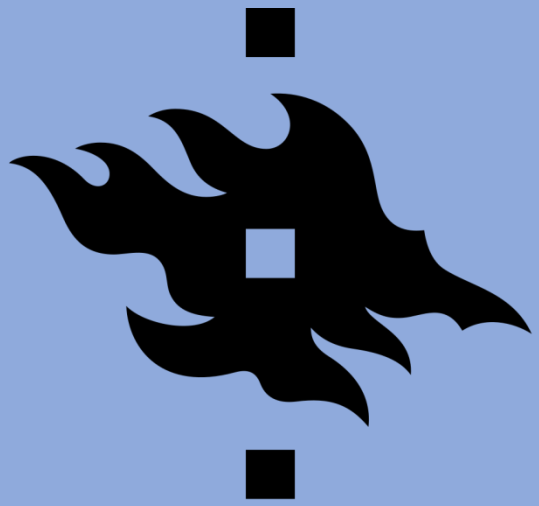

DISTRIBUTED SYSTEMS

Lecture 11 – Distributed Systems Research

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Helsinki, Finland, 2019.

Device-to-Device Paradigm

- **Device-to-Device** (D2D) communication enables **direct communication between nearby mobile devices** without the involvement of a BS or the evolved NodeB (radio transmission site)

- D2D communication has **always been present in the unlicensed spectrum**, but it was not investigated in the **licensed spectrum**

Jameel, Furqan, et al. "A survey of device-to-device communications: Research issues and challenges." *IEEE Communications Surveys & Tutorials* 20.3 (2018):

D2D Motivation / Use Cases

- Better reuse of available spectrum
- Lower transmission power (i.e., improved energy efficiency)
- Enhancing cell coverage and throughput at cell edge
- Provision of emergency services (in licensed spectrum) when cellular infrastructure is damaged
- Support local data services efficiently through unicast, groupcast, and broadcast mechanisms
  - Social proximity-based applications (e.g., Tinder, Waze, and Facebook)
  - Streaming applications (e.g., forming clusters and groupcasting within a cluster (Google Chromecast, IPTV))

Jameel, Furqan, et al. "A survey of device-to-device communications: Research issues and challenges." *IEEE Communications Surveys & Tutorials* 20.3 (2018):

