Device-to-Device (D2D) Communications in LTE-A Networks

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Outline

1. Introduction to D2D
   - What is it?
   - Why use it?
   - How is it different from other technologies?
2. D2D communications classification & possible usage cases
3. D2D technical requirements
   - Link establishment
   - Basic research issues and possible solutions
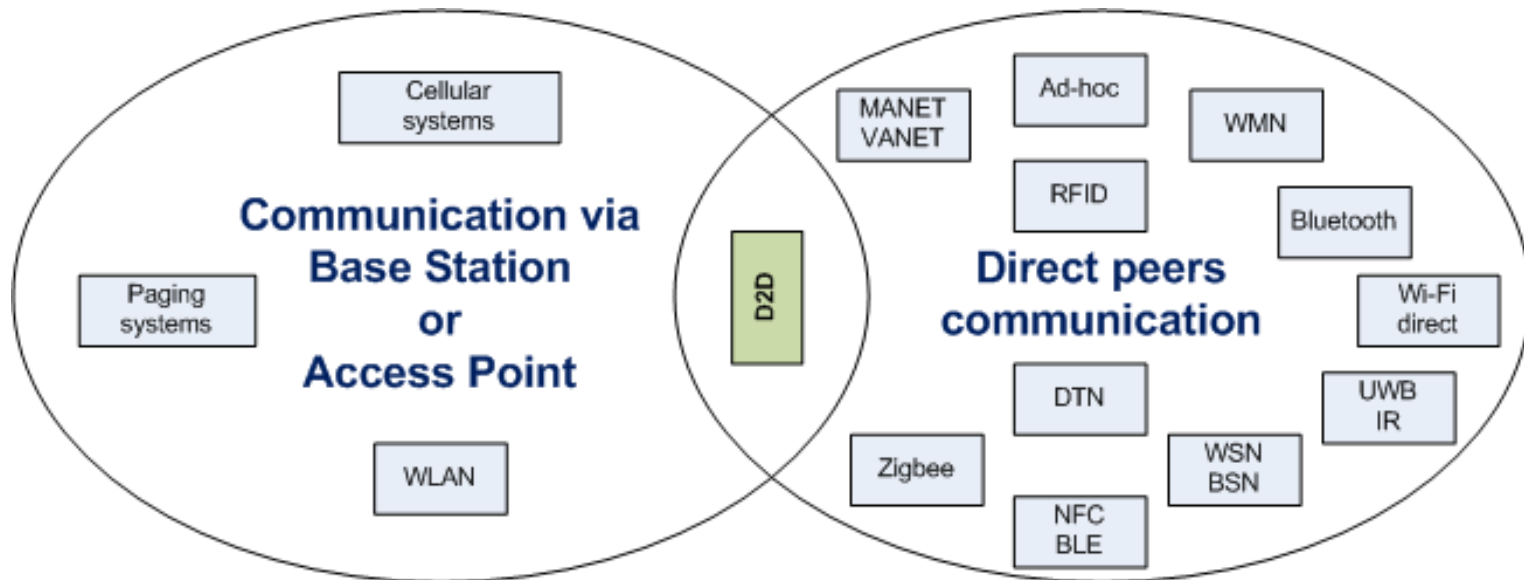4. Enhancements to an LTE-A network to enable D2D and future considerations

Introduction to D2D

Wireless technologies

Categorization based on network assistance –

Where D2D lies:

1st perspective → Control
2nd perspective → Data

Direct communication (1/2)

- **Mobile/Vehicular Ad-hoc NETwork (MANET/VANET):** self-configuring, independent movement, frequent changes

- **Bluetooth:** short distances, unlicensed ISM band

- **Bluetooth Low Energy (BLE):** lower power & range, faster

- **Wi-Fi (Wireless Fidelity) Direct:** Without access point, Automated setup

- **Near Field Communication (NFC):** Few centimeters range, 2-way communication
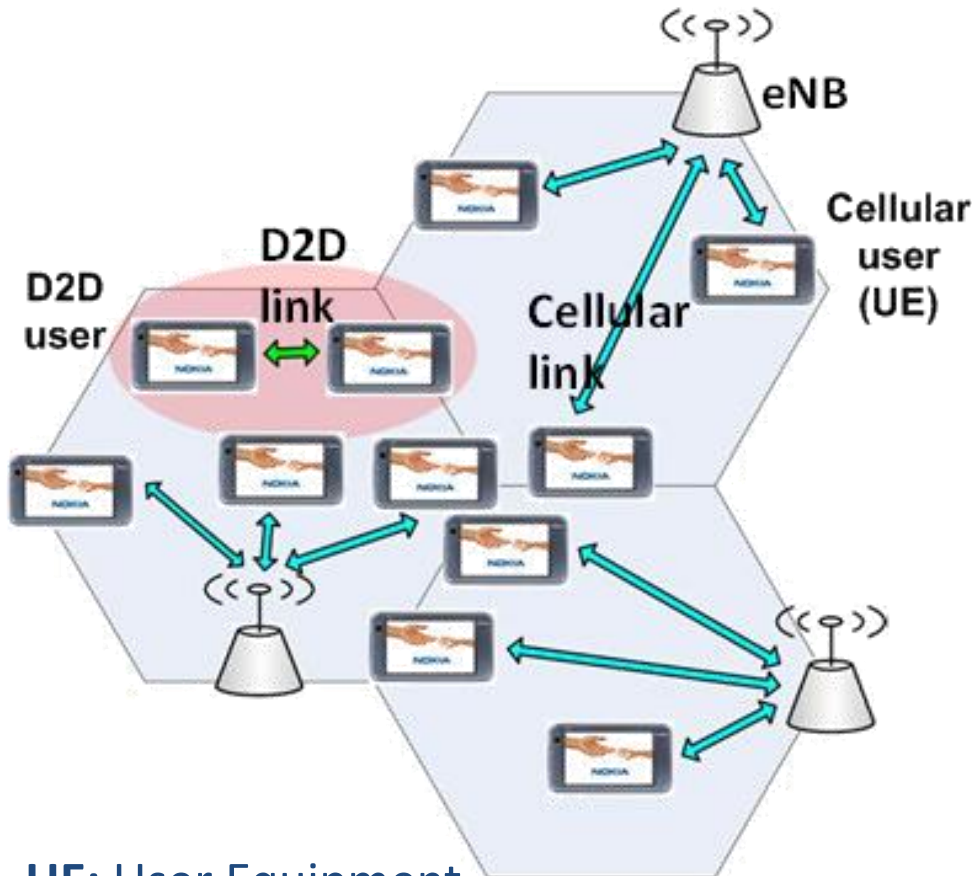
Direct communication (2/2)

- **Zigbee:** small nodes, long battery life, ad-hoc, short range, low rate (traffic management systems, wireless light switches)

- **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

- **Radio-Frequency IDentification (RFID):** Identify tags attached to objects, one-direction

- **Ultra-wideband (UWB):** very low energy level for short range, high bandwidth

- **Infrared (IR):** short range, line of sight, bidirectional

D2D definition

UE: User Equipment
eNB: evolved NodeB

Define D2D as:

- Wireless & mobile **direct** pair communication without infrastructure

- **Network-assisted** D2D links

- Utilising **licensed** spectrum

- H2H or M2M

- Take advantage of the **physical proximity** of the communicating devices
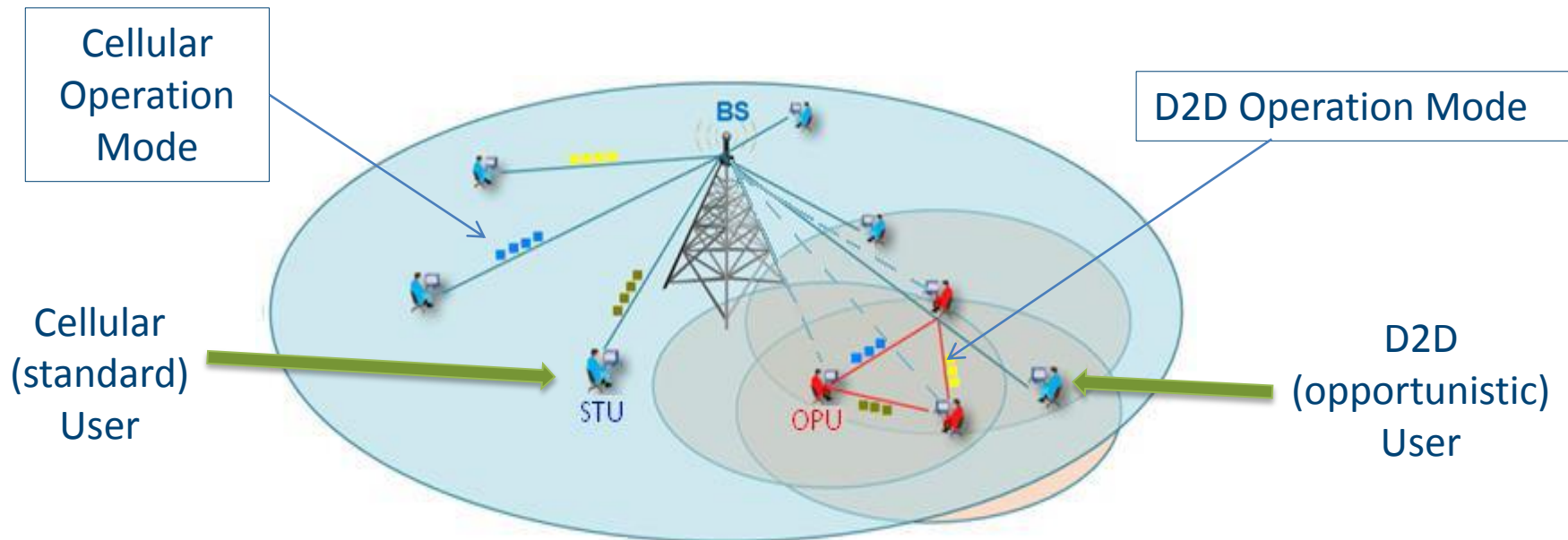
Incentives for D2D (1/5)

- **Proximity gain:**
  - Higher bit rates (throughput)
  - Lower delays (latency)
  - Lower power consumption

- **Hop gain:**
  - single link (not different resource for UL/DL)!

