



# **D2D communication in cellular networks**

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**June 2014**



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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

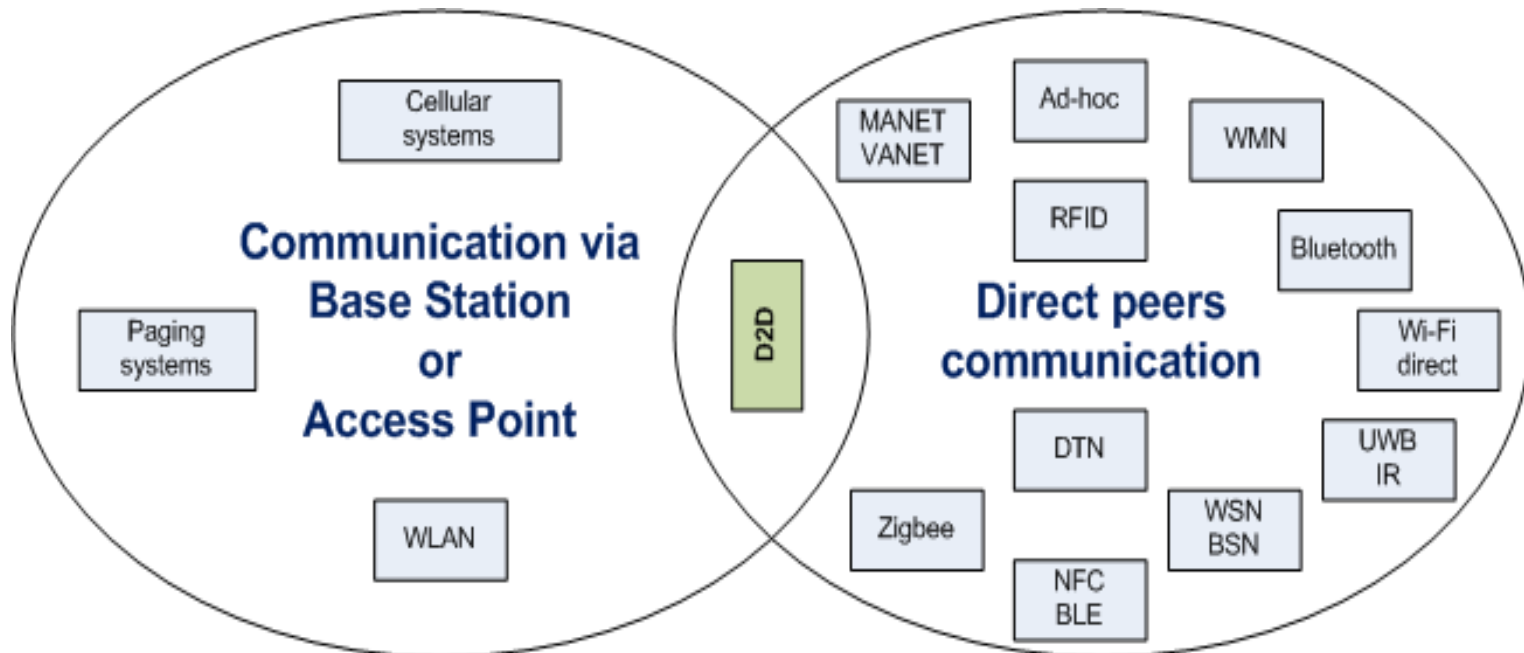
Wireless technologies are applied to different wireless networks:

- **Wireless Mobile/Cellular Networks**
  - GSM, UMTS, LTE, LTE-A
- **WLANs**
  - WiFi, WiFi direct
- **WSN**
  - Zigbee, 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

# Wireless Networks/Technologies

Categorization based on network assistance

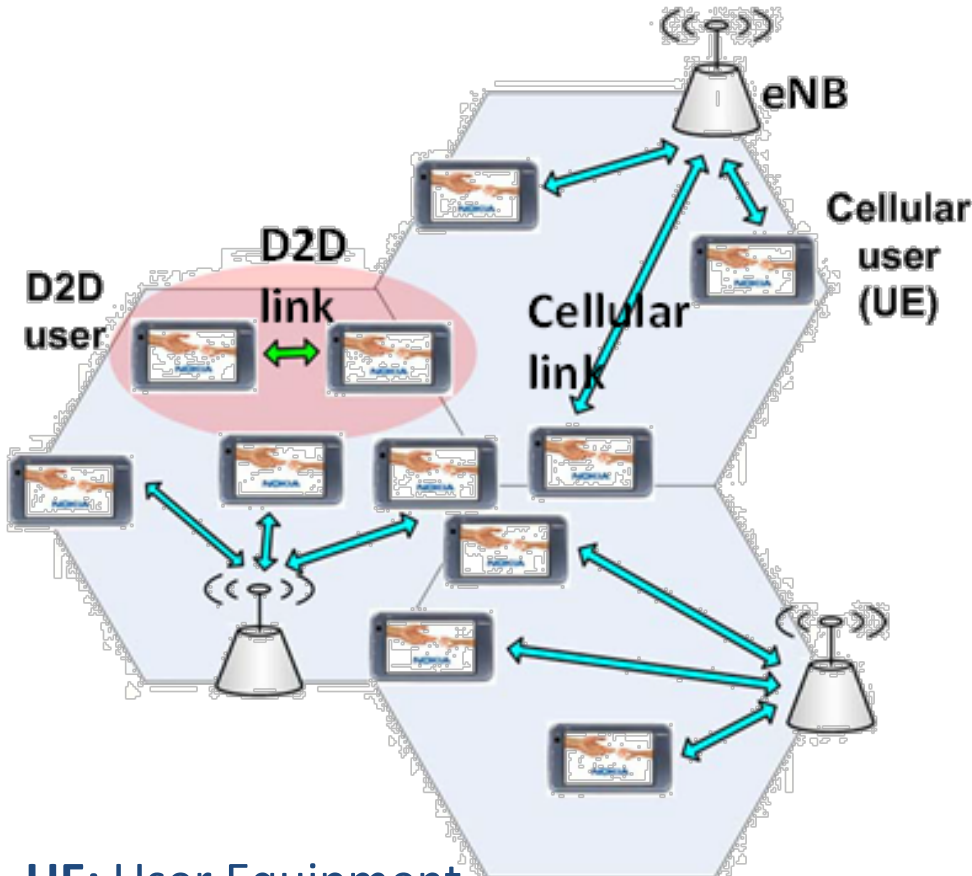
Where D2D lies:



1<sup>st</sup> perspective → Control

2<sup>nd</sup> 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*)

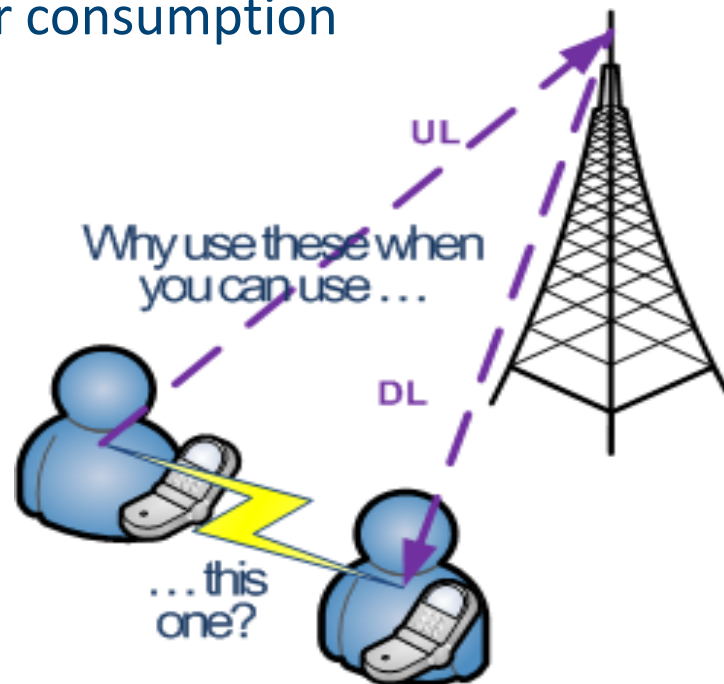
# Motivation for D2D (1/6)

- **Proximity gain:**

- Higher bit rates (throughput)
- Lower delays (latency)
- Lower power consumption

