

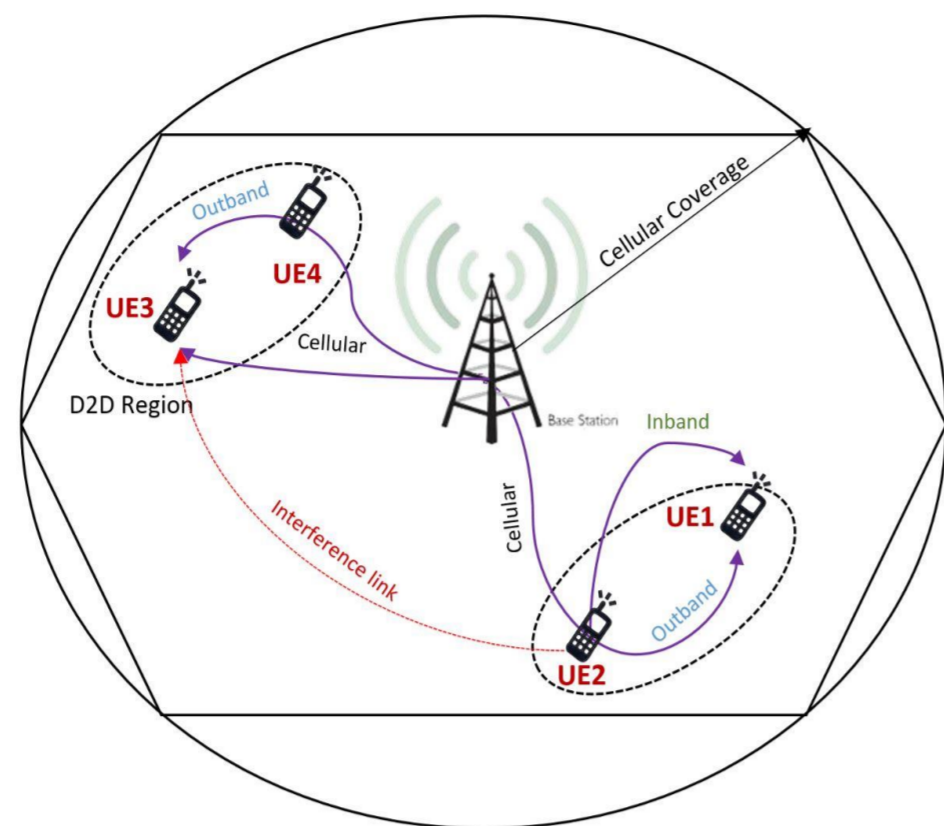
Multi-Path D2D Leads to Satisfaction

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Introduction

- **Multi-Path D2D:**
Optimisation framework to schedule D2D and cellular links under flow demands.



- D2D technologies:



- Fair scheduler driven by a **Satisfaction metric.**

Multi-Path D2D (MPD2D)

- MPD2D couples D2D connection modes:
 - Inband Underlay.
 - Inband Overlay.
 - Outband.
- Splits flow demands over **multi-paths.**
- Lightweight metric in order to raise satisfaction over time.
- **Goals:**
 - Maximise aggregate cell **throughput.**
 - Minimise **energy consumption.**
 - Increase **satisfaction fairness** over time.
 - Serve all flows.
- **Challenges:**
 - Computational complexity
 - Interference management