Why use these when you can use …

UL

DL

… this one?
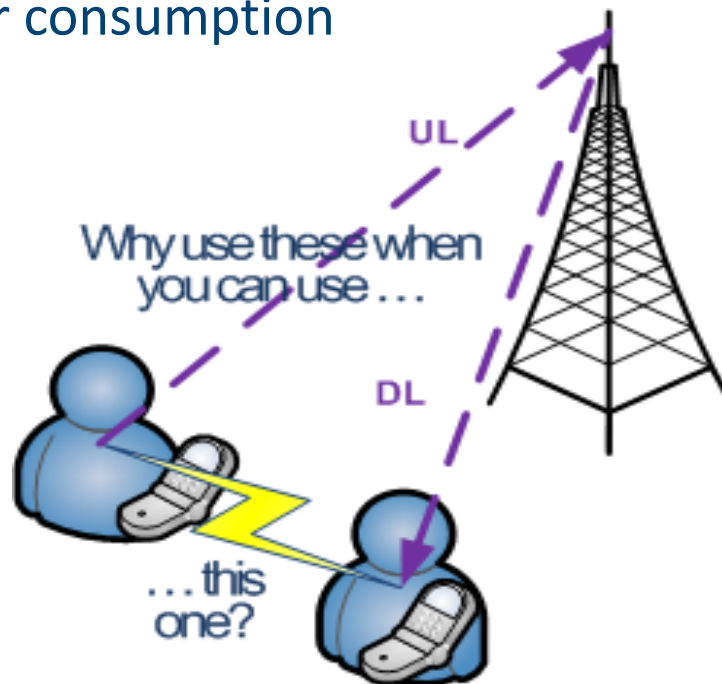
Incentives for D2D (2/5)

- **Reuse gain:**
  - Radio resources utilization: spatial spectral reuse
  - Tighten system reuse factor
  - Spectral efficiency increase

Cellular Operation Mode

D2D Operation Mode

Cellular (standard) User

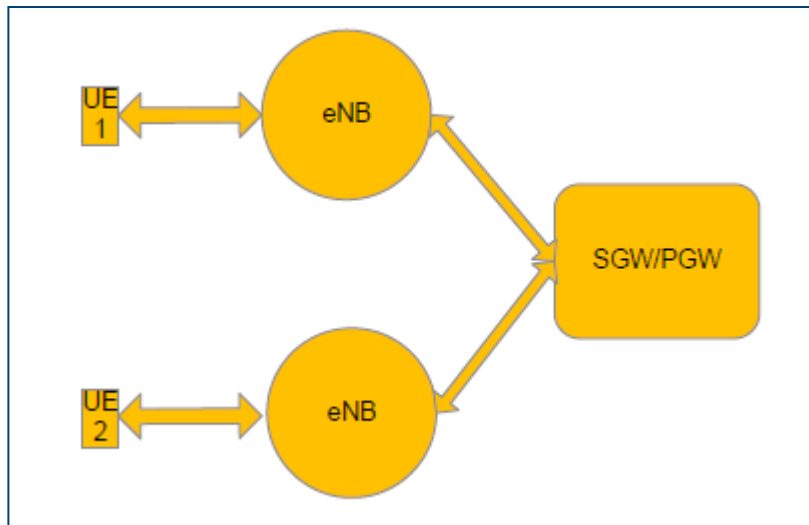D2D (opportunistic) User

Incentives for D2D (3/5)

- **Increased coverage**:
  - UE relaying
  - Handle poor cellular coverage conditions
  - Appealing for emergency relief
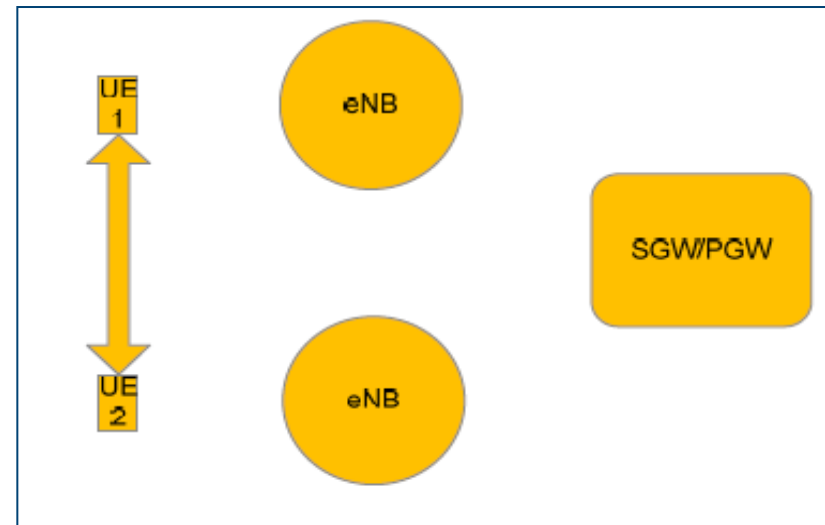
Incentives for D2D (4/5)

- **eNB offloading**
- **Core network decongestion**
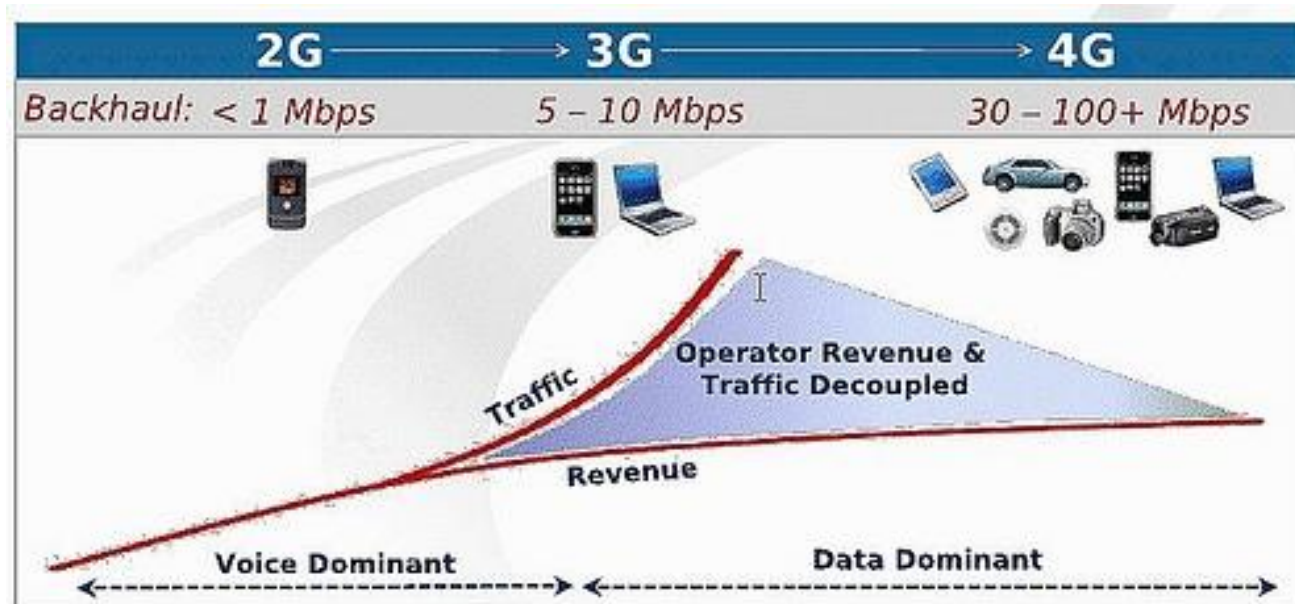
Conventional - Without D2D

With D2D

Incentives for D2D (5/5)

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

- **New types of P2P services:**
 - Enables communication between consumer devices and cell phones

D2D vs. current technologies

- The operator **controls** the communication process to provide better user QoE

- D2D can provide **QoS guarantee**

- D2D is **transparent** to the user
  ⇒ hidden complexity, no manual detection-pairing

- Provides safe **identity** in communications

- Increased **security**

- Covers larger distances ⇒ **mobility** freedom (Bluetooth range is ≈ 10m, while a device in D2D mode has a potential range of hundreds of meters away – Remember that a D2D device may be in the cell edge but it can and should reach the eNB in cell center)

- Avoids uncontrollable **interference** of unlicensed band

- Not subject to a device's technical **limitations**

- Provides **profits** for the operators
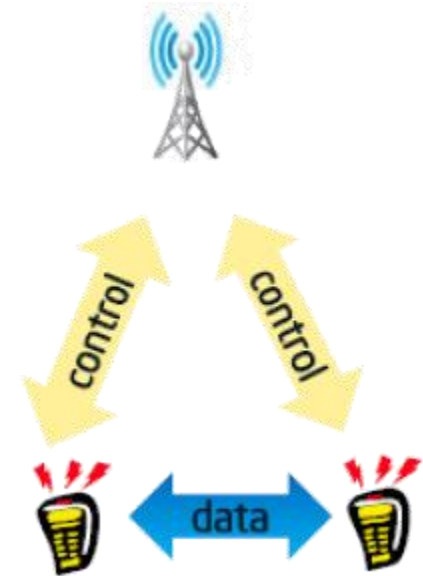
D2D vs. Cognitive Radio (1/2)

- **Cognitive Radio:** "A fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network & user demands"
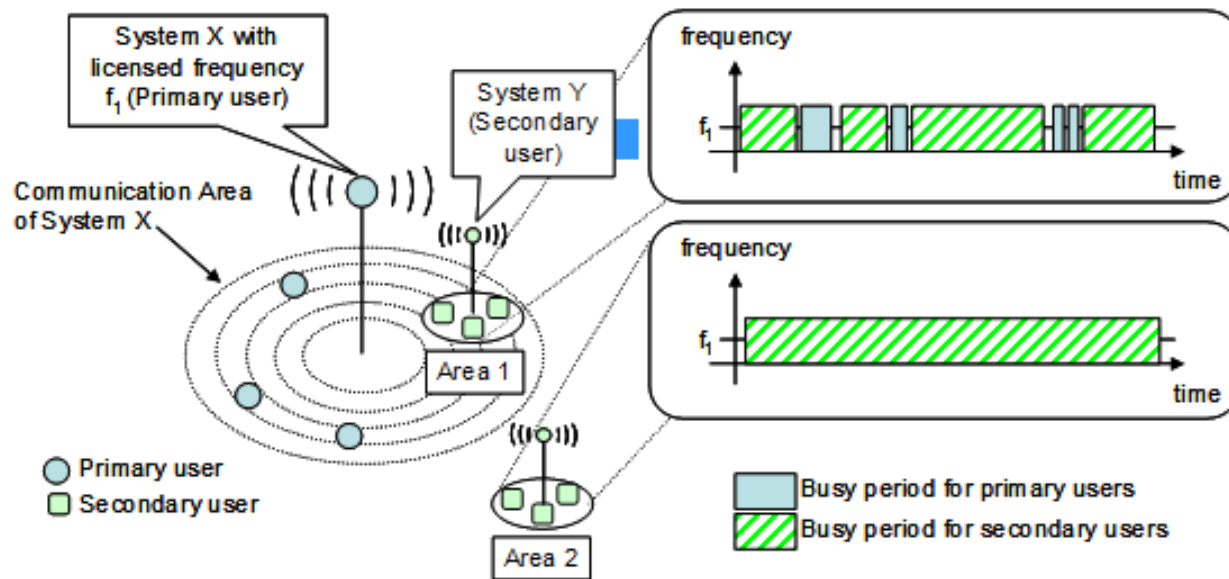