- **Hop gain:**

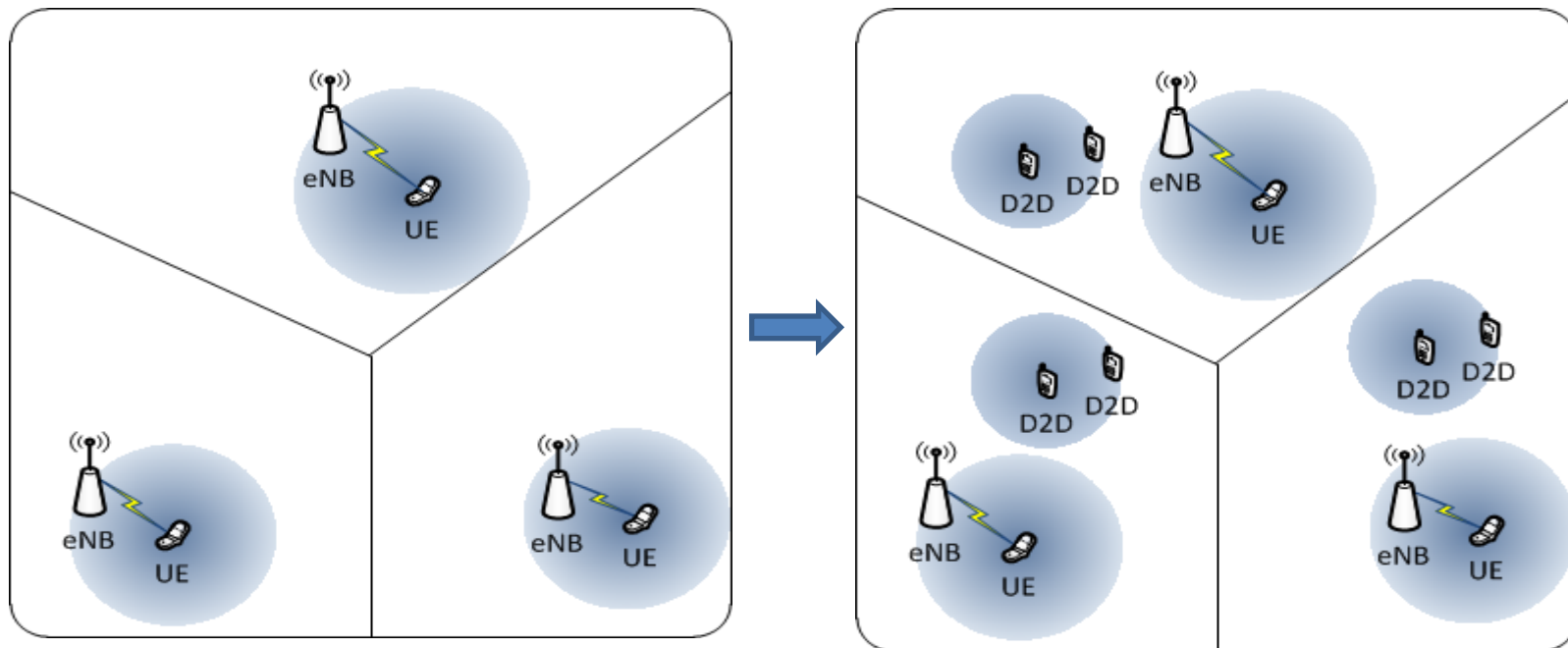
- single link (not different resource for UL/DL)!





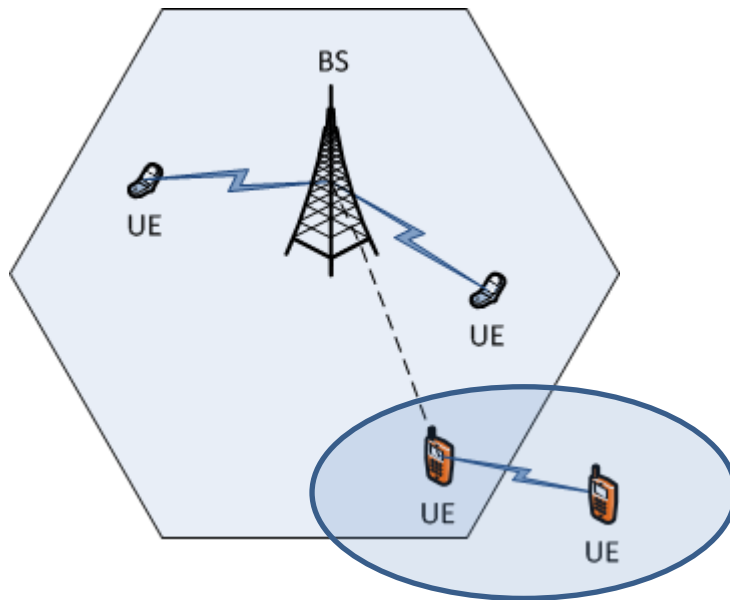
# Motivation for D2D (2/6)

- **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)

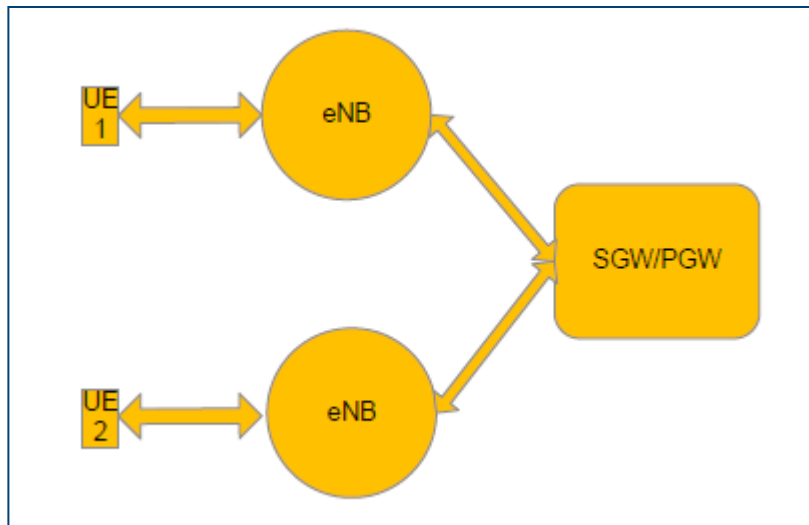
- **Public protection and disaster relief:**
  - There are millions of smart cellular devices ! But they can hardly used in emergency situations
  - Direct communication would be vital in scenarios where the network is down



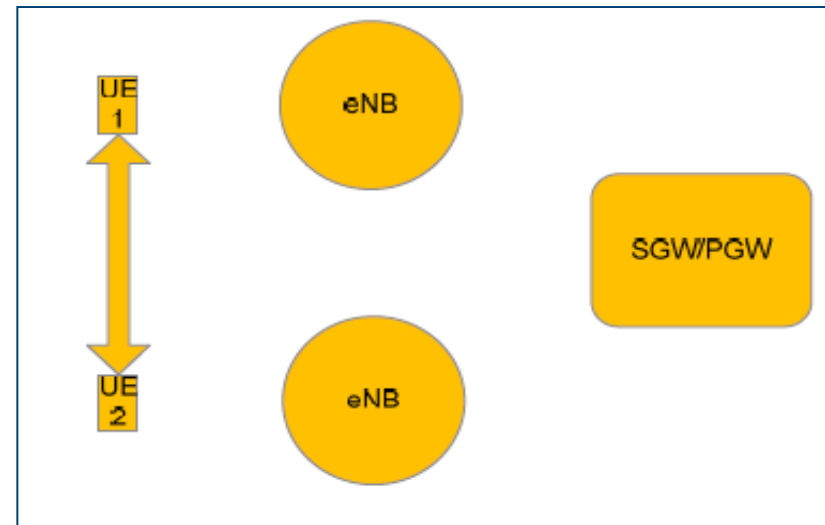
# Motivation for D2D (5/6)

- eNB offloading
- Core network decongestion

Conventional - Without D2D

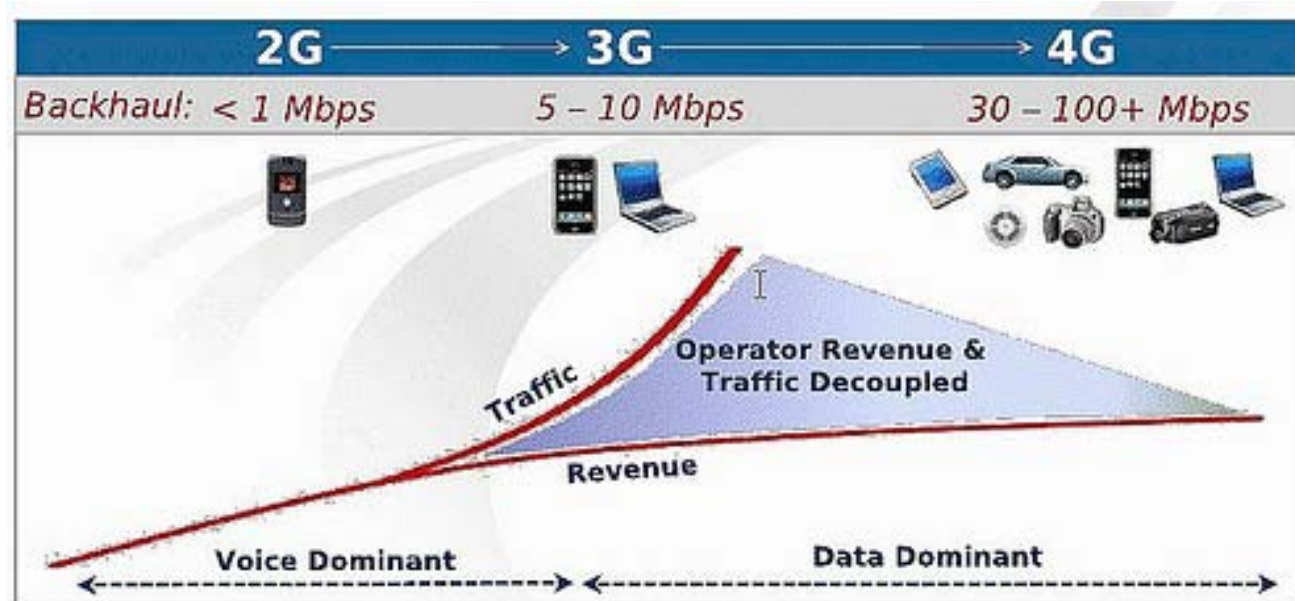


With D2D



# Motivation for D2D (6/6)

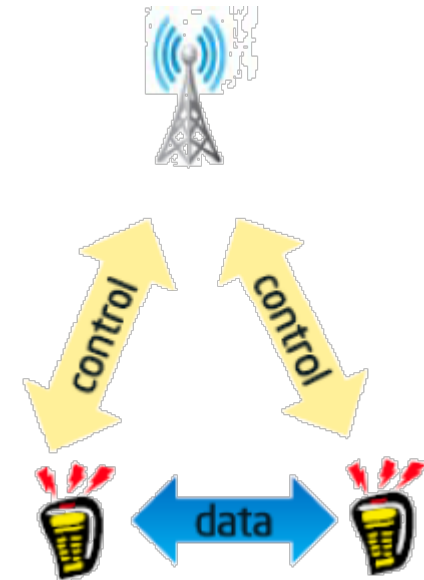
- **Operator profits:**
  - Towards covering the widening gap between network traffic and service revenue