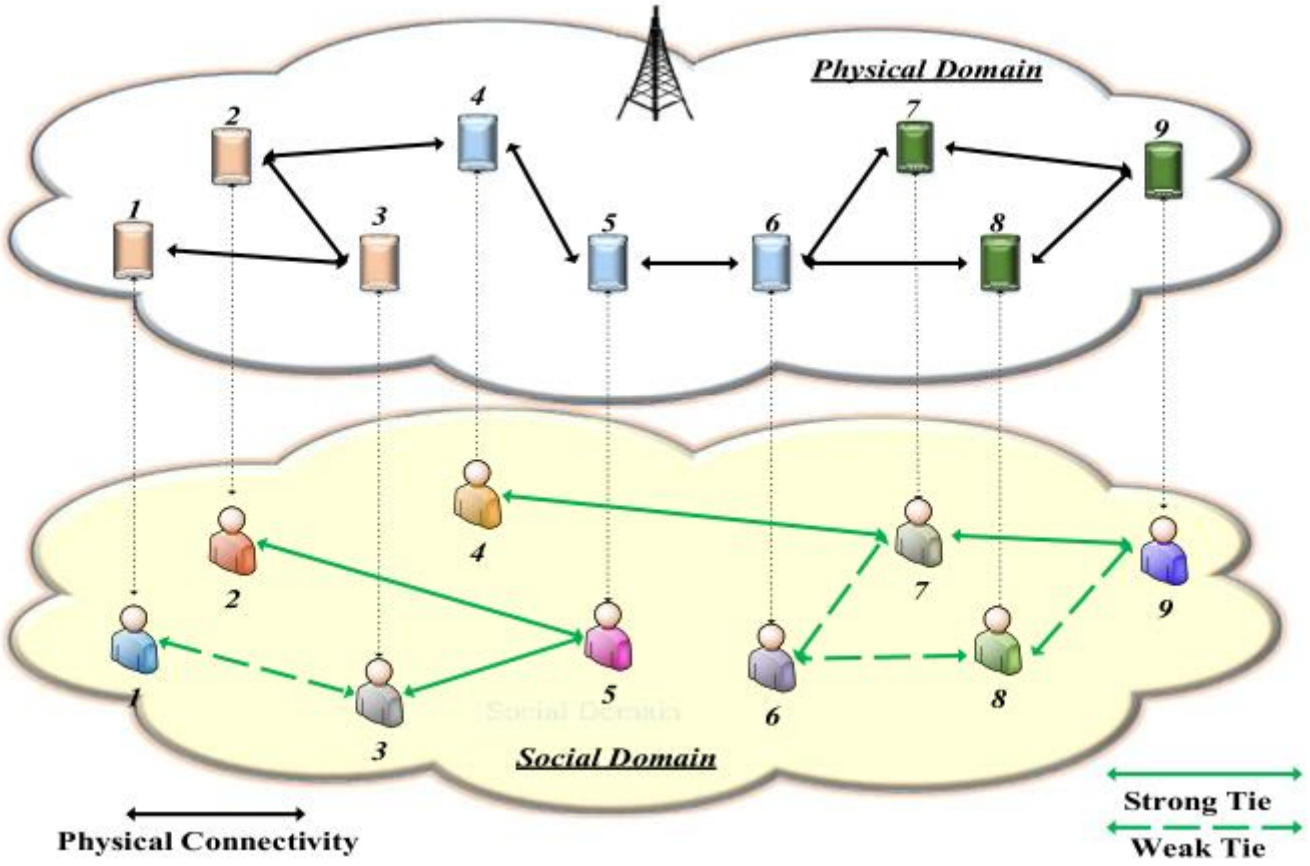
D2D Enabling Technologies

TABLE III: Overview of different D2D technologies.

Standard/ Technology	**Zigbee**	**BLE**	**Bluetooth 4.0**	**UWB**	**RFID**	**RuBee**	**ANT**	**Z-Wave**	**Insteon**
Coverage area	30 - 100 m	10 m	10 m	<10 m	100 m	30 m	Home area	30 m	Home area
Frequency band	ISM	2.4 GHz	2.4 GHz	3.1 - 10.6 GHz	860 - 960 MHz	131 KHz	2.4 GHz	900 MHz	902 - 924 MHz
Network topology	Mesh/Star	Star	Star	Star	Peer-to-peer	Peer-to-peer	Mesh/Star	Mesh	Mesh
Data rate	250 Kb/sec	1 Mb/sec	3 - 24 Mb/sec	480 Mb/sec	10 - 100 Kb/sec	9.6 Kb/sec	1 Mb/sec	9.6 Kb/sec	13 Kb/sec

Jameel, Furqan, et al. "A survey of device-to-device communications: Research issues and challenges." *IEEE Communications Surveys & Tutorials* 20.3 (2018):

Socially Aware D2D



Ahmed, Manzoor, et al. "A survey on socially aware device-to-device communications." *IEEE Communications Surveys & Tutorials* 20.3 (2018): 2169-2197.

Social D2D Research Areas

- Peer discovery
- Resource allocation and interference management
- Throughput optimization
- Energy efficiency

Ahmed, Manzoor, et al. "A survey on socially aware device-to-device communications." *IEEE Communications Surveys & Tutorials* 20.3 (2018): 2169-2197.

Peer Discovery

Technical Problems	Utilized Social features			
Employed Techniques	Ties	Trust	Community	Selfishness
Overlapping communities detection method in D2D network, from which beacon detection rates can be identified.	-	-	Y	-
Utilized beacon mechanism and leveraged social interaction information of community and centrality of cellular user.	-	-	Y	-
Joint social-position cooperation and partner selection algorithm based on available social and position information at mobile terminals.	-	Y	-	-
Cloud based social proximity tracing, which offloads computation, helps the UE trigger D2D pair discovery.	Y	-	-	-
Mobile cloud based client-server system, where audio data from D2D environment is used for proximity check in terms of grouping the devices by audio similarity.	-	Y	-	-
Device sociality concept based on social relationships among network devices. Most salient predicting variables includes SMS and emails for personal and organizational affinity.	Y	-	-	-
Peer discovery and match mechanism. Residual energy is leveraged for matching process.	-	-	Y	-
Admission policy using statistical information among D2D users, such as contact frequency and contact duration.	Y	-	-	-