Frequency utilization of primary and secondary users in Cognitive Radio Environment

D2D vs. Cognitive Radio (2/2)

Spectrum Sensing Cognitive radio

- Spectrum **sensing** techniques (UE's responsibility)

- Spectrum **management**: Analysis & decision for best available spectrum

  $\Rightarrow$ Sophisticated algorithms & HW

- **Power control**

- Regular **exchange** of information between co-operative nodes

- Not fast enough for heavily **loaded** LTE network with fast scheduling variations

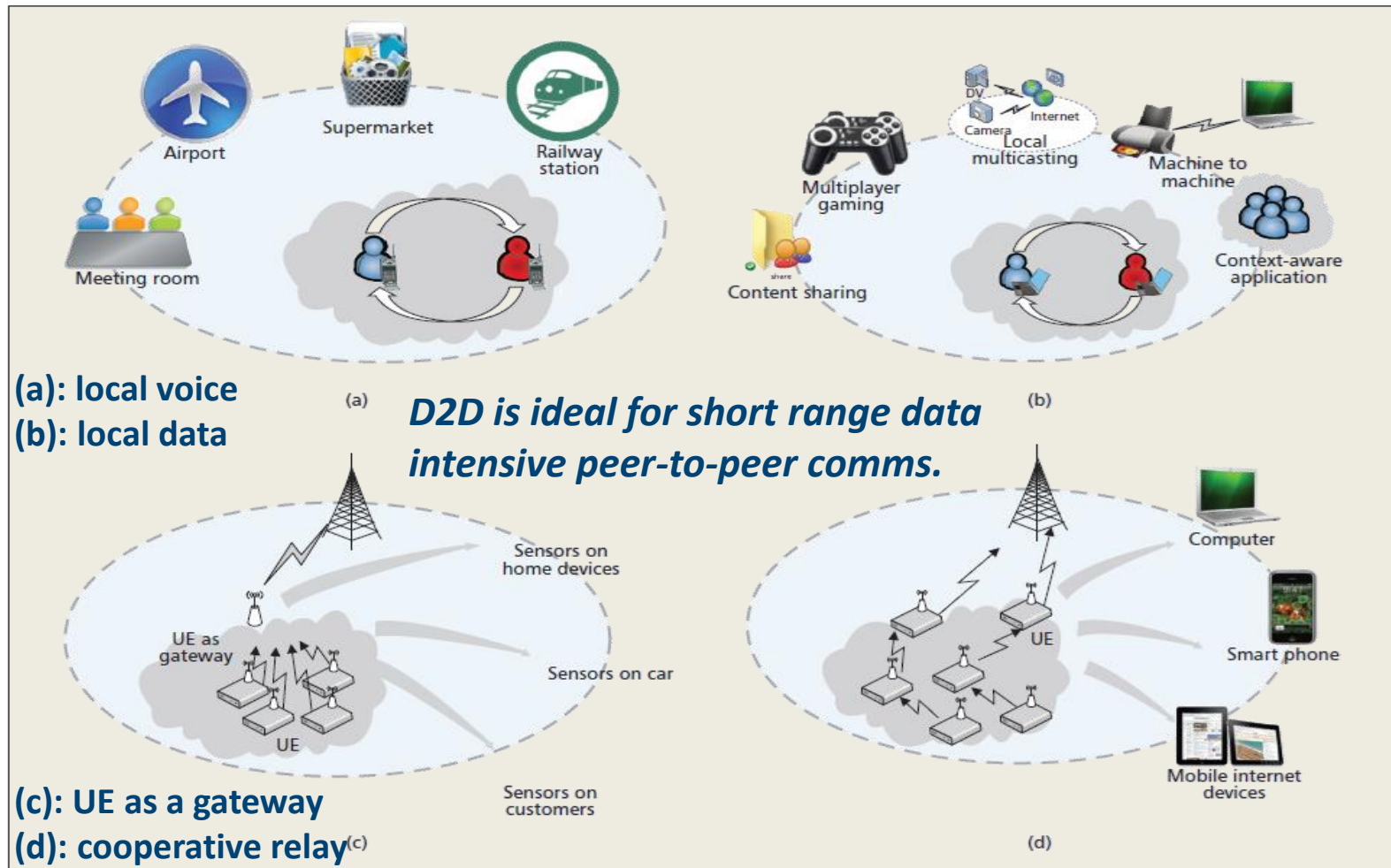- **Optimizes** the use of available spectrum while minimizing interference
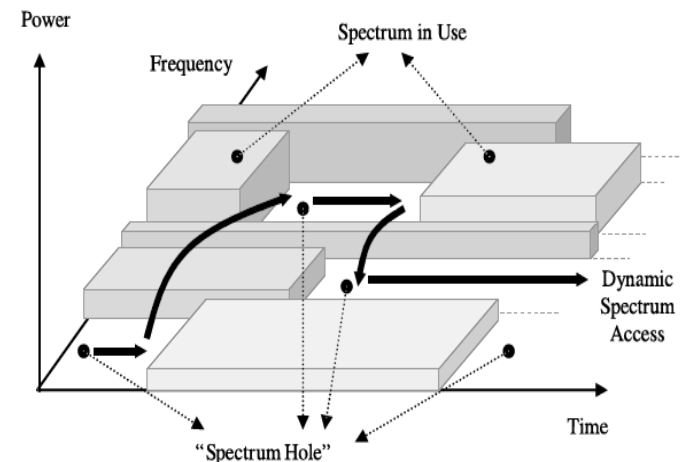
D2D communications classification
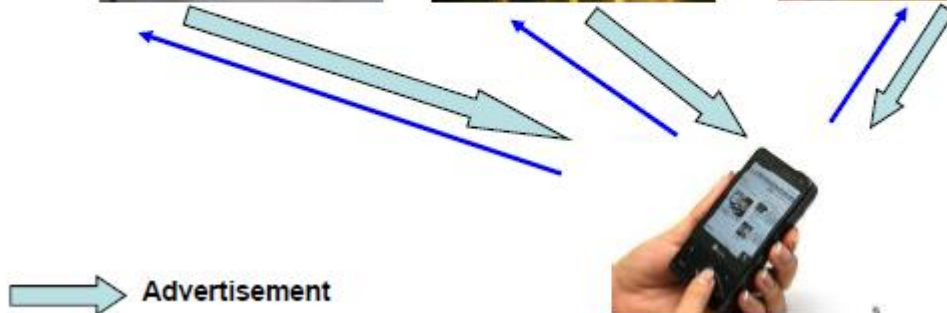# &
possible usage cases

Classification

- **Level of operator control:** Fully / Loosely controlled D2D mode (Access authentication, Connection setup, maintenance & control, Resource allocation)

- **Spectrum categories:** Unlicensed / FDD licensed / TDD licensed / Guard band between FDD and TDD

- **Resource allocation:** Distributed / Centralized

- **Peer discovery:** Distributed / Centralized

- **Paging and connection establishment:** Fully / Loosely controlled, Licensed / Unlicensed

- **Usage cases:** Peer-to-Peer / Relay

Usage cases & applications

(a): local voice
(b): local data

D2D is ideal for short range data intensive peer-to-peer comms.

(c): UE as a gateway
(d): cooperative relay

D2D paradigms (1/3)

Proximity-based mobile advertisement

- Offers, stores, services, products
- Similar for Public Alert, Tsunami/Earthquake warnings

Advertisement

Interactive discovery

Offloading cellular network

- **D2D connections:** Visitors download promotional material from a media server (using a URL)

- **Cellular network:** Phone calls & internet

D2D paradigms (2/3)