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

# D2D Vs. Current direct comm. technologies

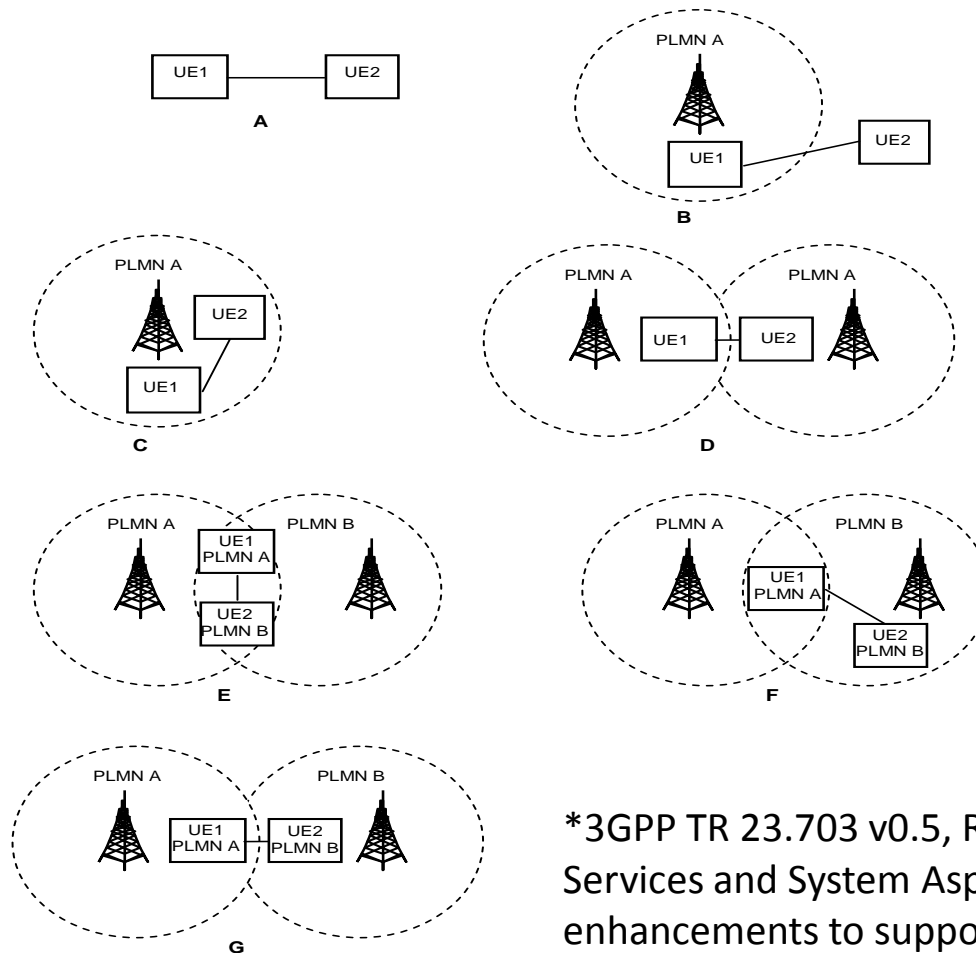
- **Operator controlled**
- **QoS guarantee**
- **Transparent** to the user
- Increased **security**
- **Mobility** freedom (larger distances)
- **Reliability** – use of licensed band
- Indirect **synchronization** through the eNB





# D2D standardization activities

## 3GPP scenarios for ProSe\*

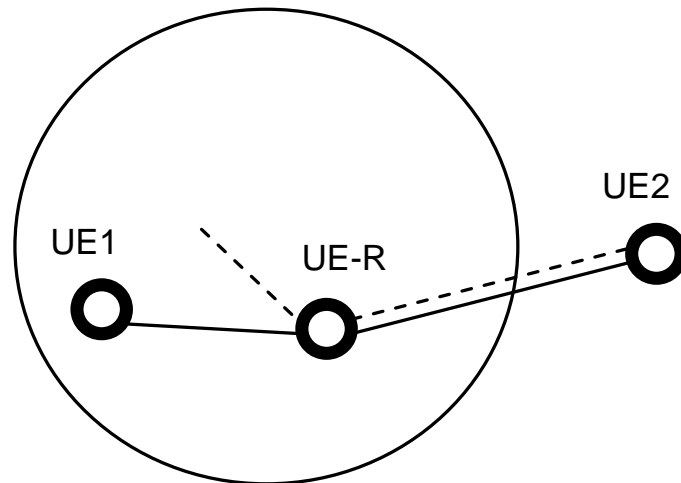


\*3GPP TR 23.703 v0.5, Rel 12, "Technical Specification Group Services and System Aspects; Study on architecture enhancements to support Proximity Services (ProSe)", Jun. 2013

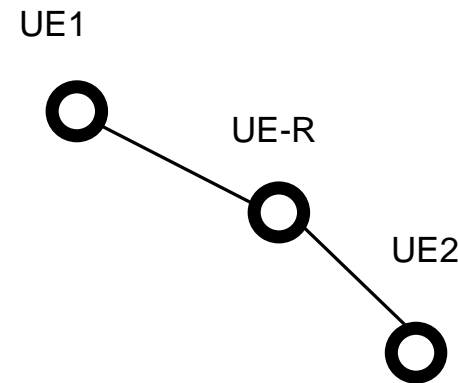
# D2D standardization activities

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



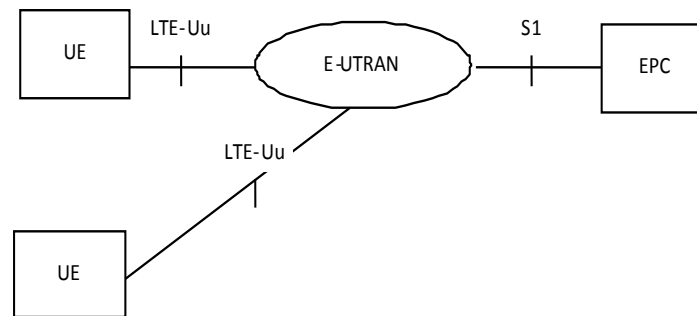
B: UE-to-UE relay

\*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

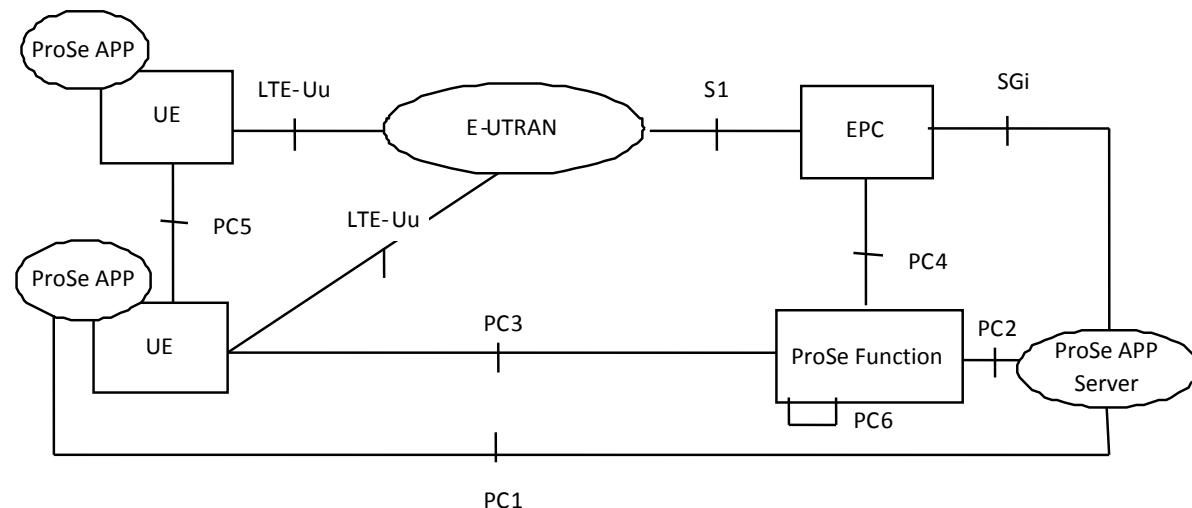


# D2D standardization activities

- **Conventional Architecture**



- **Architecture with D2D (ProSe)**



# D2D standardization activities

- **Discovery Models**
  - **Model A ("I am here")**
    - **Announcing UE**
    - **Monitoring UE**
  - **Model B ("who is there"/"are you there")**
    - **Discoverer UE:**
      - requests certain information
    - **Discoveree UE:**
      - receives the request message



# D2D challenges

# D2D Challenges

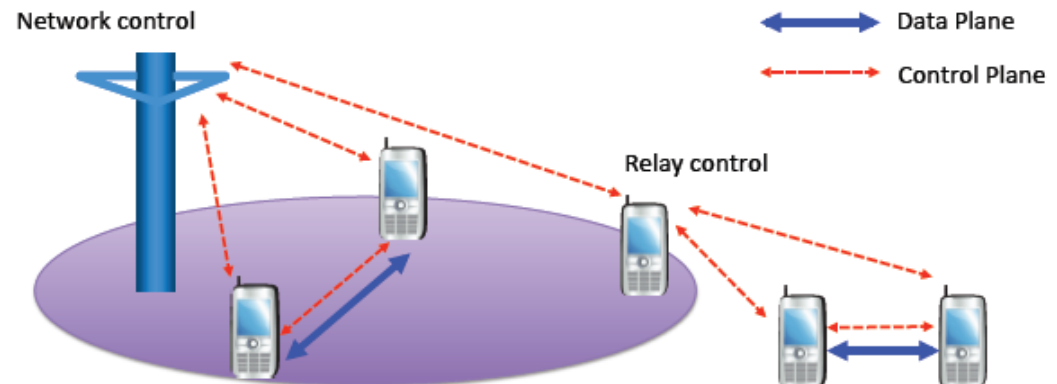
- Higher layer issues:
  - security, authorization, privacy and billing
- **Radio access issues:**
  1. Design and management challenges
  2. Synchronization challenges
  3. Device discovery challenges
  4. Direct communication challenges