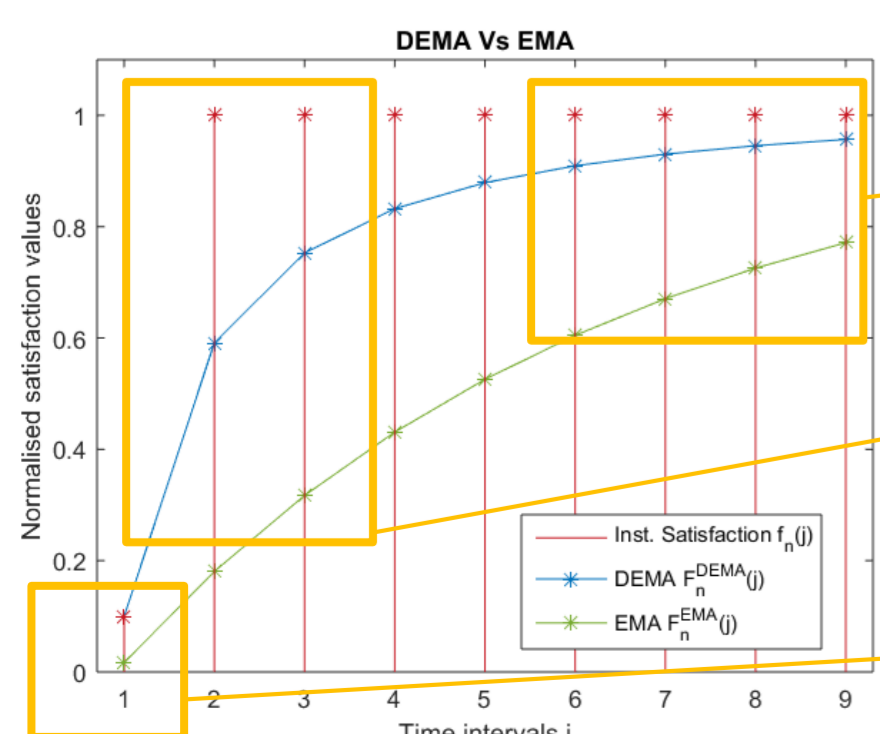
Dynamic Exponential Moving Average (DEMA)

- We introduce satisfaction indicators to measure how UEs exploit the network over time.
- $f_n(j)$ is the instantaneous satisfaction of node n in time interval j .
- $F_n(j)$ is the accumulated satisfaction of node n until time interval j .

$$F_n(j+1) = \xi(j)F_n(j) + (1 - \xi(j))f_n(j) \quad \forall j \geq 1$$

$$\xi(j) := \frac{\mu^{j-1} - 1}{\mu^j - 1} \quad \mu > 1$$

- **DEMA gets adapted to the length of the system history through dynamic weights and reacts very quickly to changes** compared to EMA:



Approaches proper values faster.

Quickly reacts to big change.

No mistake in first value.

Optimisation framework

- We maximise a network utility function $U_n(j)$ based on throughput, energy and satisfaction.
- For satisfaction metric, $f_n(j) = U_n(j)$.
- **MILP** formulation:

$$\max z(j) = \sum_{n \in \mathcal{N}(j)} U_n(j) / F_n(j)$$

- **Technology constraints:** UEs set directed links with only one node in same interface.
- **Interference constraints:** SINR cannot decay more than a threshold.
- **Flow constraints:** All flows must be served over multi-paths.

- NP-hardness \longrightarrow We propose **DIMM** and **DEMM** as heuristics.

Heuristics & Results

Algorithm 1 DIMM: D2D Intensive Multimode Multi-path

Input: $\mathcal{N}, \mathcal{L}, \mathcal{F}$: Sets of users, links and flows.

$\{I_{n,m}^i\}, \{\gamma_{n,m}^i\}$: interference parameters.

Output: $\mathbf{Y} = \{Y_{n,m}^i\}$: Set of decision variables.

Initialize: $Y_{s,e}^0 = Y_{e,d}^0 = 1 \quad \forall (s,e), (e,d) \in \mathcal{F}$

for $(s,d) \in \mathcal{F} \mid s,d \in \mathcal{N}$ do

$Y_{s,e}^0 = Y_{e,d}^0 = 1$

if $Y_{s,u}^3 = Y_{u,d}^3 = 0 \quad \forall u \in \mathcal{N}$ then

$Y_{s,d}^3 = 1$

$\mathbf{Y}^2 = \mathbf{Y}; \max z = z = U_{net}(\mathbf{Y})$.

while $\mathbf{Y}_{old} \neq \mathbf{Y}$ do $\mathbf{Y}_{old} = \mathbf{Y}$

for $(n,m) \in \mathcal{L}^{D2D}$ do

for $i \in \{1,2\}$ do

$Y_{n,m}^{i,?} = 1; Y_{n,m}^{k,?} = 0 \quad \forall k \in \{1,2\} - \{i\}$

$Y_{n,u}^{k,?} = Y_{u,m}^{k,?} = 0 \quad \forall u \neq n, m; \forall 0 \leq k \leq 2$

$z = U_{net}(\mathbf{Y}^2)$

if $z > \max$ & SINR and Flows satisfied then

$\mathbf{Y} = \mathbf{Y}^2; \max z = z$

else

$\mathbf{Y}^2 = \mathbf{Y}$

for $i=3$ do

$Y_{n,m}^{3,?} = 1; Y_{n,u}^{3,?} = Y_{u,m}^{3,?} = 0 \quad \forall u \neq n, m$

$z = U_{net}(\mathbf{Y}^2)$

if $z > \max$ & Flows satisfied then

$\mathbf{Y} = \mathbf{Y}^2; \max z = z$

else

$\mathbf{Y}^2 = \mathbf{Y}$

Algorithm 2 DEMM: D2D Expeditious Multimode Multi-path

Input: $\mathcal{N}, \mathcal{L}, \mathcal{F}$: Sets of users, links and flows.