Location-aware social networking

- Locate your friends in the vicinity

- Find new connections that share common interests

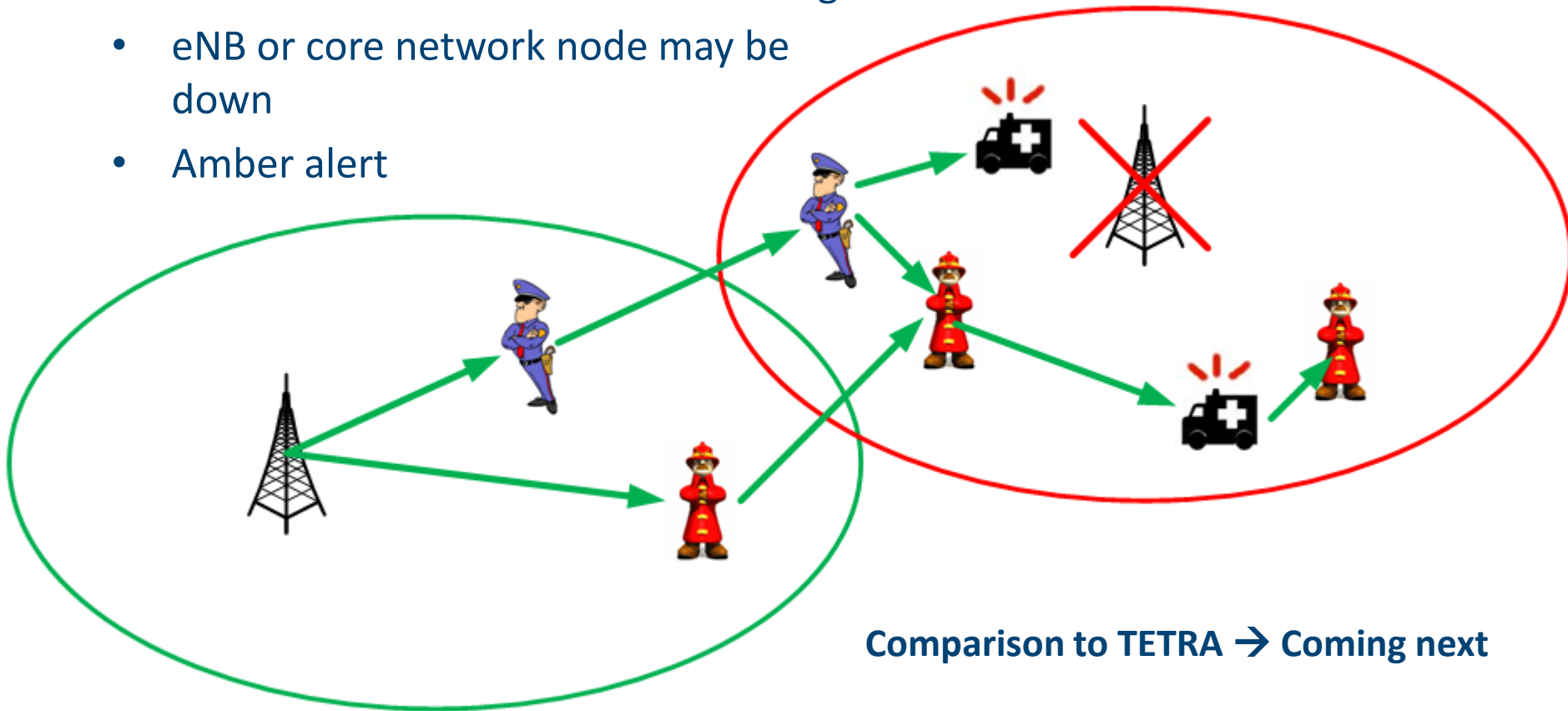- Buy and Sell Local Services and Goods

http://www.shape.ag

D2D paradigms (3/3)
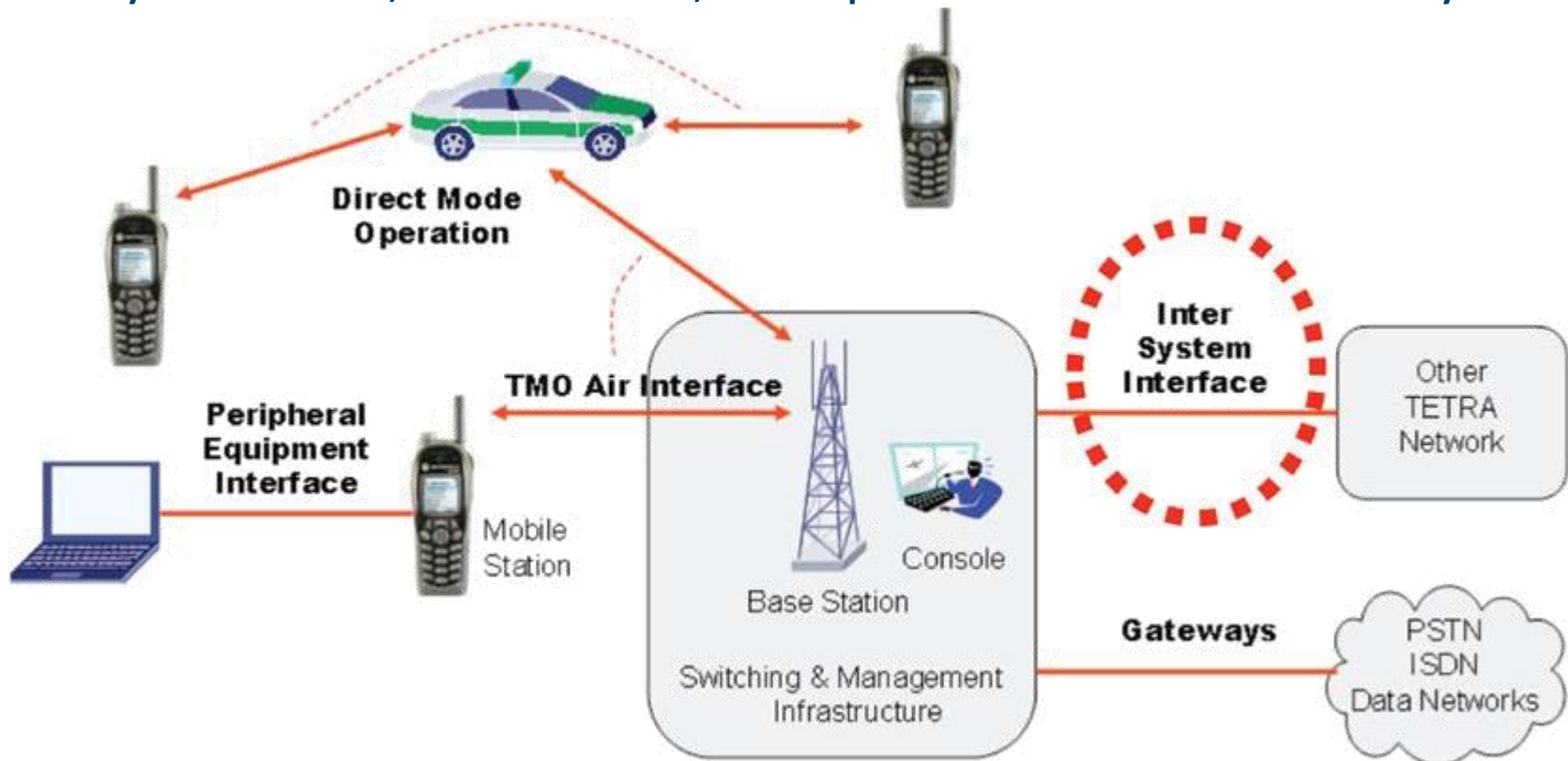
Public safety & Emergency relief

- Under no or limited network coverage

- eNB or core network node may be down

- Amber alert

Comparison to TETRA → Coming next

Terrestrial Trunked Radio

Use by government agencies, emergency services, for public safety networks, train radios, transport services and military

D2D technical requirements

An underlay to cellular comms

- **Motivation**: Cost-efficient access to the licensed spectrum, spatial spectrum reuse and congestion avoidance
- Capability for **hybrid** connections: UE-eNB and UE-UE
- **Handover** from D2D connection to cellular when the latter achieves higher throughput or if one of the policies is violated
- D2D UEs controlled by **eNB**: Resource allocation & Power control for interference mitigation
- **Core Network** not involved in actual data delivery → only signaling of session setup, charging, policy enforcement
- **Transparent** to the user
- **No** service **differentiation**