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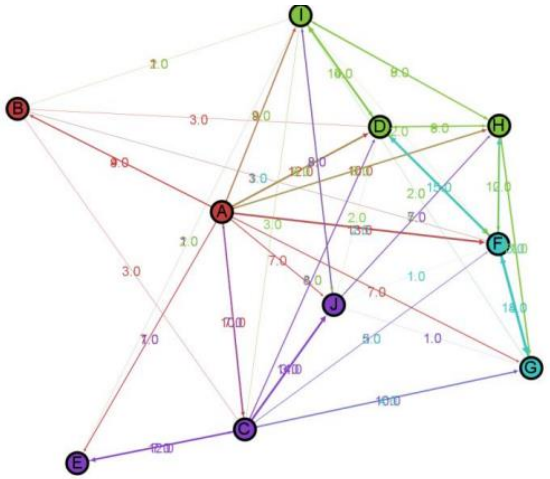
Device Social Affinity Model

- Estimate social affinity based on electronic communication statistics

- Apply graph theoretic methods to establish D2D links and create D2D communities based on the social affinity



$$\text{Social Affinit } y_{ij} = \alpha E_{ij} + \beta M_{ij} + \gamma c_{ij} + \varepsilon,$$

where

E is email interactions
M is instant message interactions
C is phone call interactions between i and j

Choi, Jang-Ho, et al. "Estimating social tie strength for autonomous D2D collaborations." *International Journal of Future Computer and Communication* 4.1 (2015): 7.

