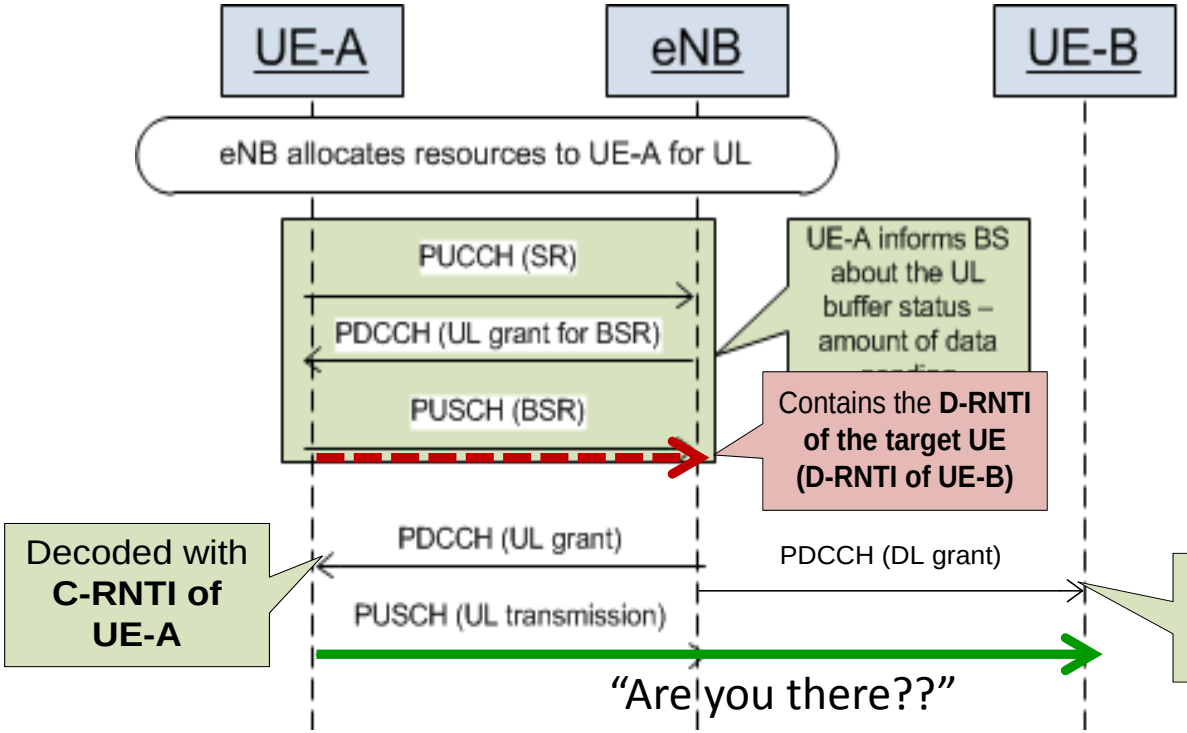
Introduced as a new

D-RNTI is a new ID produced at UEs using App layer ID or MSIN

(3GPP TS 36.331)

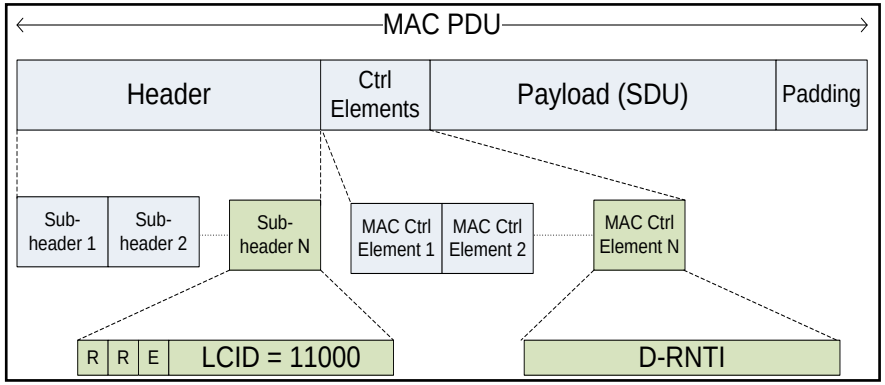
one mapping between D-RNTIs and C-RNTIs

***RRCConnectionRequest* field descriptions**
establishmentCause
Provides the establishment cause for the RRC connection request as provided by the upper layers. W.r.t. the cause value names: highPriorityAccess concerns AC11..AC15, 'mt' stands for 'Mobile Terminating' and 'mo' for 'Mobile Originating.
randomValue
Integer value in the range 0 to $2^{40} - 1$.
ue-Identity
UE identity included to facilitate contention resolution by lower layers.



UE-A can produce

eNB utilizes the D-RNTI - C-RNTI mapping to find C-RNTI of UE-B and informs both UE-A and UE-B about the allocation grant



*SR: scheduling request
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