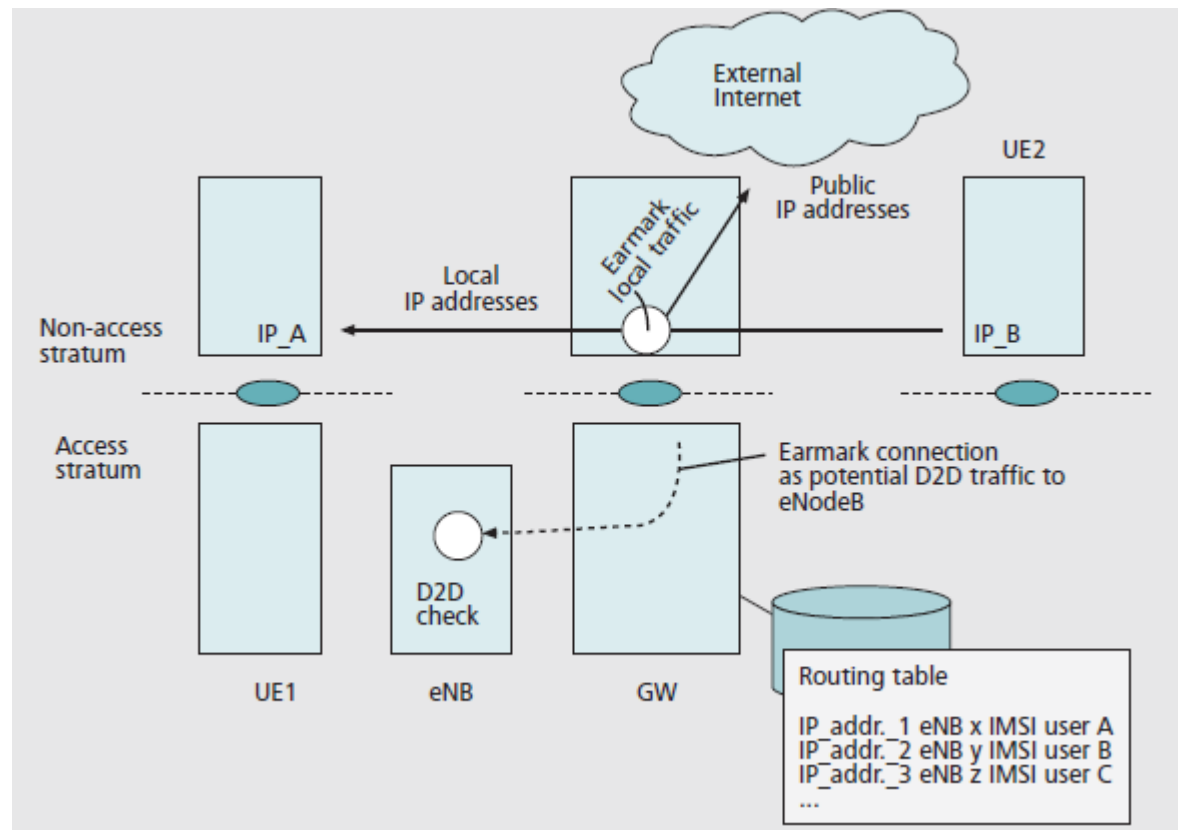# D2D comm. establishment (1/2)
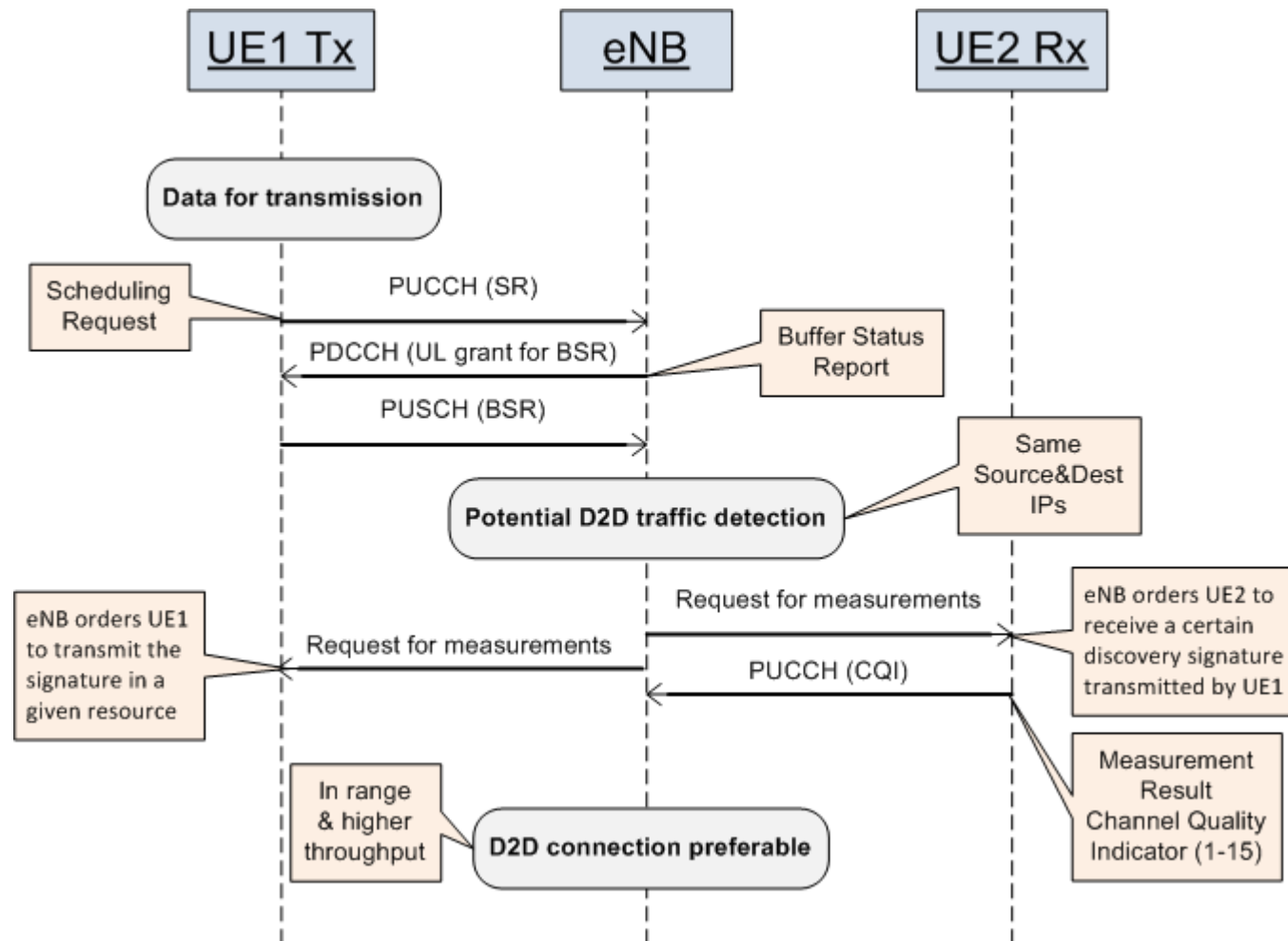
D2D comm. establishment (2/2)
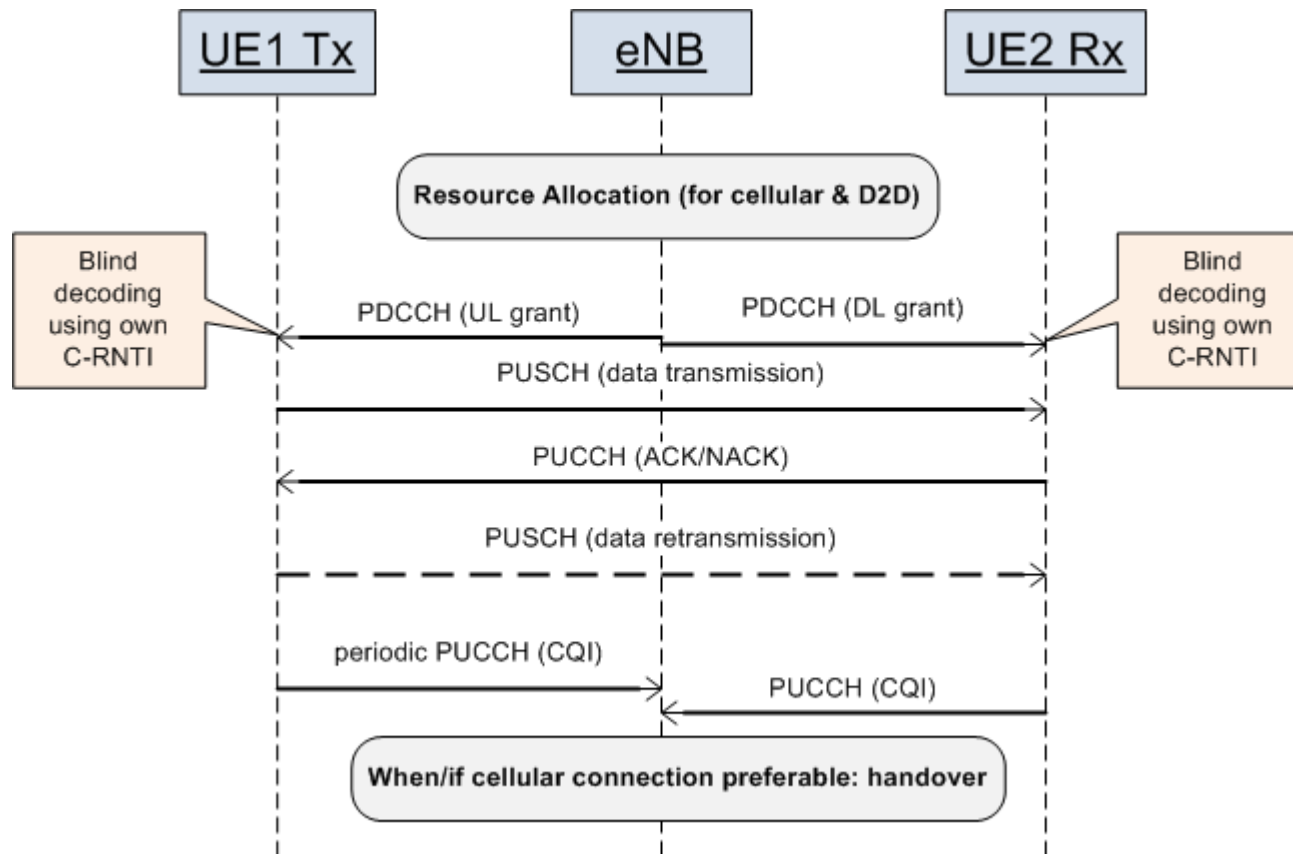
Potential D2D traffic detection

- GW earmarks local traffic to indicate potential D2D traffic to eNB
- eNB checks if the 2 devices can set up a D2D connection

Enhanced functionalities

UE

- Peer discovery - paging
- Perform periodic channel measurements
- Transmit these CQI measurements to the eNB or to other UE
- Direct transmission / reception of data
- Maintain both a link to eNB + a D2D link

eNB

- Peer discovery
- Physical layer procedures (synchronisation)
- Connection establishment
- Interference coordination
- Radio resource management (mode selection, scheduling, PRB allocation)
- D2D Power control
- Handover: D2D ↔ Cellular

Main research issues overview

- Intra- and Intercell interference mitigation

- Radio resources allocation management

- Best mode selection

- Power control optimisation mechanism

- Trade-offs between cellular and D2D performance

- D2D session setup and management

- Peer device and service discovery techniques

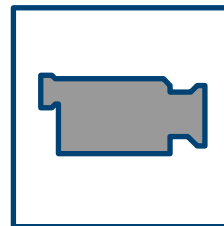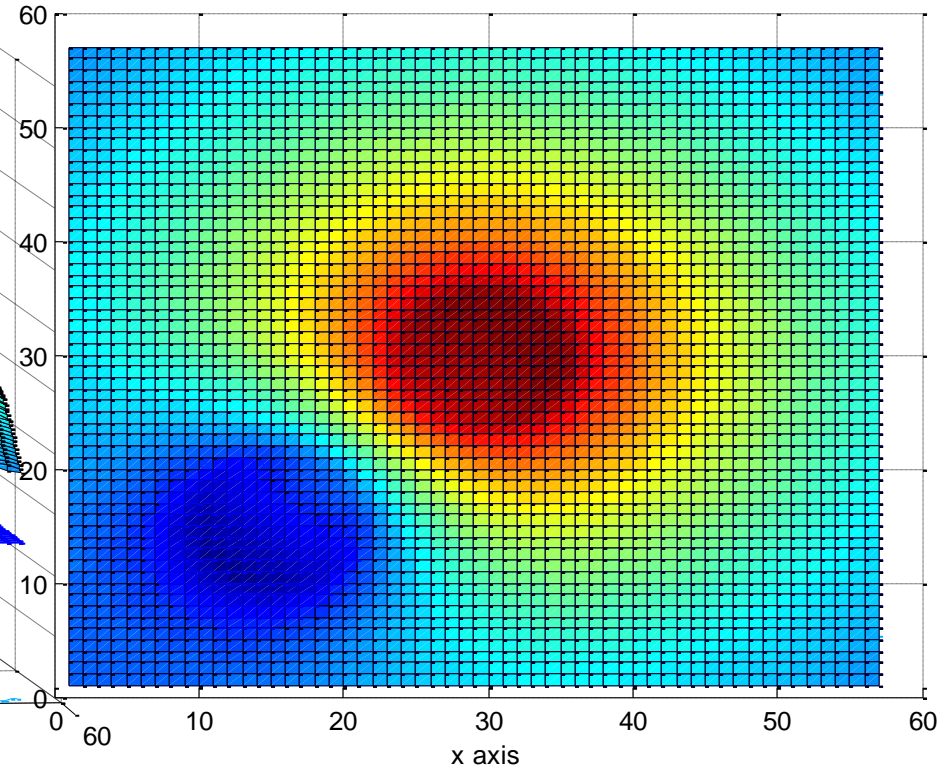- Paging