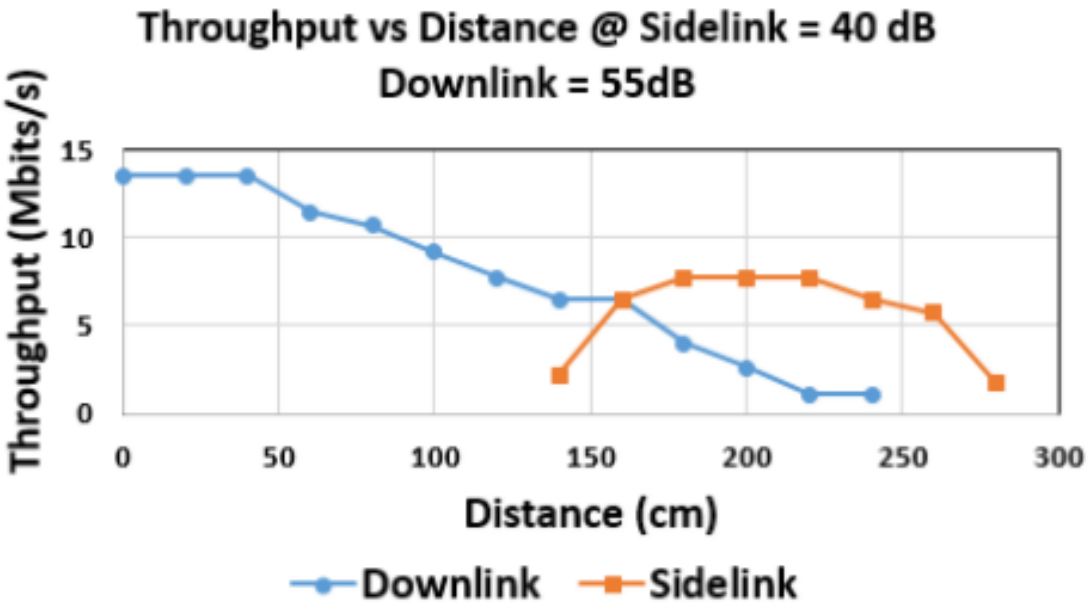
Resource allocation and interference

SGUM game model utilizing social-relationships. Strength of social-ties greatly impacts SGUM.	Y	-	-	-
Distributed algorithm based on SGUM game.	-	-	Y	-
Optimal social-community aware resource allocation algorithm leveraging the social-characteristics of community and centrality .	-	-	Y	-
Hierarchical bipartite-based pairing and clustering under the umbrella of graph matching theory are considered for resource allocation.	Y	-	-	-
For MISO cooperative communication, trust degree based beam forming is designed.	-	Y	-	-
Taking physical link condition and social-information of D2D users, system computational complexity is reduced.	Y	-	-	-
Cluster formation for the categorization of multiple D2D groups. Half-duplex scheme and a full-duplex scheme are used for channel sharing between the cellular links and the D2D links.	Y	-	-	-
Matching game for context-aware resource allocation problem is formulated, based on utility functions that captures both physical and social metrics.	Y	-	-	-
Evolutionary game based subcarrier and power is framed distributively, considering content, device and social domains.	Y	-	-	-
Game theory is employed to reduce interference and framed utility maximization problem utilizing social and physical distance.	Y	-	-	-
For interference management proximity based Poisson Point Process is leveraged to model the spatial distribution of BS and D2D users, while social interaction is modeled as Zipf based marks.	Y	-	-	-

Ahmed, Manzoor, et al. "A survey on socially aware device-to-device communications." *IEEE Communications Surveys & Tutorials* 20.3 (2018): 2169-2197.

D2D in 3GPP (e.g., LTE, 5G)

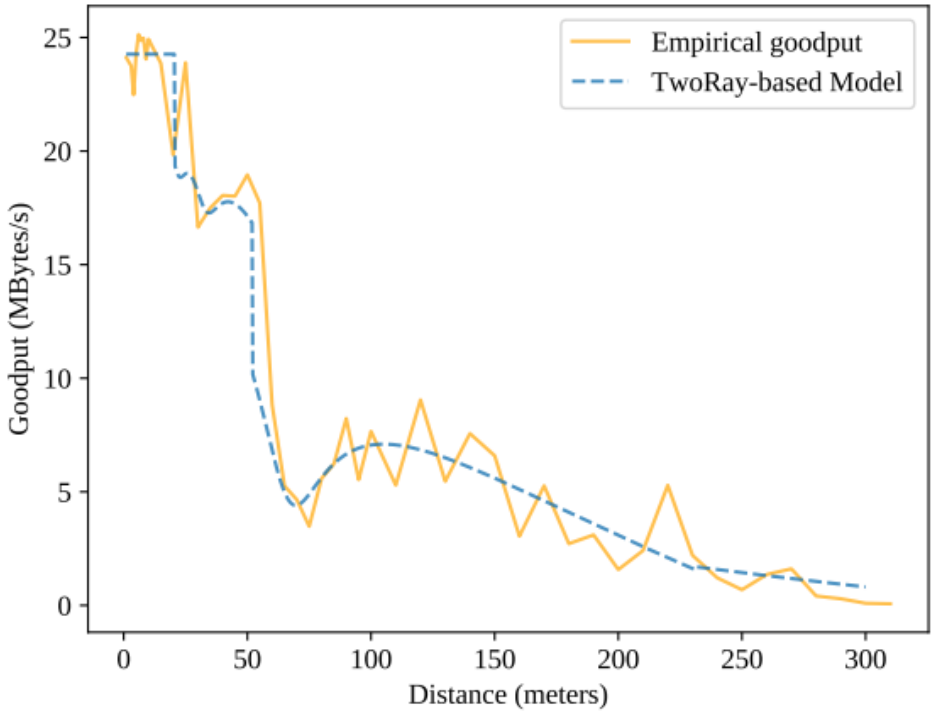
- D2D has also been standardized in 3GPP LTE release 12 and later expanded
- LTE D2D communication can act as a relay to improves performance in troublesome areas



Jain, Shekhar, Yi Zhang, and Luiz A. DaSilva. "LTE Standard-Compliant D2D Communication: Software-defined Radio Implementation and Evaluation." *arXiv preprint arXiv:1904.12934* (2019).