# 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?



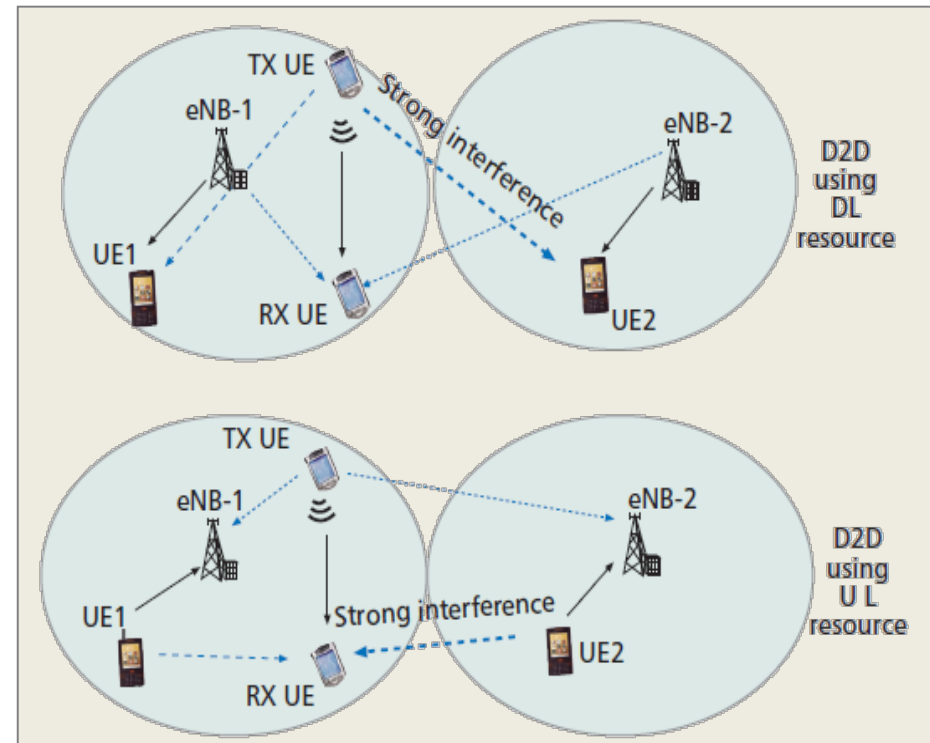
# D2D Challenges

## 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

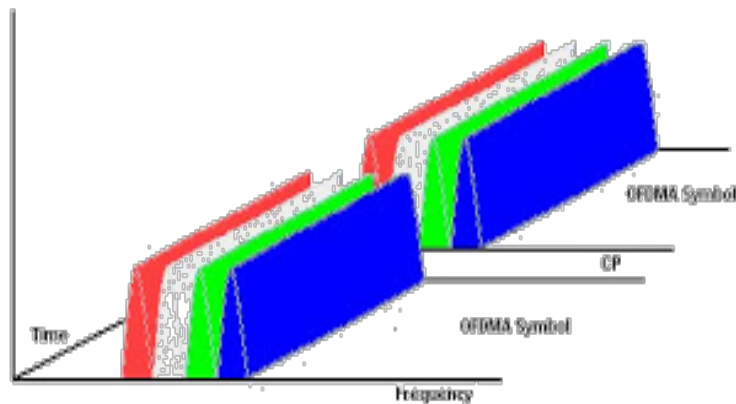


# D2D Challenges

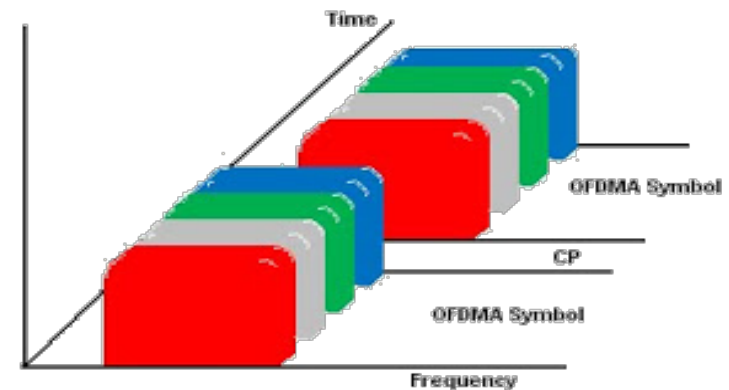
## Radio access issues

### 1. Design and management challenges – modulation format

LTE-A PHY



DL: OFDMA



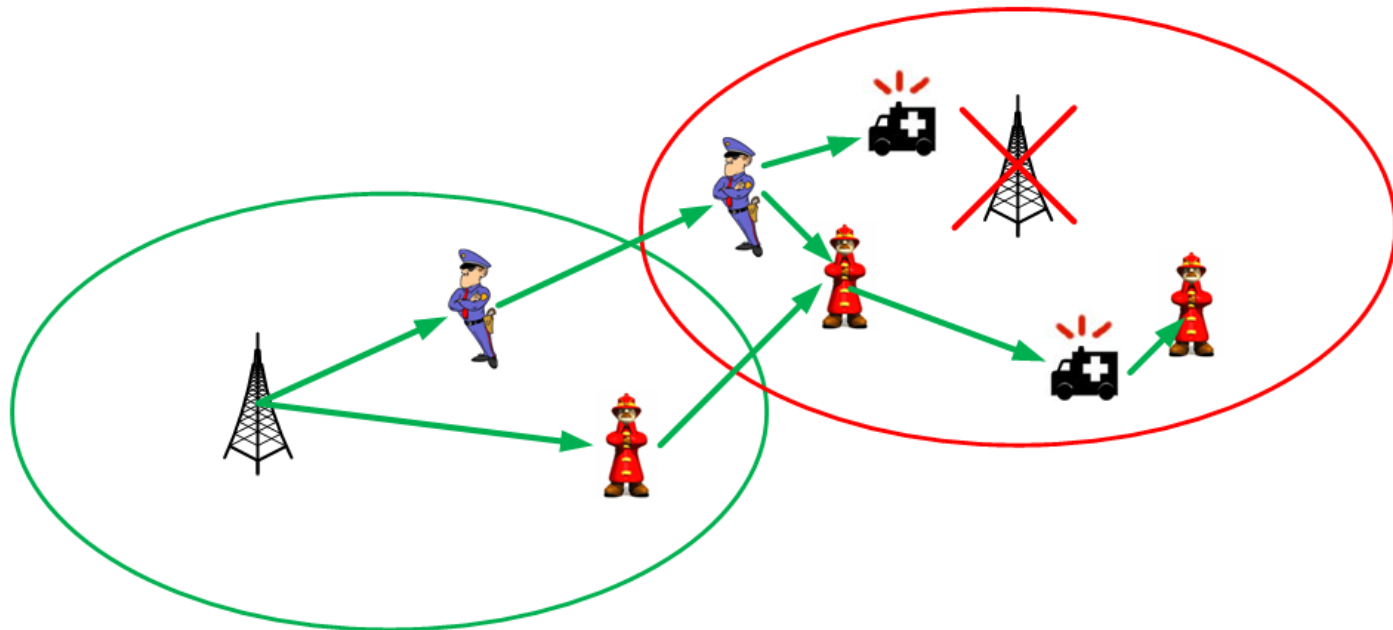
UL: SC-FDMA

# 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 is much more difficult
- periodic transmission of synchronization signals from UEs may be needed (PSS/SSS sequences)



# D2D Challenges

## Radio access issues

### 3. 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**



# D2D Challenges

## Radio access issues

### 4. Direct communication challenges

- **Cellular/Direct mode selection**
- **Radio management:** Interference management/ Resource allocation/Power control
- **Operation types:** unicast, relay, groupcast, and broadcast