Interference problem (1/2)
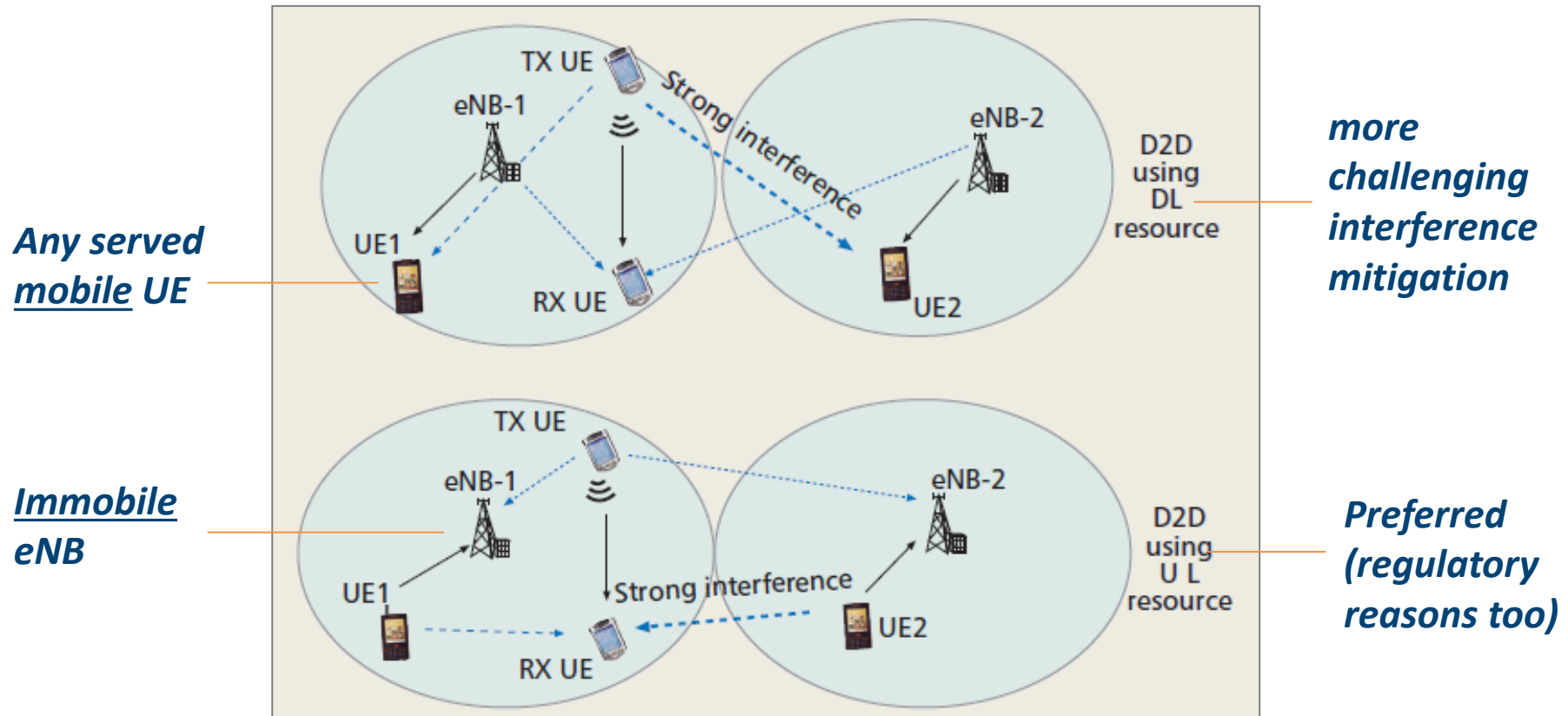
- **Intracell** and **Intercell** interference *(different cell synchronization)*
- Between cellular and D2D *(overlapping time and frequency resources)*
- Between D2D and D2D *(undesired proximity)*

Interference problem (2/2)

D2D effect on cellular communications

D2D effect on cellular communications

eNB   D2D Tx   UE Tx
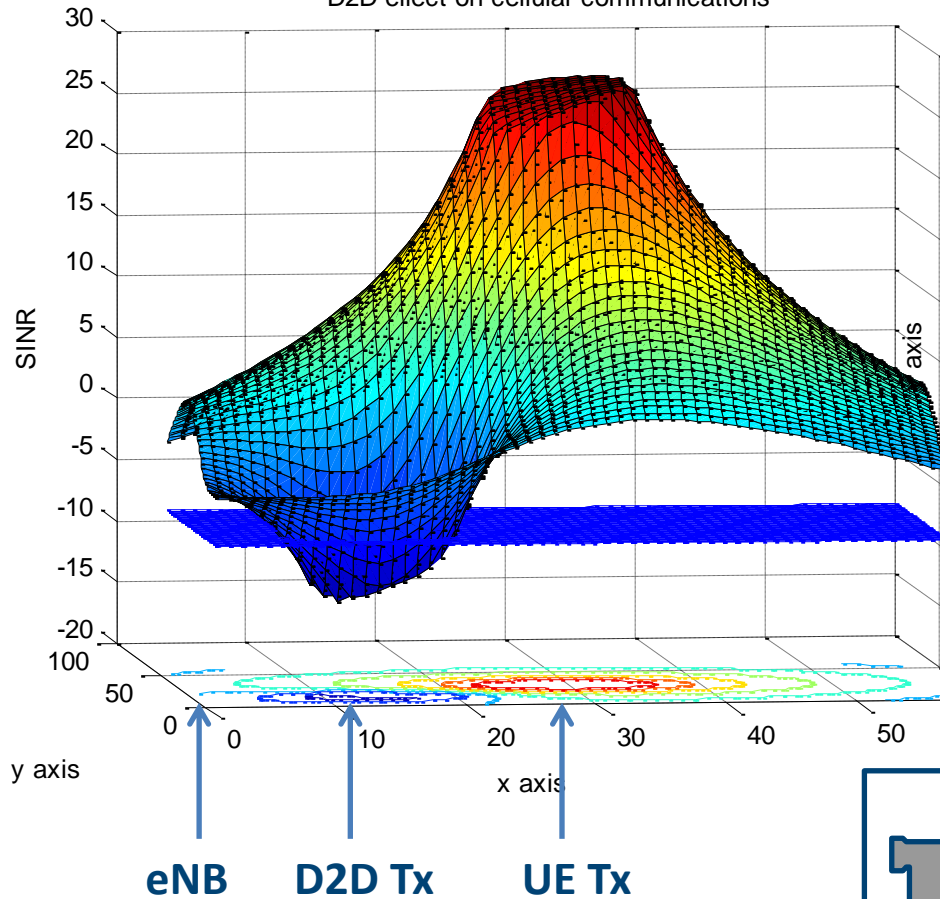
Best mode selection

- **Decision**: Should D2D pair communicate directly or via the eNB, i.e.: *select D2D or cellular mode?*

- 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

- Use what **criteria**, measurements, algorithms to decide (periodic/event-triggered)?

- When deciding **consider**:
  - D2D link quality and cellular link quality
  - Instantaneous load situation of the cell, buffer status of users and QoS
 - Received Signal Strength or distance between 2 nodes
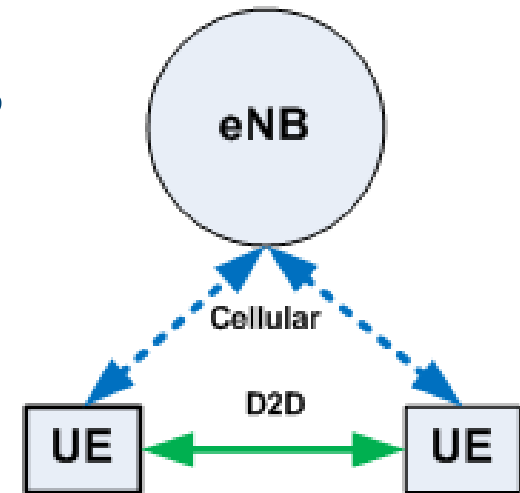
Resource sharing mode

- **Reuse mode:** D2D reuses the whole resources (ULre/DLre)

- **Dedicated mode:** D2D receives half of the resources

- **Cellular mode:** D2D is relayed by the eNB

- *The mode selection scheme selects for UL and DL the mode with the highest sum rate that fulfills the cellular SINR constraint.*
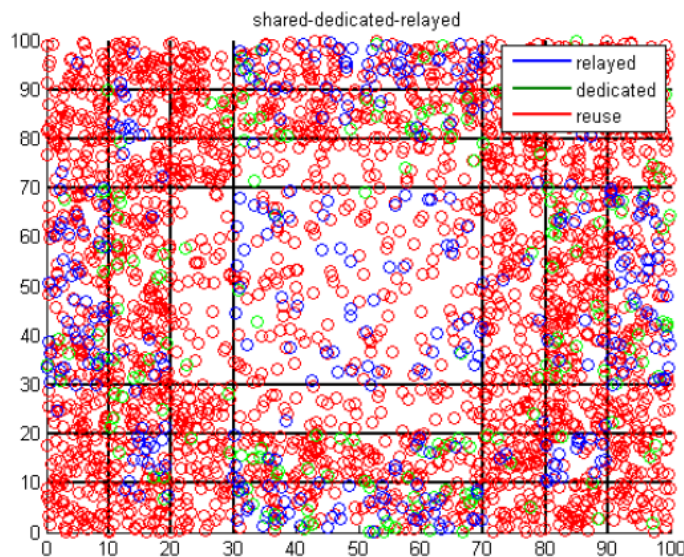

(a) Cellular uplink phase (Transmitter locations)
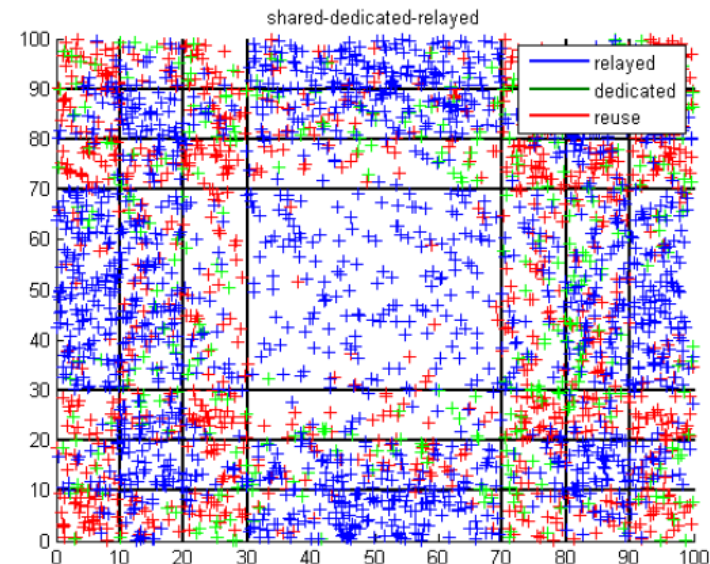
(b) Cellular downlink phase (Receiver locations).