D2D in Android

- D2D is available in Android through an implementation of WiFi direct called Nearby
- Throughput can be modeled by two-ray ground reflection model

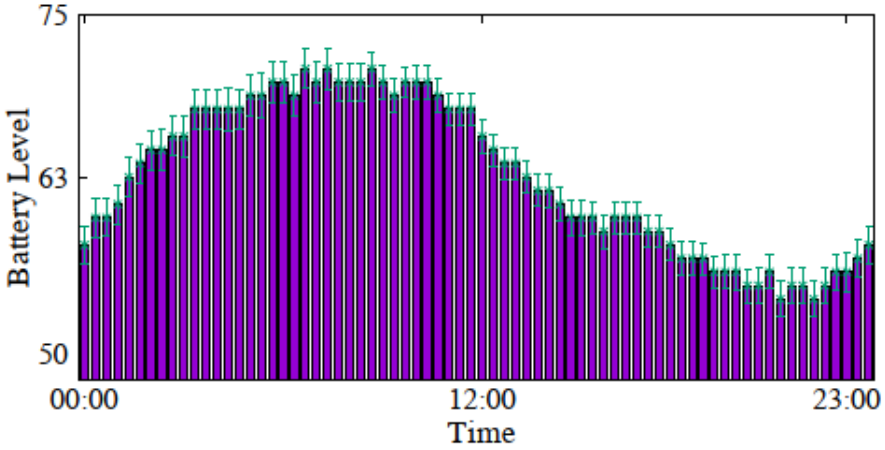


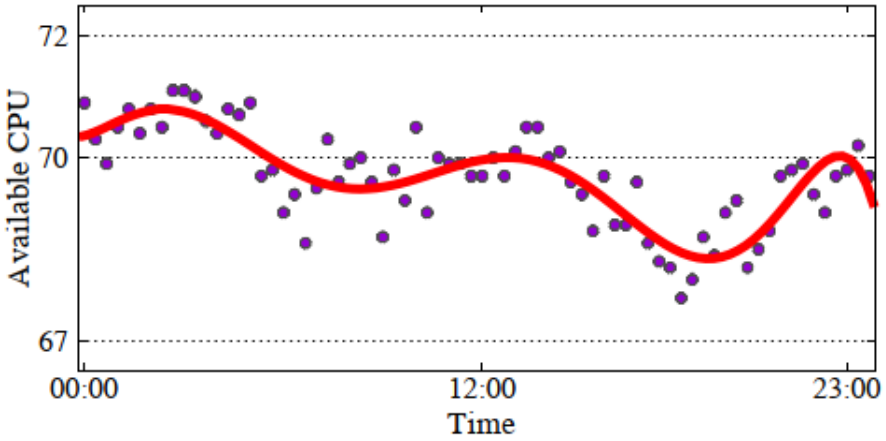
$$PL_{\text{tworay}}(d) = 20\log_{10}\left[4\pi\frac{d}{\lambda}\sqrt{(1+\Gamma_{\perp}\cos\varphi)^2+\Gamma_{\perp}^2\sin^2\varphi}^{-1}\right]$$

Bertier, Clément, et al. "Modeling Realistic Bit Rates of D2D Communications between Android Devices." *Proceedings of the 22nd International ACM Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*. ACM, 2019.