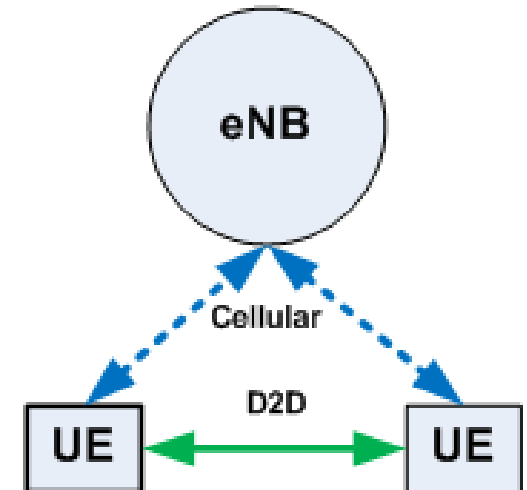
# D2D Challenges

## Radio access issues

### 4. 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



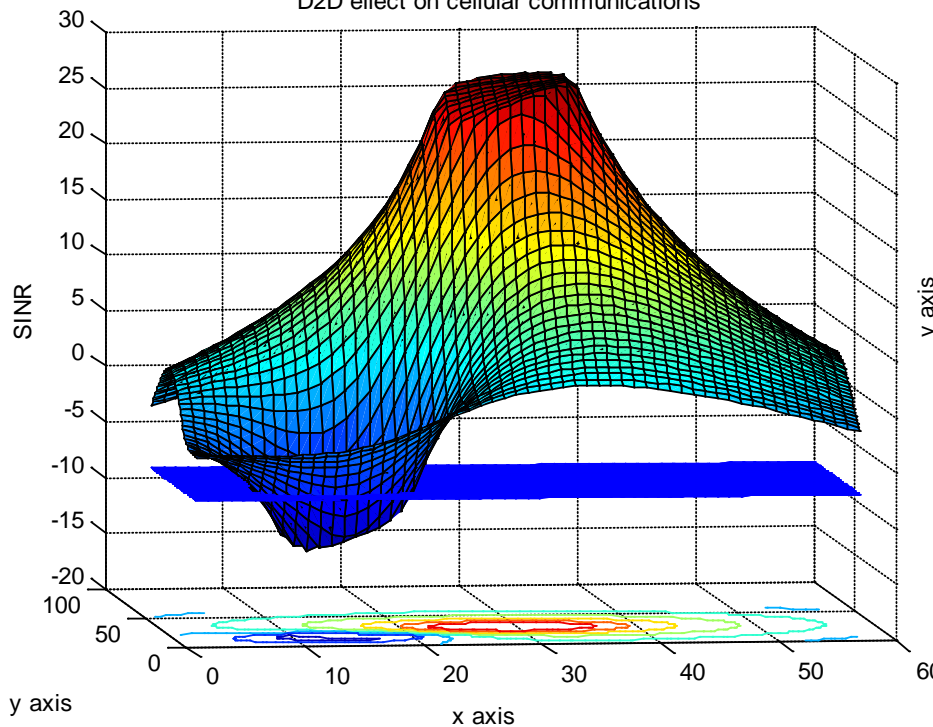
# D2D Challenges

## Radio access issues

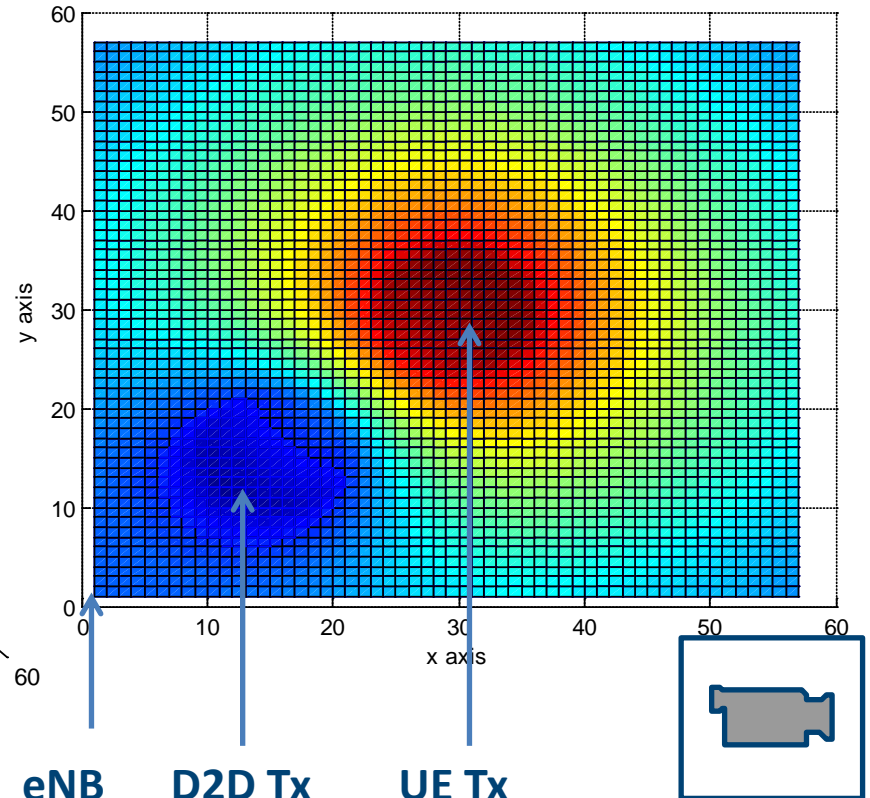
### 4. Direct communication challenges

#### Interference management for Spatial spectrum reuse

D2D effect on cellular communications



D2D effect on cellular communications





# Specific solutions for enabling D2D communication in cellular networks



## **Solution 1: Direct communication**

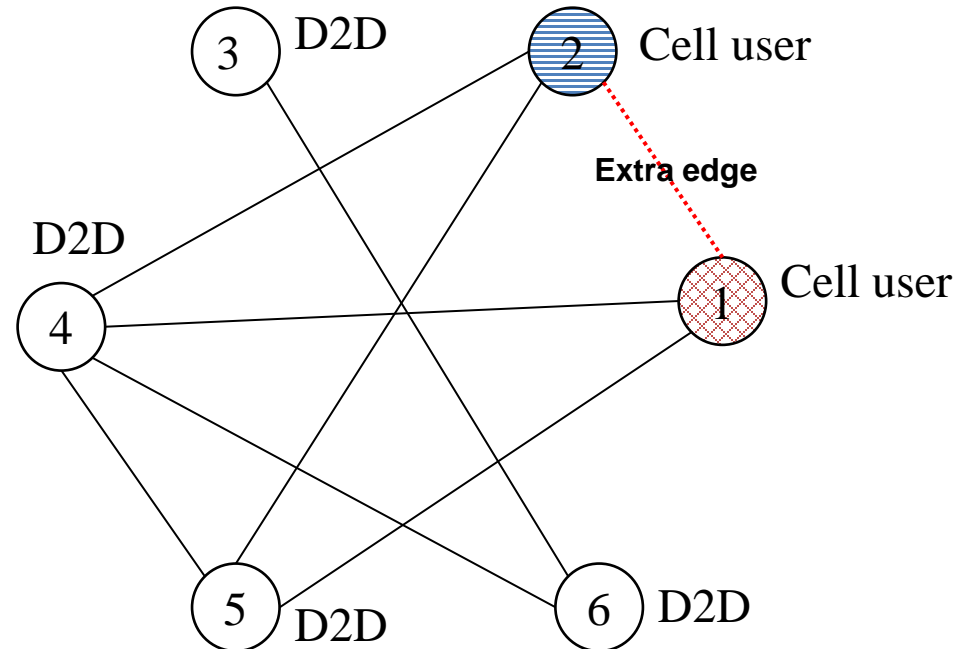
# **Interference-aware resource allocation for D2D communication**

# Graph-Coloring

## D2D Resource Allocation

### Graph representation of the network topology

- **Vertices:** represent either UEs with allocated resources (cell UEs) or pairs of intra-cell communication requests.
- **Edges:** represent interferences between vertices implying that connected vertices cannot use the same spectrum (resources) simultaneously.
- **Extra edges:** connect the cell UEs with each other, visualizing the primary resource allocation.