Resource allocation (1/2)

1. Either **centralized** or **distributed**

2. If centralized select mode

- 1st option: **Reserved** resource pool for D2D semi-statically

- 2nd option: **Reuse** resources assuring avoidance/cancellation of mutual interference via proper scheduling & power control

3. If reuse mode, allocate resources efficiently

DL: OFDMA

UL: SC-FDMA
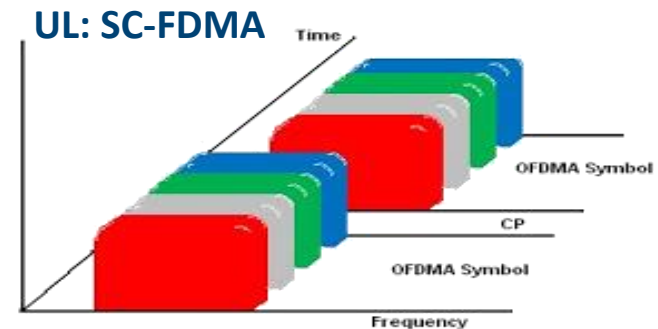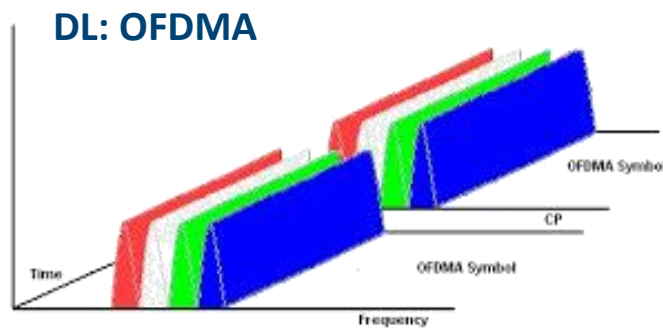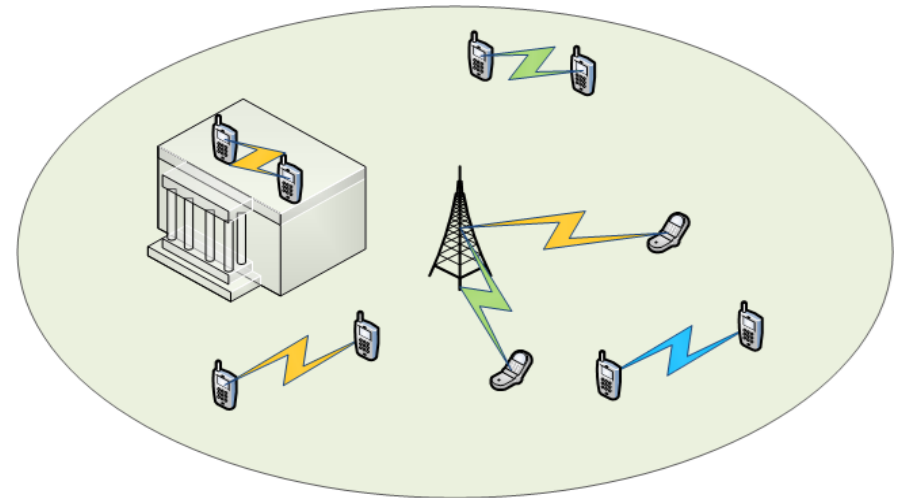
Resource allocation (2/2)

**Interference-aware methods for efficient spectrum sharing among cellular and D2D connections:**

- Mixed integer nonlinear programming (MINLP) problem formulation & greedy RB selection algorithm

- Graph-coloring theory

- Game-theory

- Auction-based strategy

- QoS-based resource allocation scheme

- Minimize maximum channel gain between cellular+D2D UE

- Neighborhood detection and reporting to the eNB:
  Measure interference from other UEs or use GPS information

 ⇒ Users self-allocate resources or are allocated by the eNB

Power control

- **1st option:** Predefined maximum D2D transmit level so that cellular degradation is tolerable

- **2nd option:** Dynamic power control:

▪ Reduce *near-far effect* → protects eNB

▪ Enables spatial spectrum reuse

▪ $SINR_{eNB} = \dfrac{Received\ power\ from\ cellular\ UL\ transmission}{Received\ power\ from\ D2D\ transmissions + Noise}$

▪ Cellular and D2D treated with same priority

▪ Cellular user priority by guaranteeing a minimum transmission rate

▪ **Power optimization**: With respect to max rate optimization (MIFTP)

- **3rd option:** UE determines pathloss by received power in DL and scales UL transmit power accordingly (eNB power known)
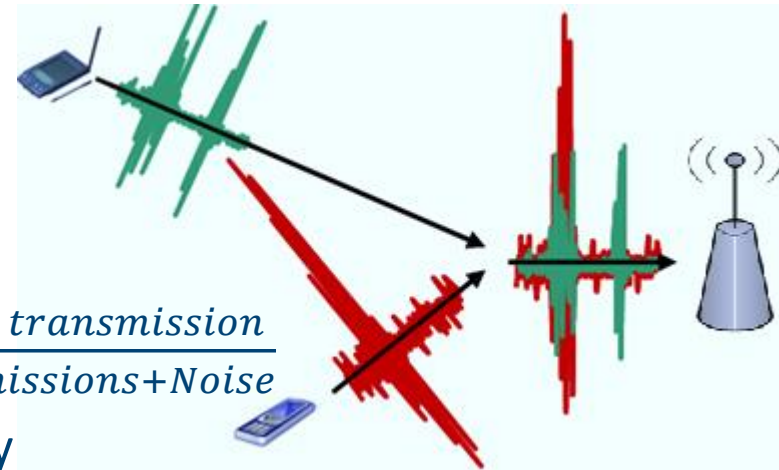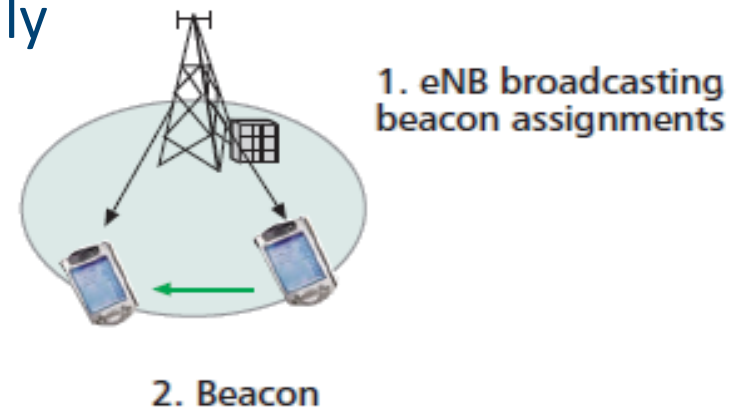
Peer discovery (1/4)

Overview

- Device / User / Group / Service discovery

- Meet in time, space, frequency

- Independent of D2D procedure

- Do not reveal the actual radio conditions between the D2D candidate nodes

- Proximity-based service (ProSE)

- Restricted or open discovery depending on UE permissions

Buddy
Gamers
Advertisers
Unknown

◄--► Desired link
◄--► Interference link
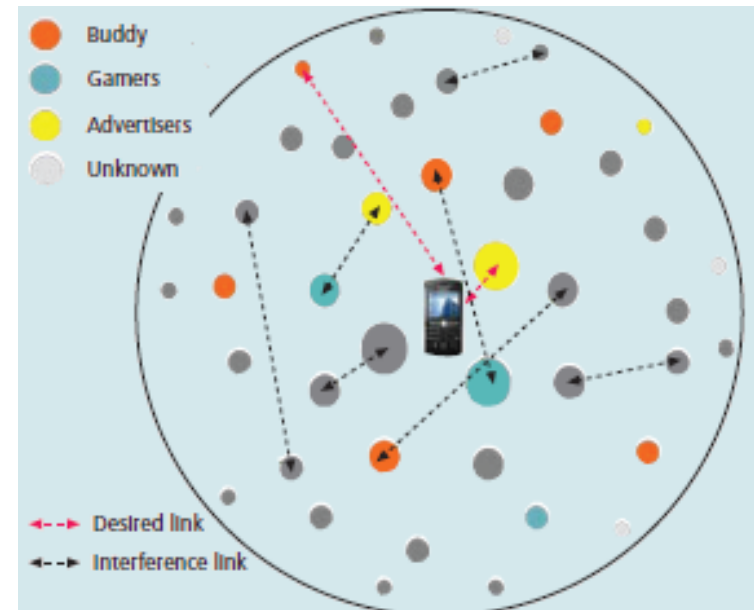
Peer discovery (2/4)

Centralized approach - with network support

- **A-priori**: Detect D2D candidates in advance by coordinating the sending of/scanning for beacons

- **A-posteriori**: Network (PDN or MME) realizes the proximity of two communicating nodes while a cellular session is already ongoing (packets eavesdropping)

- Faster, more efficient, user friendly

1. eNB broadcasting beacon assignments

2. Beacon

Peer discovery (3/4)

Distributed approach - without network assistance

- Periodical transmission of UE beacon signals (= identity)
- Sophisticated scanning
- Security procedures
- Requires user interaction
- Time and energy consuming
- More flexible and scalable than a centralized approach
- PHY and MAC mechanism for Wireless Personal Area Networks (WPAN) **Peer Aware Communications (PAC)** optimized for P2P, fully distributed, infrastructure-less communications

Peer discovery (4/4)

Qualcomm solution

- Network-assisted discovery
- All devices synchronize to an external time source
- Semi-statically, time-synced allocated resources for discovery signals
- Periodically every device transmits its peer discovery signal and also listens to others' discovery signals
- Communicate when decoded signal "makes sense"
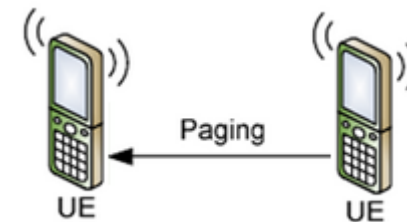- How to pick Peer Discovery Resource? What if all used?
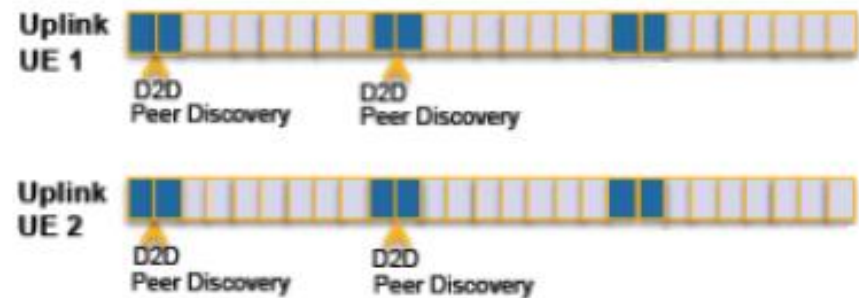
Paging