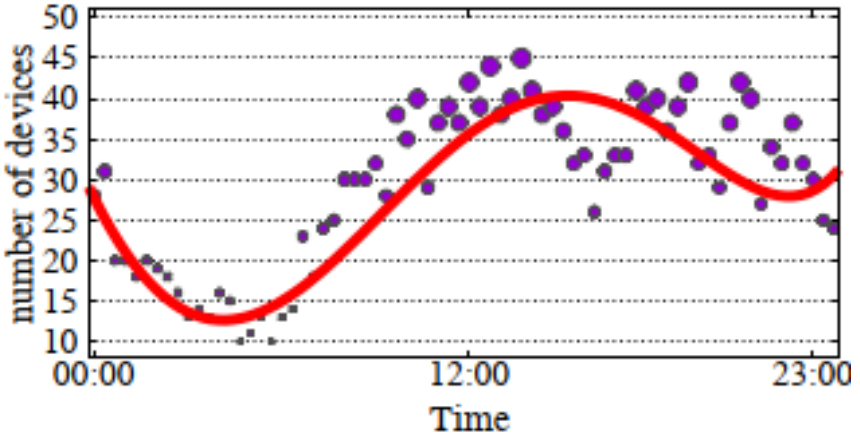
D2D Task Offloading Potential

- Could a neighbor be helpful? Yes, CPU and Battery available





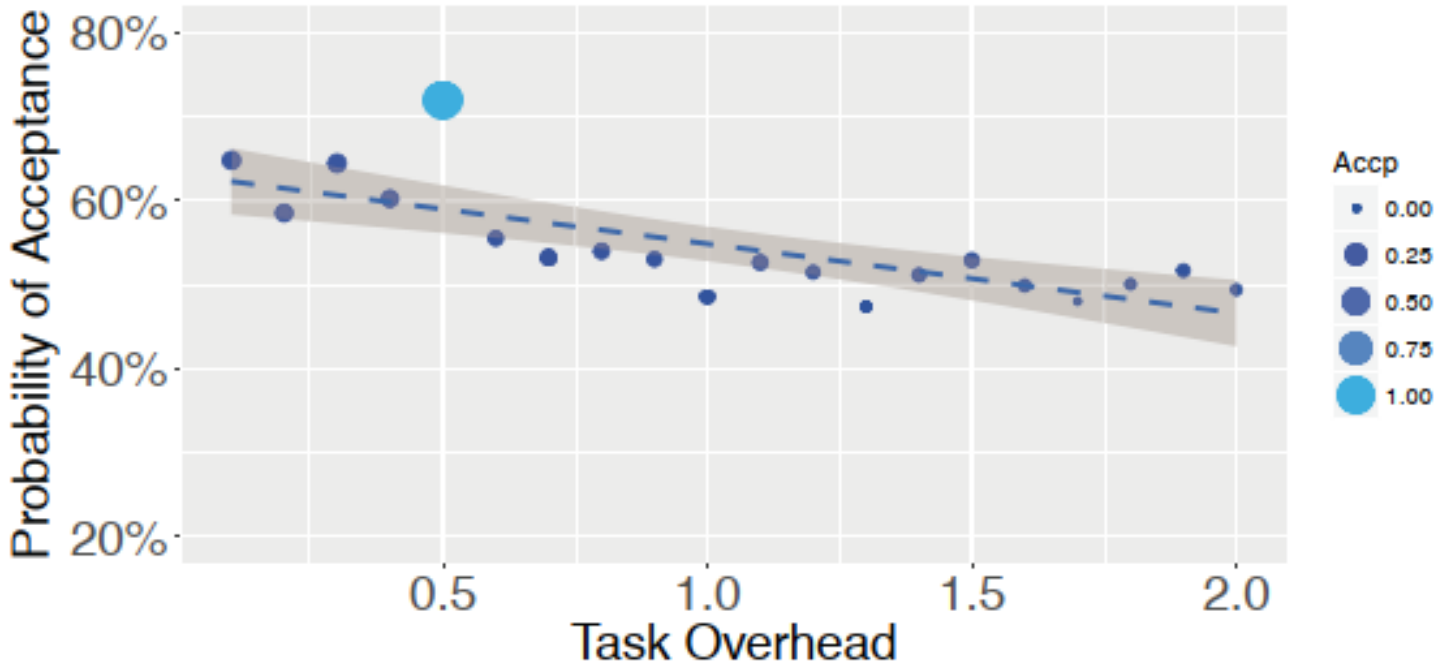
- How could a neighbor help?
  - Bluetooth, WiFi direct, etc. readily available



Chatzopoulos, Dimitris, et al. "D2D Task Offloading: A Dataset-Based Q&A." *IEEE Communications Magazine* 57.2 (2018): 102-107.

D2D Task Offloading Potential

- Would a neighbor help (even assuming some battery drain)? Yes, if drain is low (e.g., <2%)