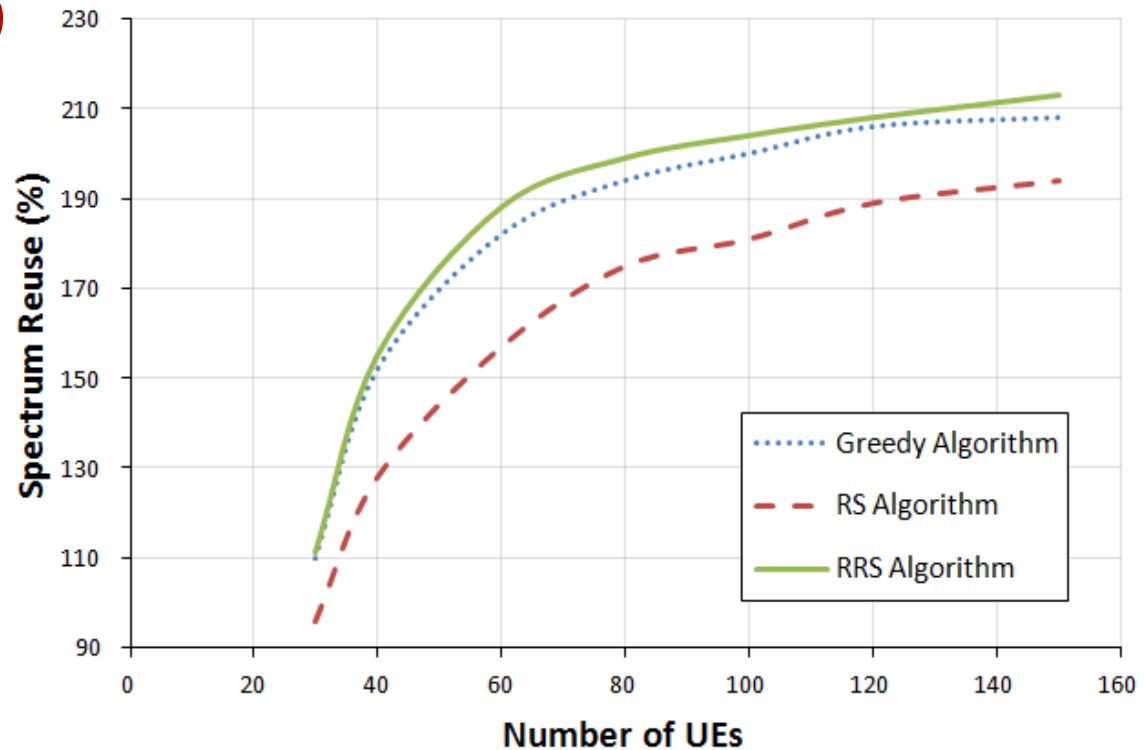


# Graph-Coloring D2D Resource Allocation

**OBJECTIVE:** maximize the spectrum utilization

**Exploit:** graph-coloring algorithms:

- **Greedy**
- **Random Sequential (RS)**
- **Repeat RS**

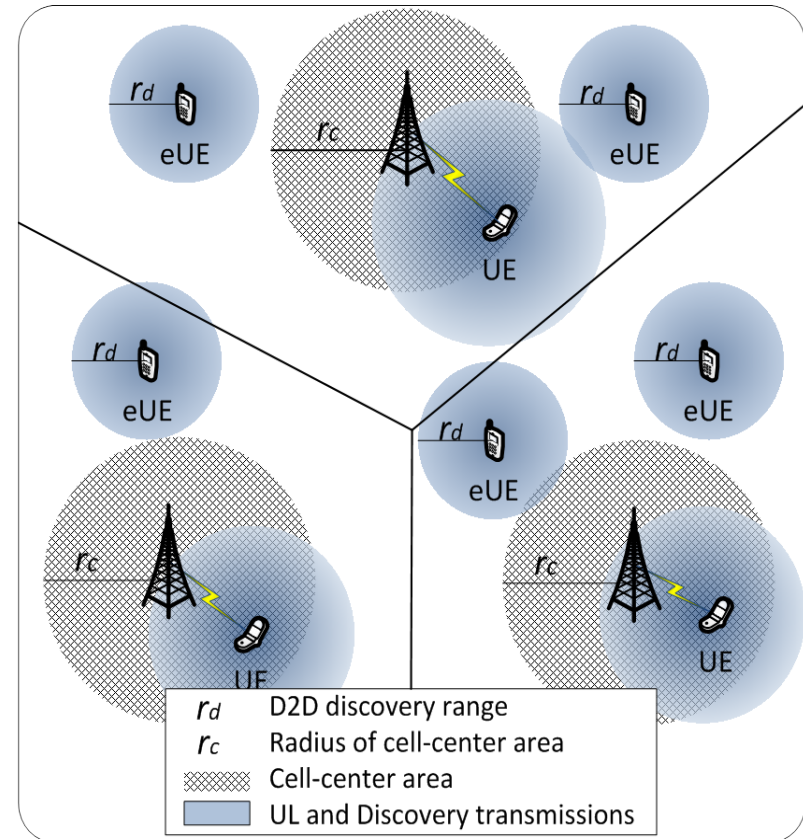
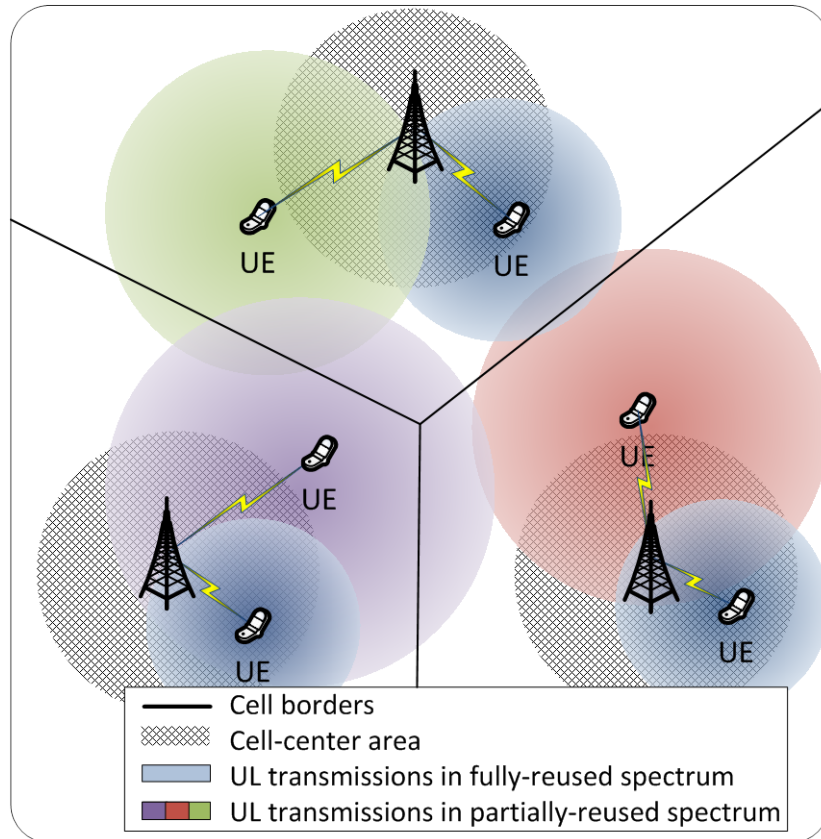




## Solution 2: Device discovery

# Interference-unaware coordination scheme

# Exploiting FFR to Enable discovery transmissions





# Exploiting FFR to Enable discovery transmissions

- **Assumption 1** – The transmitted signals from any node of system  $\mathcal{S}$ , are affected by: i) **Rayleigh fading** ii) path loss degradation described by a **simplified model**
- **Assumption 2** – The number of transmitting UEs and eUEs in the area follows a stationary Poisson Point Process (PPP)

# Exploiting FFR to Enable discovery transmissions

- Conventional FFR

$$D_c \leq r_c = \left[ \frac{-\ln(1 - \theta_c)}{\lambda_c \cdot u_c^{2/a} \cdot G} \right]^{1/2}$$

- FFR with additional Discovery transmissions

$$r'_c = r_c \cdot q \quad q = \left[ \frac{(\varepsilon_d - f \cdot \lambda_c)}{\varepsilon_d} \right]^{1/2}$$

# Exploiting FFR to Enable discovery transmissions

- A degradation is needed since  $q < 1$

$$q = \left[ 1 - \frac{f \cdot \lambda_c \cdot G \cdot D_d^2 \cdot u_d^{2/\alpha}}{-\ln(1 - \theta_d)} \right]^{1/2}$$

- Expected degradation,  $u$ : target SINR

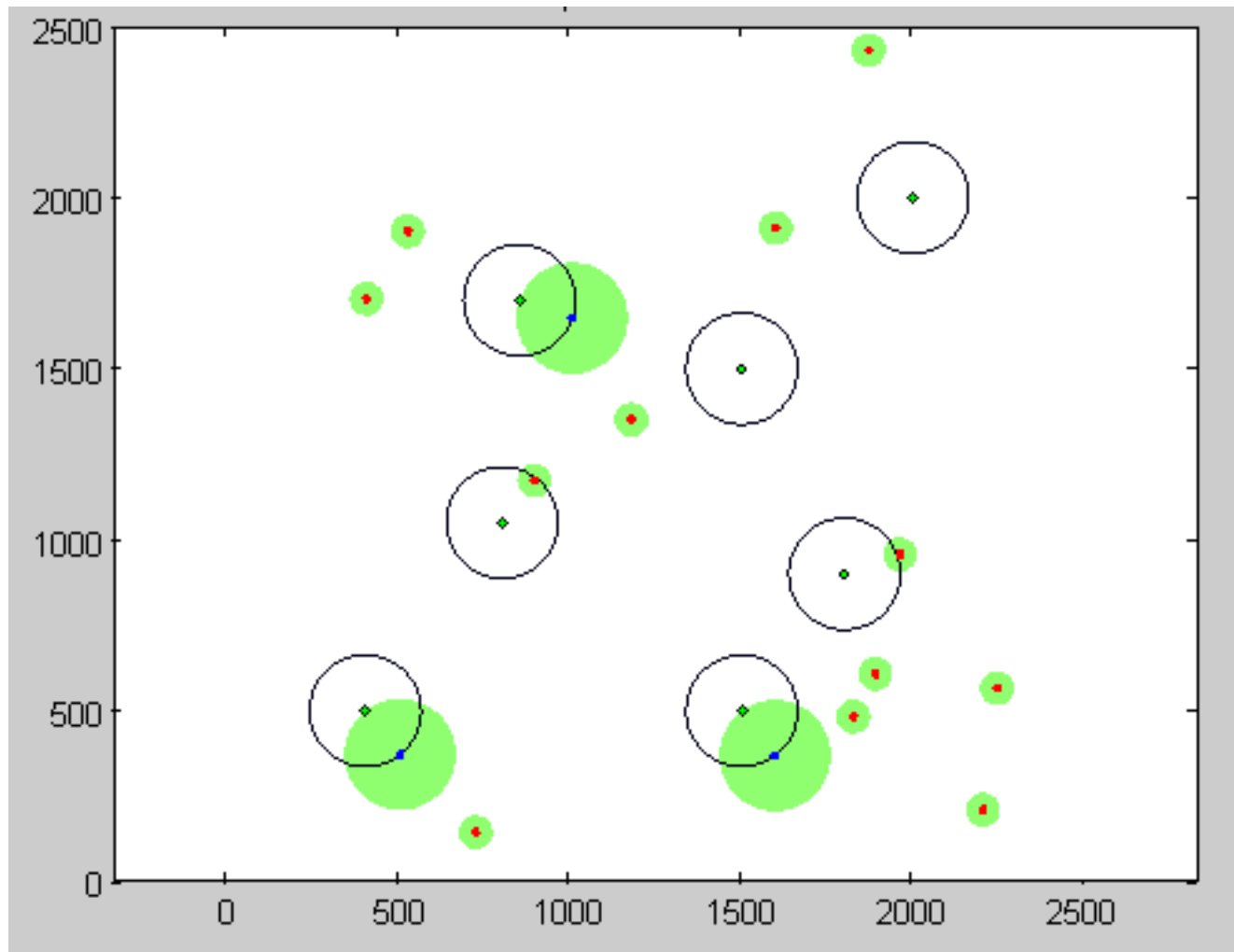
$$u'_c = u_c \cdot q^\alpha$$

# Exploiting FFR to Enable discovery transmissions

Parameter	Value
Number of <u>eNBs</u> ( $ eNB $ )	7
Magnitude of the area ( $a(\Omega)$ )	$6 \cdot 10^6 \text{m}^2$
Distribution of UE transmitters	Poisson
Distribution of <u>eUE</u> transmitters	Poisson
loading factor ( $z$ )	0.45
Path loss model	3GPP 36.942
Channel type	Rayleigh Fading (unit mean)
Environment	urban
Thermal Noise Density	$-174 \text{ dBm/Hz}$
Noise figure	5 dB
UE/ <u>eUE</u> antenna type	Omni-directional
UL Cellular Resource allocation	RB in band $B_1$ allocated to UEs in cell-center area
UL Cellular Resource allocation scheme in band $B_1$	Proportional fair
UL power control for UEs	Minimum transmission power to achieve the target SIR threshold
Discovery resource allocation scheme	RBs in band $B_1$ are allocated in Round robin fashion. One RB can be allocated to multiple discovery transmitters