- **Conventional LTE-A paging:**
  - Core Network (MME) initiated
  - UEs monitor a specific channel at specific time instants
  - UEs process each paging message:
  - UE decodes its own ID ⇒ UE paged!
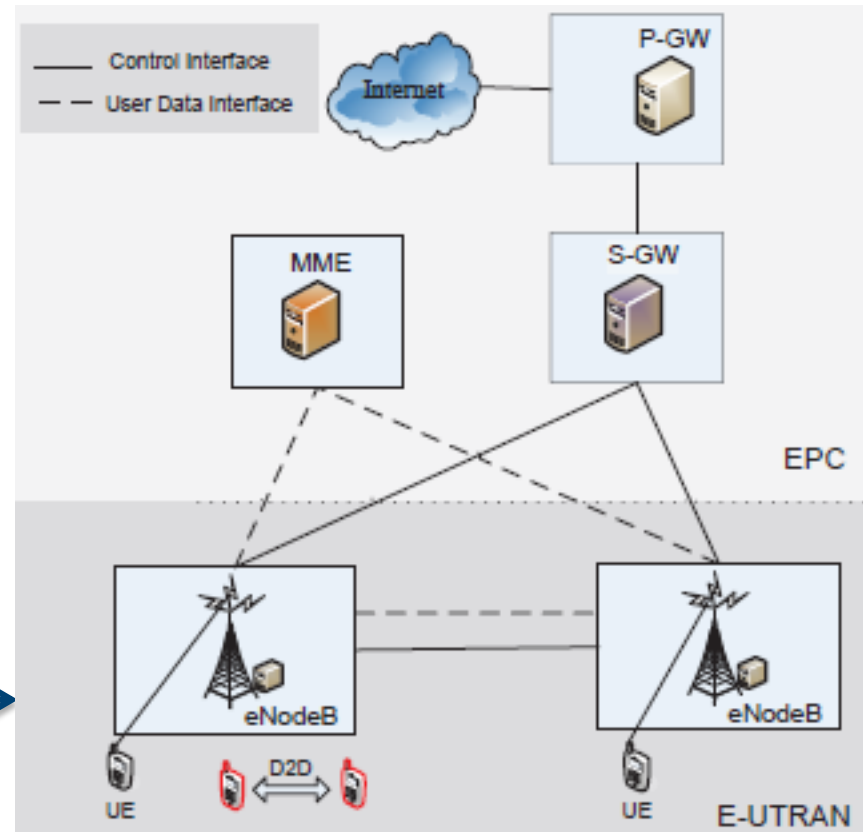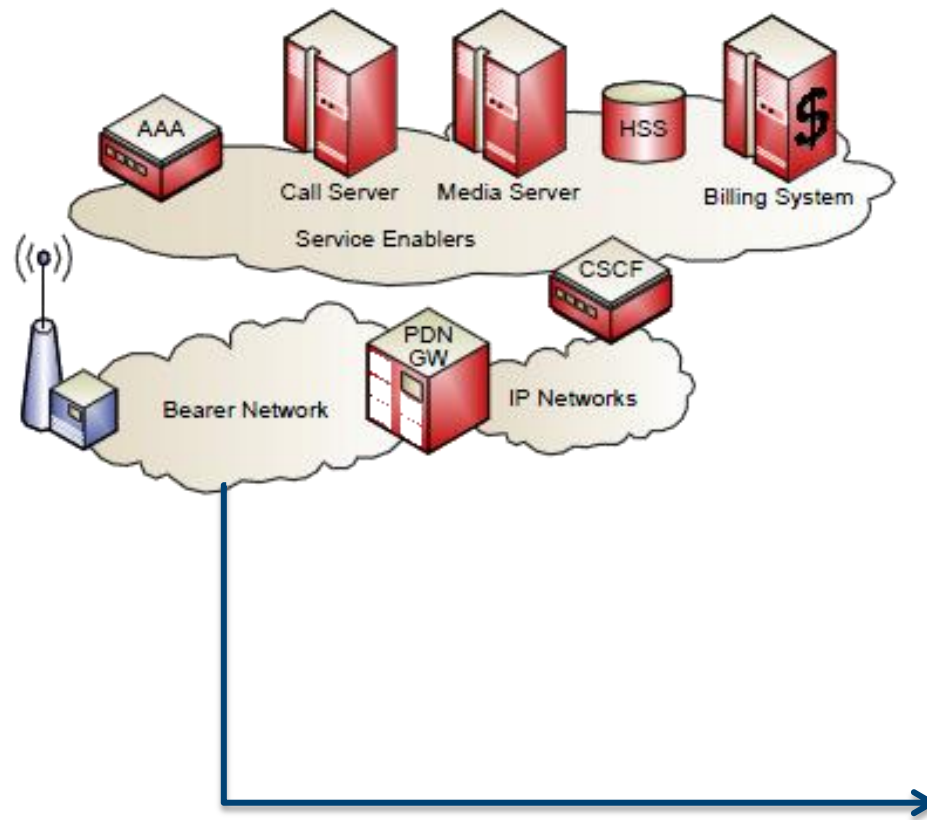 - If not ⇒ Discard and sleep
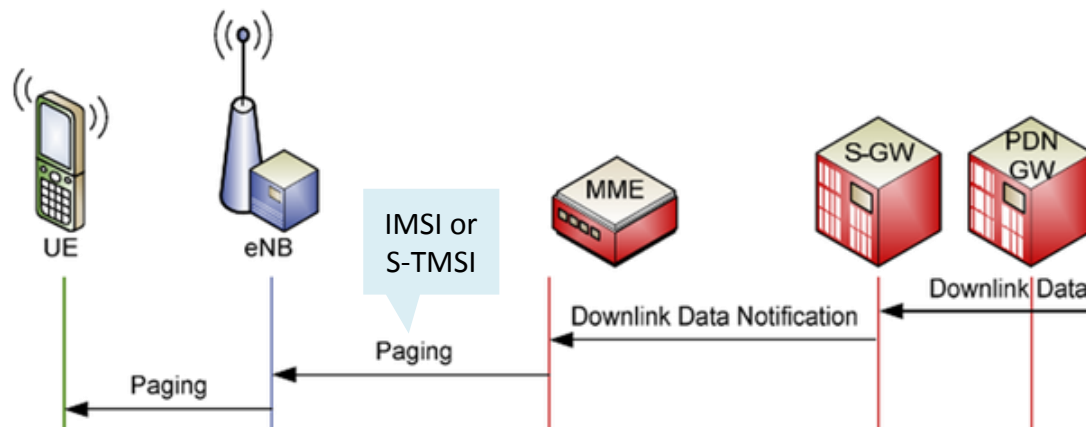
- **Direct D2D paging:**
  - Without the intervention of the eNB
  - On licensed band

Enhancements to an LTE-A network
to enable D2D
&
future considerations

LTE-A architecture overview

LTE-A enhancements for D2D

- **Radio identification & bearer setup :** MME: S-TMSI/IP, eNB: C-RNTI
- **User plane:** UDP/IP for D2D, TCP/IP for cellular links, reliable D2D transmissions by Layer 2
- **Interference management**
- **Link adaptation:** Self-adaptation to varying SINR and BLER, automated repeat requests (ARQ) retransmissions, BLER variations should be tolerable
- **Channel measurements:** Time and frequency configurable, Sounding Reference Signal or CQI
- **Mobility:**
  - Expected range of D2D is limited
  - Probably offers limited mobility support
  - Distinction of traffic flows using IP addresses

Future directions

- *"Public safety would be the primary driving force for LTE D2D in Rel-12."*

- Enhanced social networking

- Enhanced mobile advertisement

- Home automation

- **Dynamic resource adaptation**: eNB transmits DL in UL resource when the DL traffic is heavy (D2D UE capability)
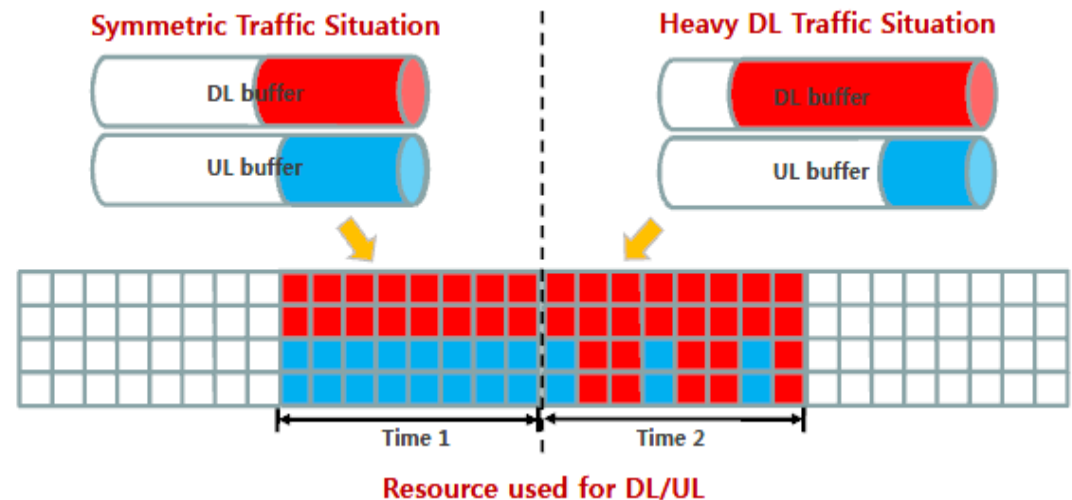
Main challenges

- **Competition** with free traditional "d2d" technologies
- **Technical** challenges: fast & light session setup
- **Integration** of current infrastructure LTE-A services, to assure the consistency of the user experience
- Low-power-always-on **proximity discovery**
- Avoid **overhead** when D2D not exploited
- Keep **conventional** UL links together with D2D
- **Lawful** interception of communication information
- **D2D relay mode:** Concern on the information security, wireless radiation and excessive consumption of their battery power, altruism
- A proper **business model** with enough incentive for users needs to be designed

Business model

- Huge dilemma: Charge or not?

- If yes, must answer the "***Pay for what***" question!

- Attract users to pay for identity, QoS and security, context information, and management, etc.

- Charge the users based on how many minutes or how much bandwidth they use in fully controlled D2D

- Charge a certain amount of fee per month irrespective of the actual D2D data flow in loosely controlled D2D

- Win-win technology paradigm

Summary

- Why D2D is a promising feature in future LTE-A systems

- Possible applications and real life scenarios

- How a D2D communication is setup from zero

- Discussion on Interference Management via proper Resource Allocation and Power Control mechanisms

- Peer discovery techniques

- LTE-A enhancements at E-UTRAN and EPC

- The future of D2D communications

Thank you for your kind attention!

"Ask me no questions, and I'll tell you no lies."

Oliver Goldsmith