$\{I_{n,m}^i\}, \{\gamma_{n,m}^i\}$: interference parameters. $\rho \in [0, 1]$.

Output: $\mathbf{Y} = \{Y_{n,m}^i\}$: Set of decision variables.

for $(n,t) \in \mathcal{N} \times \mathcal{N} \mid I_{t,e}^1 > \rho \cdot \gamma_{n,e}^0$ do $\theta_{t,r}^1 = 0, \forall r \in \mathcal{N}$

for $(n,m) \in \mathcal{L}^{D2D}$ do

for $x \in \mathcal{N} - \{n\} \mid I_{x,m}^0 > \rho \cdot \gamma_{n,m}^1$ do $\theta_{n,m}^1 = 0$

if $\theta_{n,m}^1 > 0$ then

for $x \in \mathcal{N} - \{n\} \mid I_{x,m}^1 > \rho \cdot \gamma_{n,m}^1$ do

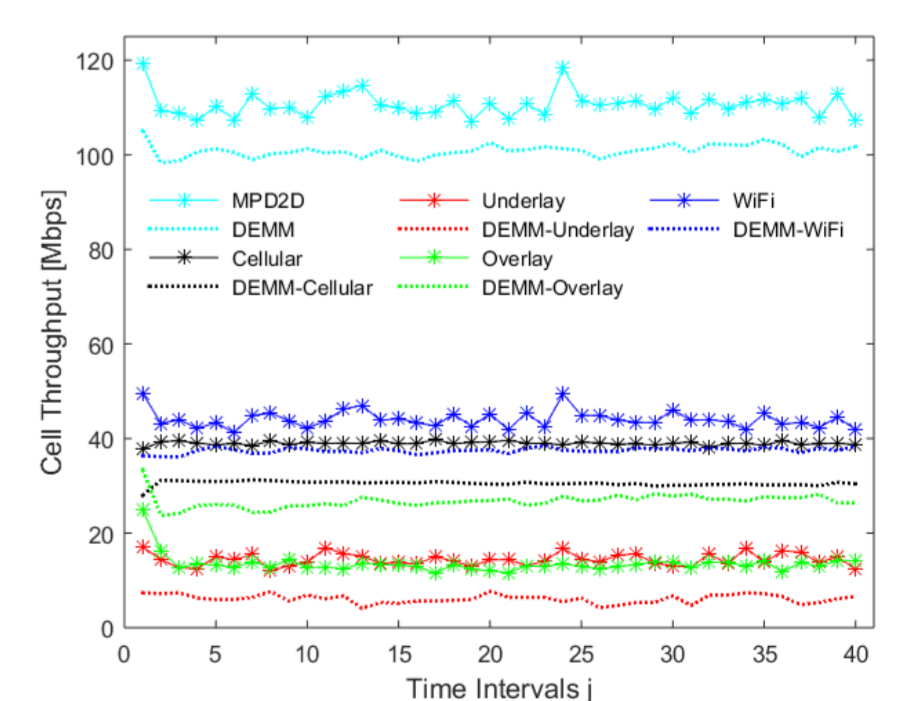
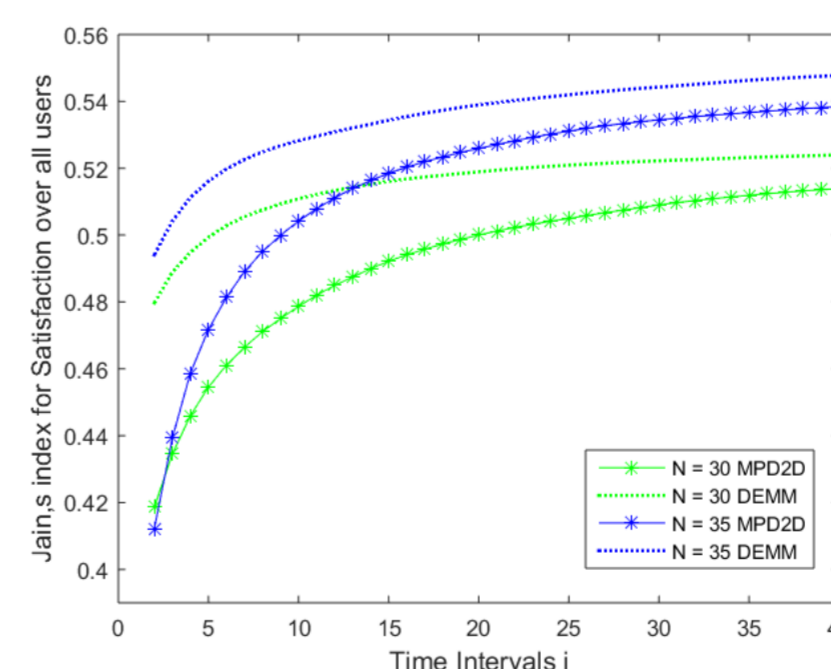
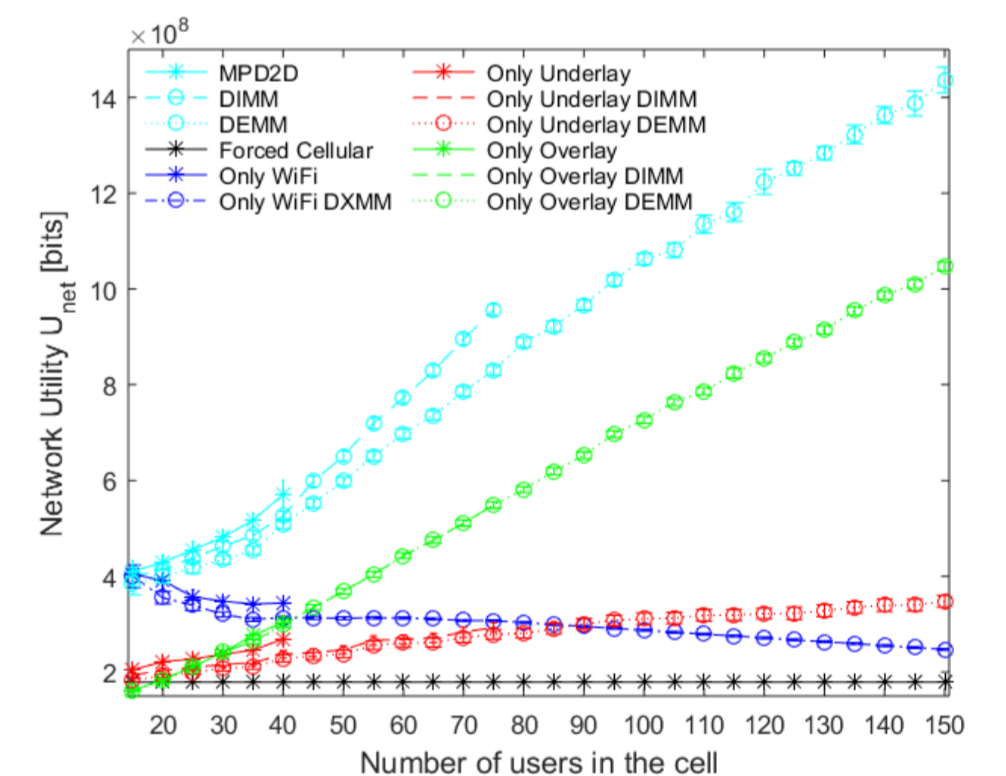
$\theta_{x,r}^1 = 0, \forall r \in \mathcal{N}$

for $(n,m) \in \mathcal{L}^{D2D}$ do

for $x \in \mathcal{N} - \{n\} \mid I_{x,m}^2 > \rho \cdot \gamma_{n,m}^2$ do

$\theta_{x,r}^2 = 0, \forall r \in \mathcal{N}$

Do DIMM without SINR checking.



- We achieve high gain compared to state of the art schemes.
- High increase of satisfaction over time.
- DEMA remains stable throughout allocation.

References

- [1] Asadi, A., Wang, Q., & Mancuso, V. (2014). A survey on device-to-device communication in cellular networks. *IEEE Communications Surveys & Tutorials*, 16(4), 1801-1819.
- [2] Asadi, A., Mancuso, V., & Jacko, P. (2015). Floating band D2D: Exploring and exploiting the potentials of adaptive D2D-enabled networks. In *IEEE WoWMoM, 2015* (pp. 1-9).