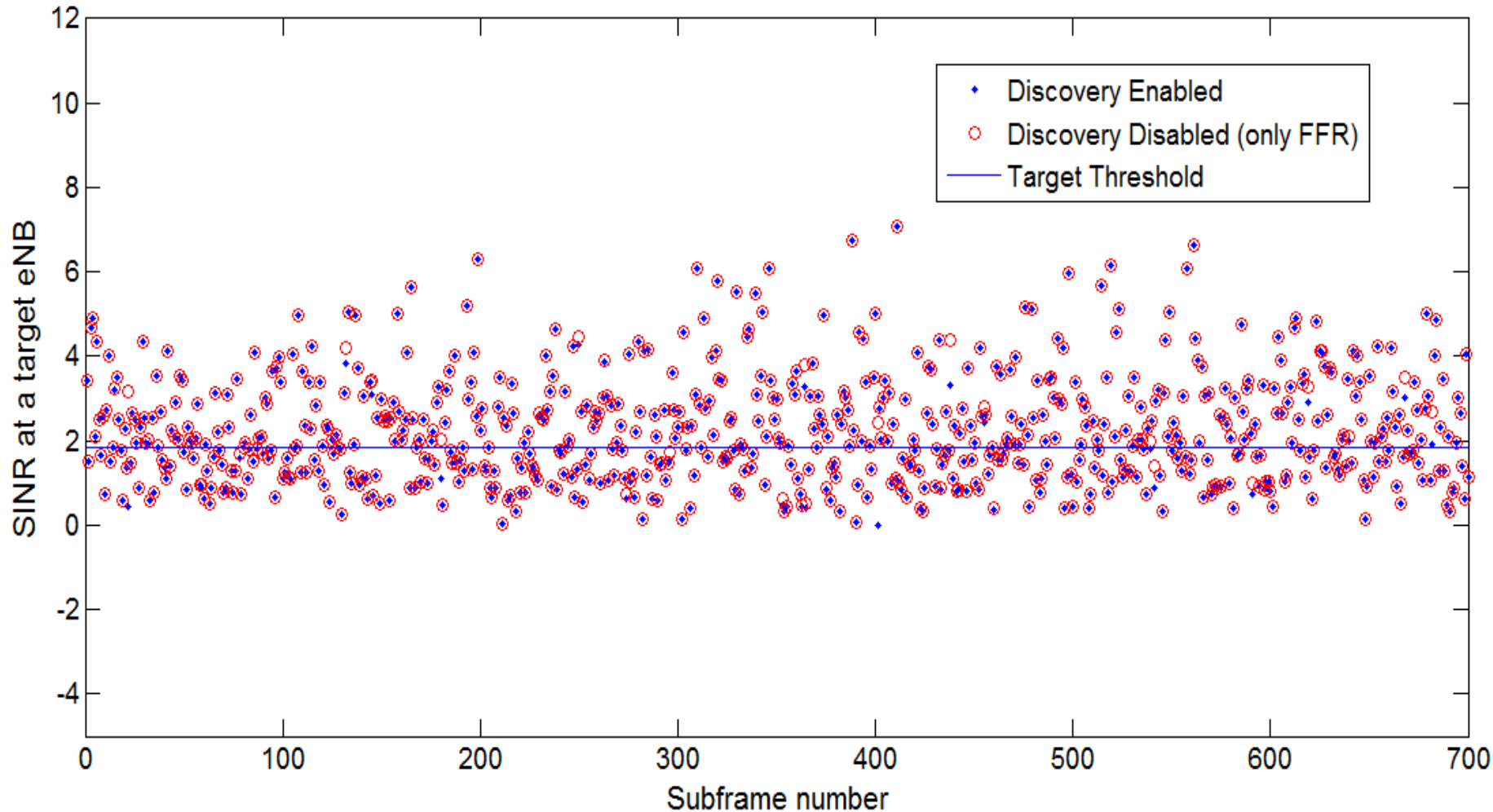


# Exploiting FFR to Enable discovery transmissions

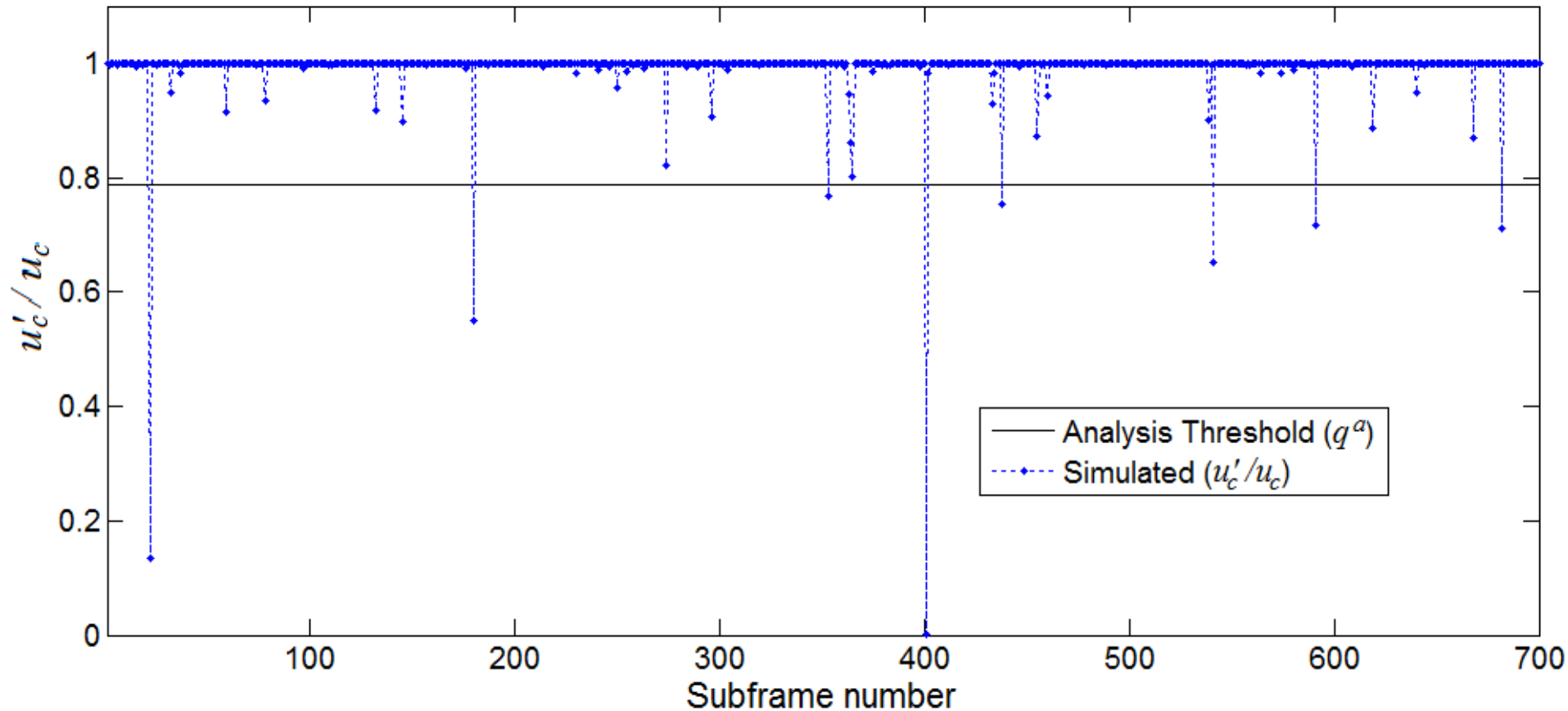




# Exploiting FFR to Enable discovery transmissions



# Exploiting FFR to Enable discovery transmissions

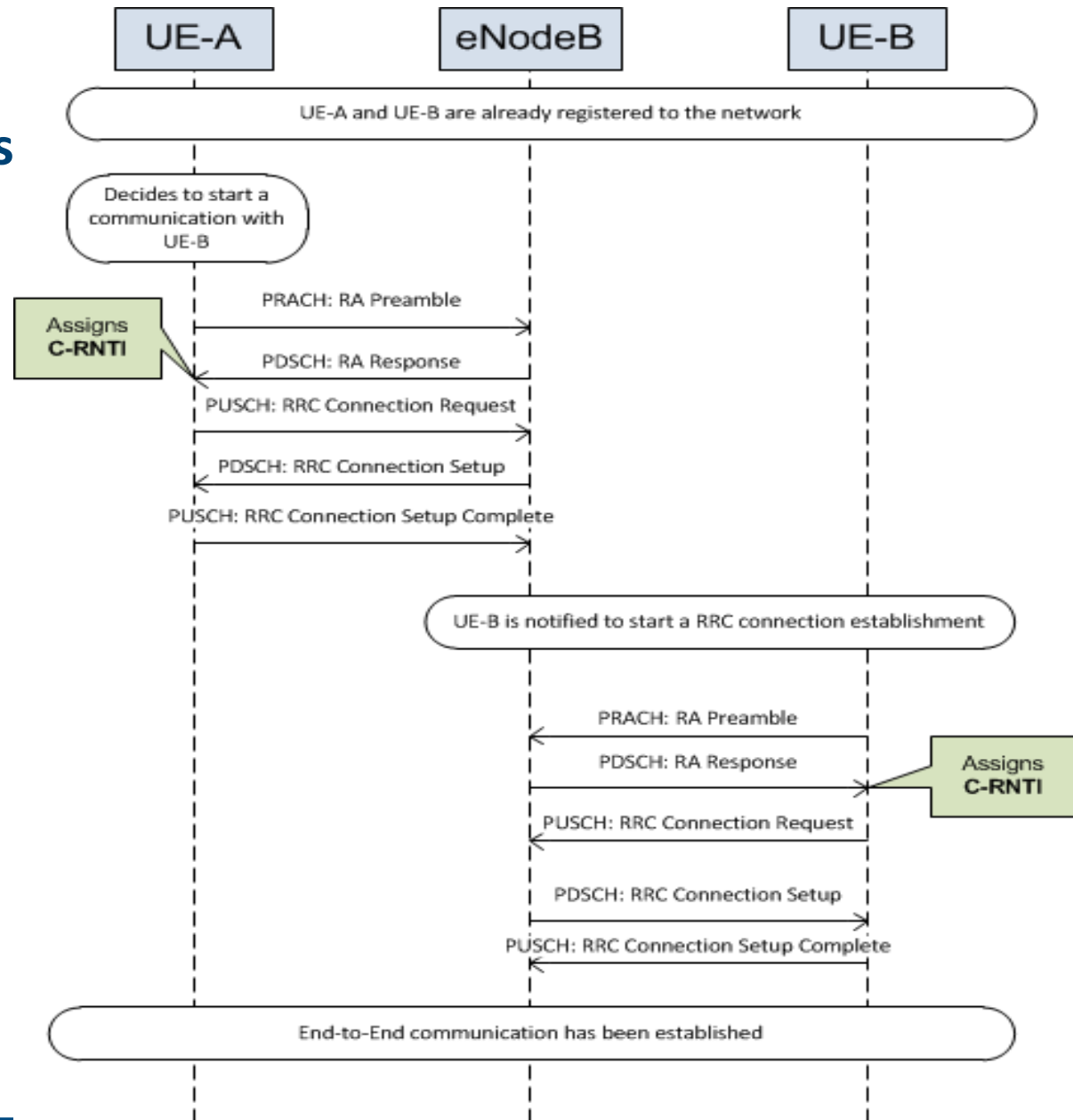




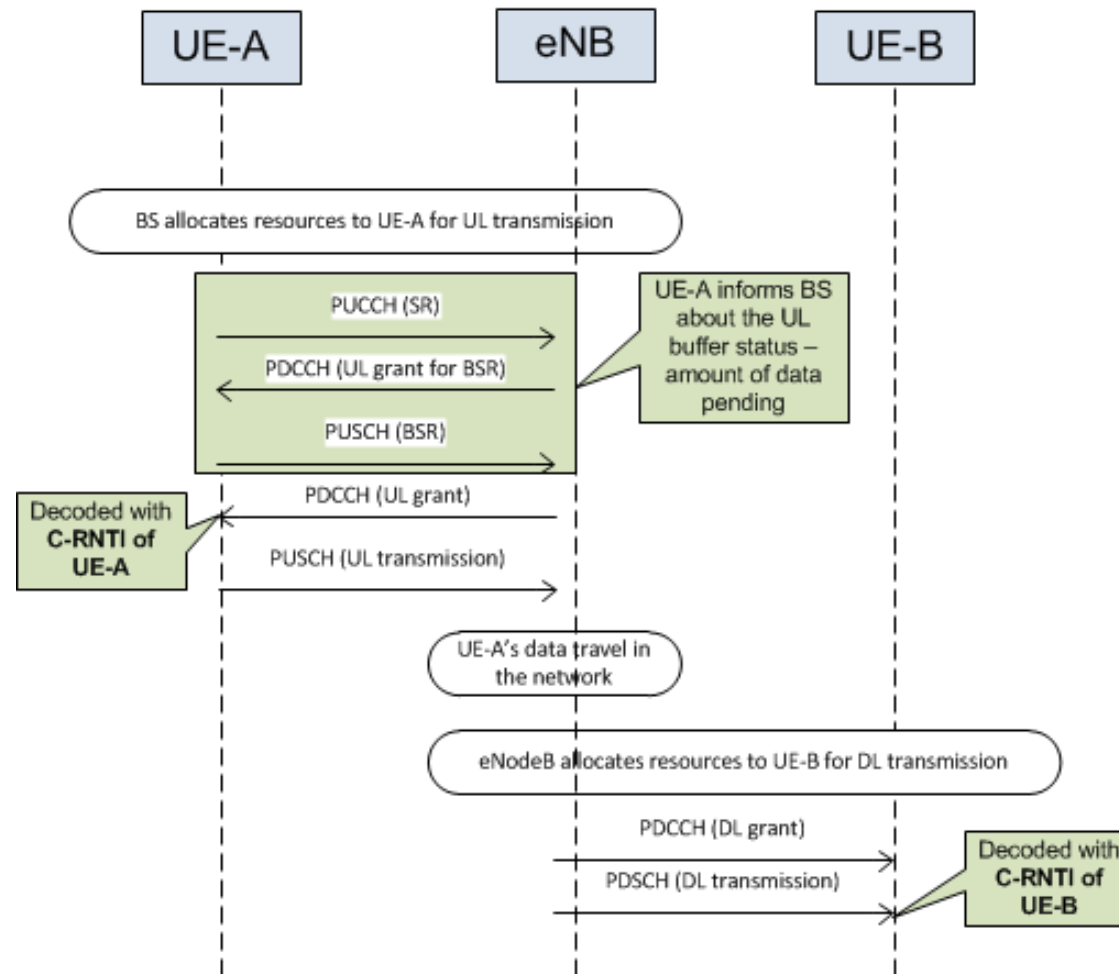
