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:

1<sup>st</sup> perspective → Control
2<sup>nd</sup> 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

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

**UE**: User Equipment

**eNB**: evolved NodeB
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)!
**Incentives for D2D (2/5)**

- **Reuse gain:**
  - Radio resources utilization: spatial spectral reuse
  - Tighten system reuse factor
  - Spectral efficiency increase
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”
D2D vs. Cognitive Radio (2/2)

**Spectrum Sensing Cognitive radio**

- **Spectrum sensing techniques** (UE’s responsibility)
- **Spectrum management**: Analysis & decision for best available spectrum ⇒ 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

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

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

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

- 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
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
  \[ \Rightarrow \text{Users self-allocate resources or are allocated by the eNB} \]
**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
  - \[ \text{SINR}_{eNB} = \frac{\text{Received power from cellular UL transmission}}{\text{Received power from D2D transmissions} + \text{Noise}} \]
  - 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
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
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