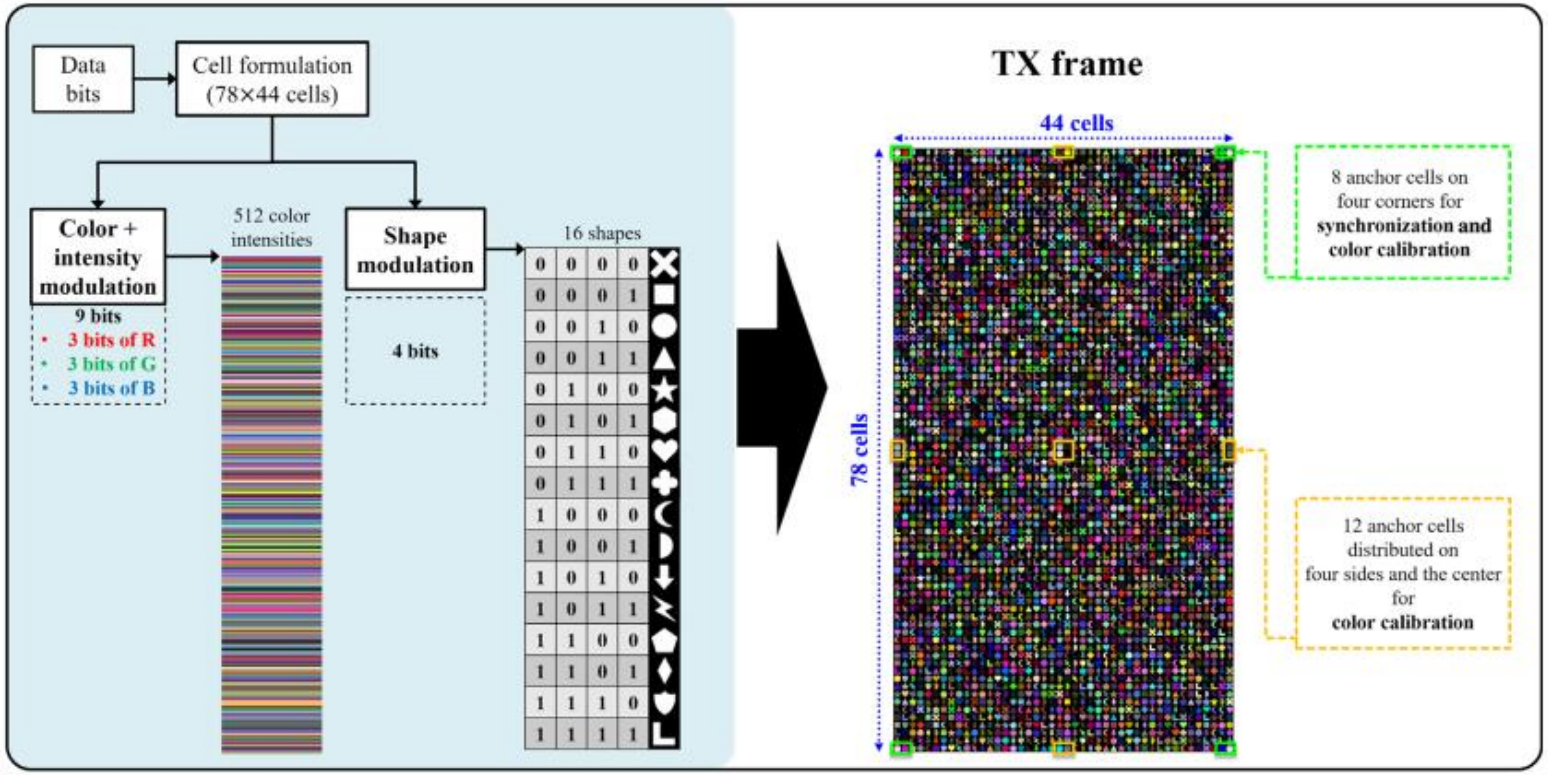
Chatzopoulos, Dimitris, et al. "D2D Task Offloading: A Dataset-Based Q&A." *IEEE Communications Magazine* 57.2 (2018): 102-107.

D2D Task Offloading Potential

- Can the safety of task offloading be ensured? Yes, using public key encryption and homomorphic encryption
- Public key useful to verify identity of parties
- Homomorphic encryption allows computation to be performed directly on encrypted data without requiring access to secret key
  - Uses RLWE (ring learning with errors, believed to be quantum resistant) rather than integer factorization as basis
  - RLWE potentially reducible to NP-hard shortest vector problem