## **Solution 3: Device discovery**

# **Radio access network enhancements for device discovery transmissions**

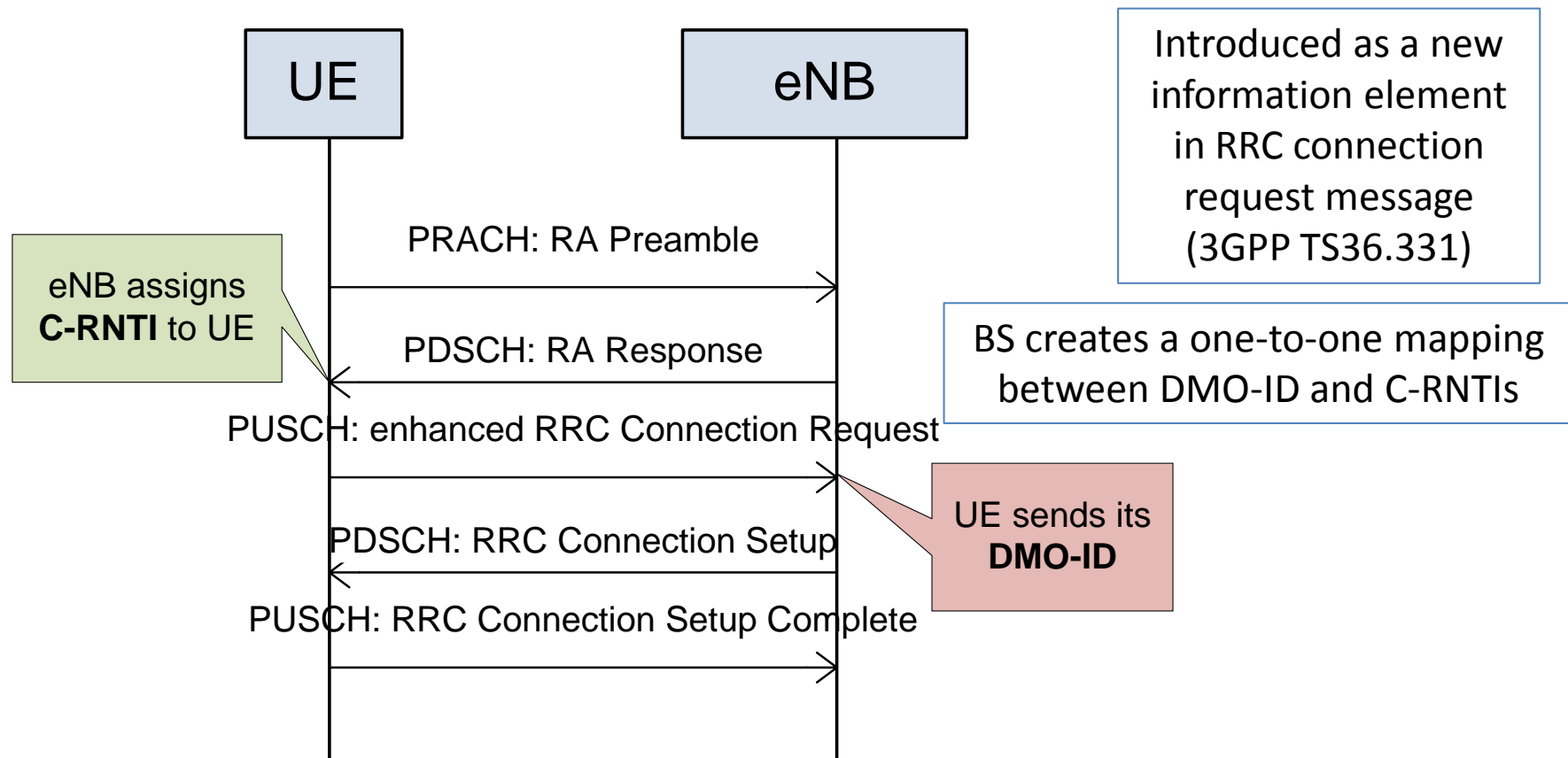
# Conventional case: Cellular Transmissions (1/2)



## Conventional case: Cellular Transmissions (2/2)



## Proposed case: Direct Transmissions (1/2)



## Proposed case: Direct Transmissions (2/2)

