Towards Energy-Efficient, Privacy-Aware, Decentralized Device-to-Device Content Delivery

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Device-to-Device (D2D) Content Delivery

- Today: Content Delivery Networks (CDNs)
  - Mobile access network still overloaded
- D2D Content Delivery: Transmits content from one to another consumer device
- Direct radio transmission, no intermediate infrastructure
- Goals:
  - Reduce access-network infrastructure utilization
  - Increase Quality of Experience (assuming bandwidth-limited infrastructures)
D2D Content Delivery Scenario

▶ Effective specifically under certain circumstances
  ▶ Many people/devices around the user
  ▶ The content is popular
▶ D2D Content Delivery combined with consumption prediction
  ▶ Based on social information or past behavior
  ▶ Predicted content is pre-fetched whenever discovered in a crowd
▶ Example: Commuting by Train
  ▶ Content predicted to be watched is exchanged at the station/in the train
  ▶ Later consumed at work/at home
Overview

- Related Work
- Problem Statement
- Approach: Energy Efficiency
- Approach: Privacy
- Next Steps, Outlook
## Related Work

### Content Delivery Networks

<table>
<thead>
<tr>
<th>Method</th>
<th>Energy-aware</th>
<th>Privacy-aware</th>
<th>Multi-Hop Discovery and Delivery</th>
<th>Discovery Layer</th>
<th>Femtocell-based</th>
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<td>yes</td>
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<td>Licensed, e.g. LTE</td>
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<td>802.11 PHY</td>
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</table>

### Central-Server-based ...

- **Centralized Disc. (Operator-ctrl’d)**: Operator mediates D2D transfer on certain “hot spots”.
- **Licensed Spectrum**:
  - **Bao13DataSpotting**: Operator mediates D2D transfer, knows every D’s cont. and pos.
  - **Golrezaei13Femtocaching**: Operator mediates D2D transfer, knows every D’s cont. and pos.

### Device-to-Device Content Delivery

- **802.15.1 (Bluetooth)**: Focused on spectral efficiency.
- **802.11-based (WiFi)**: Focused on efficient communication, Study in Urban Transport.

- **Ad-Hoc/WiFi-Dir.-based discv.**
  - **Han-eDiscovery**: Adaptation of 802.11/802.15 windows, beacon intervals etc.
- **Custom MAC-based discv.**
  - **Our approach**: Theoretical, message-based.

### 802.11-based (WiFi)
Problem: Energy Loss and User Interest

Disclosure

▶ Alternatives: LTE, Bluetooth, ZigBee, WiFi
▶ Focusing on IEEE 802.11 (WiFi)
  ▶ Unlicensed, large hardware adoption and wide communication range
▶ Current IEEE 802.11 MAC layer designed for
  ▶ low-delay, reliable communication
  ▶ between devices previously known to each other (“connection”)
▶ 802.11 for content discovery on spontaneously connected devices:
  ▶ Variety of management frames (beacons, ATIMs)
  ▶ Unnecessarily frequent / continuous medium listening
▶ Consequence: High Energy Consumption
▶ Disclosure of user interest to all devices in range
▶ How to make a self-organizing D2D content delivery system energy-efficient and privacy-aware?
Energy-Aware Content Discovery

- Single-hop D2D:
  - Stability, Medium Availability
  - Lack of incentives for intermediate nodes

- Discovery Communication:
  - Broadcasting link-layer frames in proximity
  - Agreeing on physical parameters (channel, rate) at roll-out
  - **Without** previous device scanning, participating in distributed beaconing, handshaking.
Energy-Aware Content Discovery - Sleep Cycle Comparison

- IBSS Continuous Listen State
  - Beacon Frame
  - Content Request/Advertisement Broadcast

- IBSS Powersave
  - Announcement Traffic Indication Message (ATIM)

-> Not feasible in spontaneously connected groups: hidden node problem

- Custom MAC Content Discovery
  - -> Sleep Synchronization problem
Privacy-Aware Content Discovery

- Reveal the request only to devices having the key.
  - Salt-Hash Identifiers
  - Choose a new nonce at every new request.
  - Hash every clear-text identifier using the nonce as the salt.
  - Broadcast the hashed identifiers with the nonce.

- Anonymous Addressing
  - Randomly chose and frequently change addresses on wireless medium.
  - Revealing the identity requires signal strength measurements.
Summary, Next Steps

Self-organizing D2D Content Delivery can be designed more energy-conserving and privacy-aware.

Next steps:

▶ Studying Effectivity
  ▶ Identify the situation where a D2D content delivery is effective
▶ Develop user incentives for providing content
▶ Further development to a fully-fledged protocol (MAC/Network layer)
▶ Energy- and mobility-aware simulation
▶ Prototype implementation