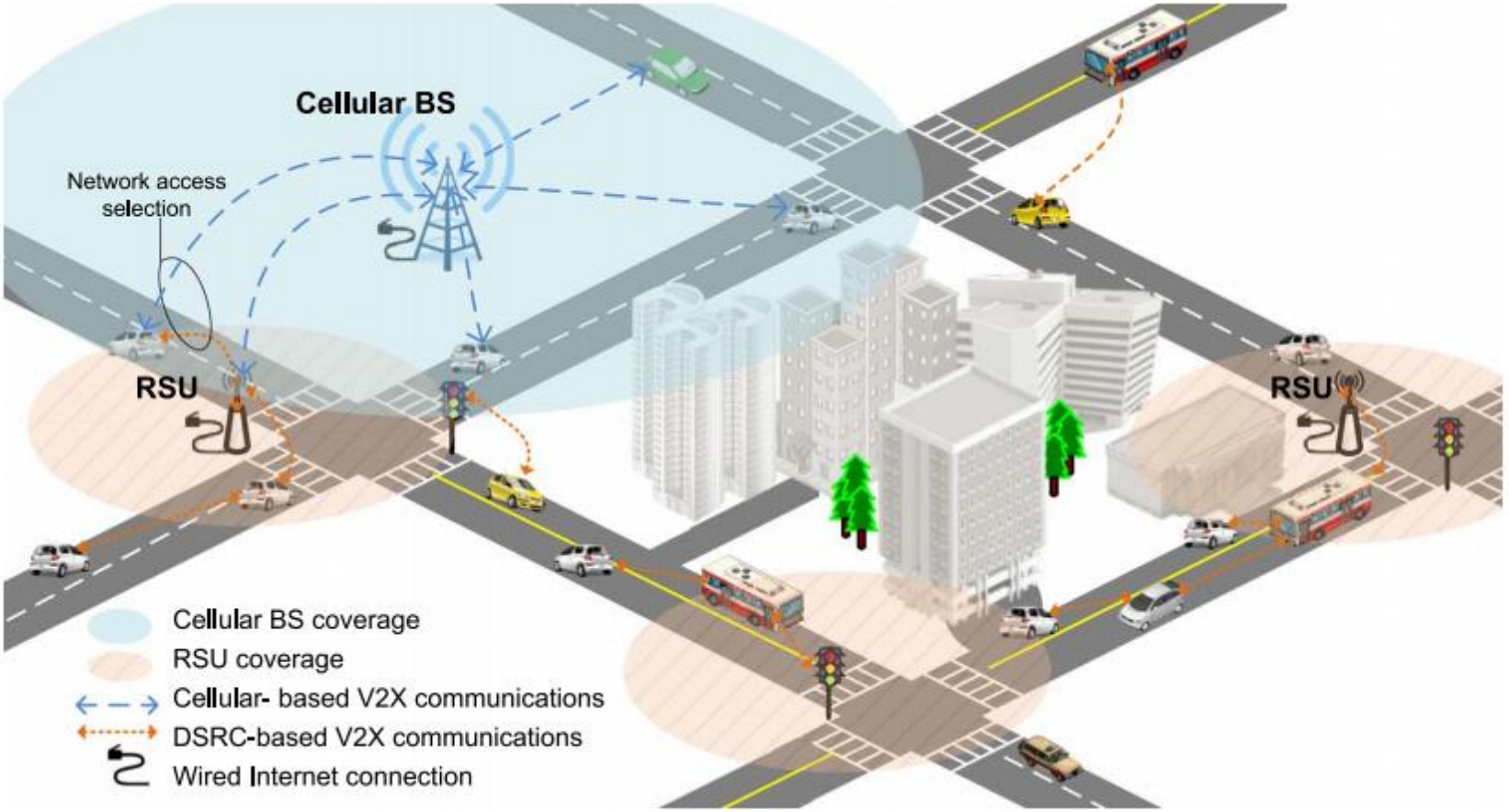
Novel D2D Communications

- Visible light communication (2.66 Mbps at 20 cm)



Griffiths, Alexander D., et al. "Scalable visible light communications with a micro-LED array projector and high-speed smartphone camera." *Optics express* 27.11 (2019): 15585-15594.

Vehicle2Vehicle Communications



D2D Research

- D2D currently only in use for very basic use cases
- Active research in many areas including novel use cases and transmission methods in licensed and unlicensed spectrum
- Research in University of Helsinki (e.g., Prof. Pan Hui and Prof. Sasu Tarkoma) in several D2D areas
  - Computational offloading via D2D
  - Social D2D