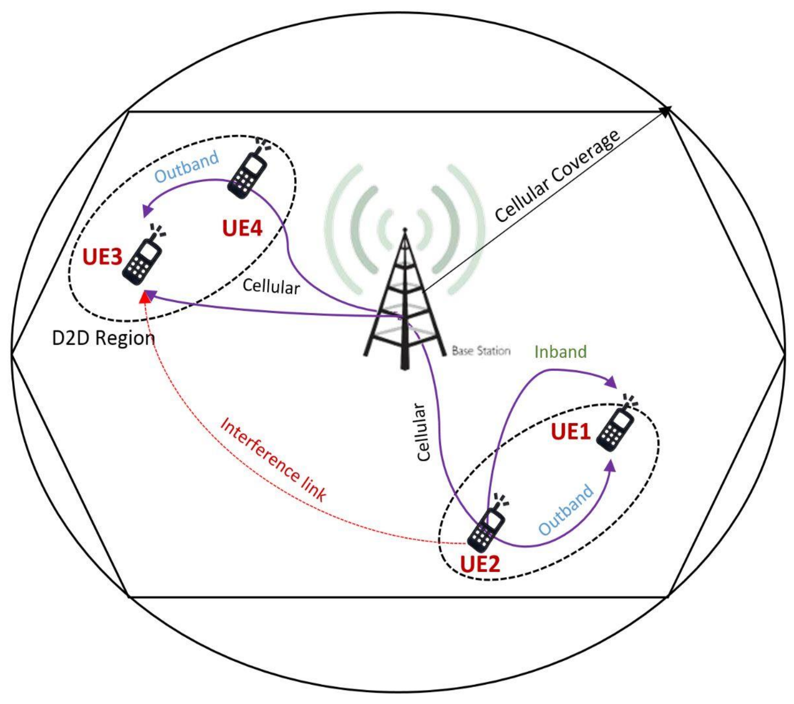
Multi-Path D2D Leads to Satisfaction

Edgar Arribas[1,2], Vincenzo Mancuso[1]
[1]IMDEA Networks Institute, [2]University Carlos III of Madrid

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

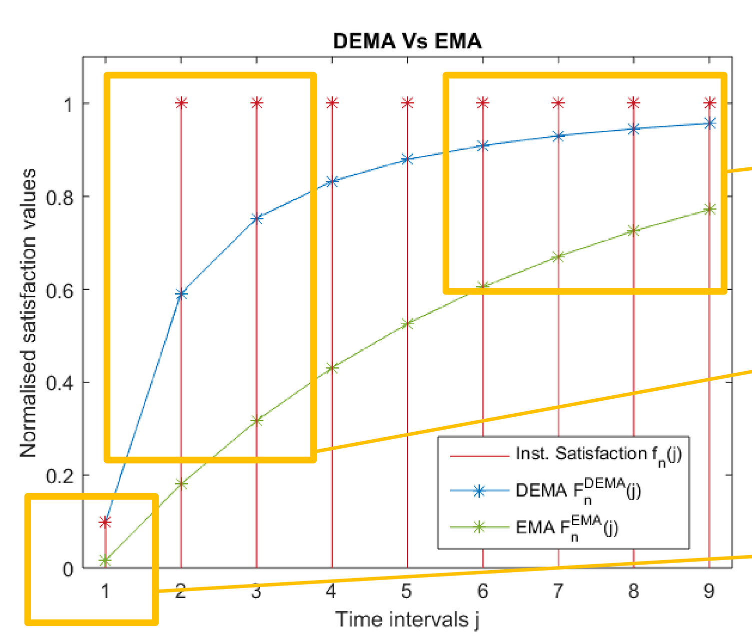
Dynamic Exponential Moving Average (DEMA)

- 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.

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

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

- 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 inteface.
- **Interference** constraints: SINR cannot decay more than a threshold.
- **Flow** constraints: All flows must be served over multi-paths.

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

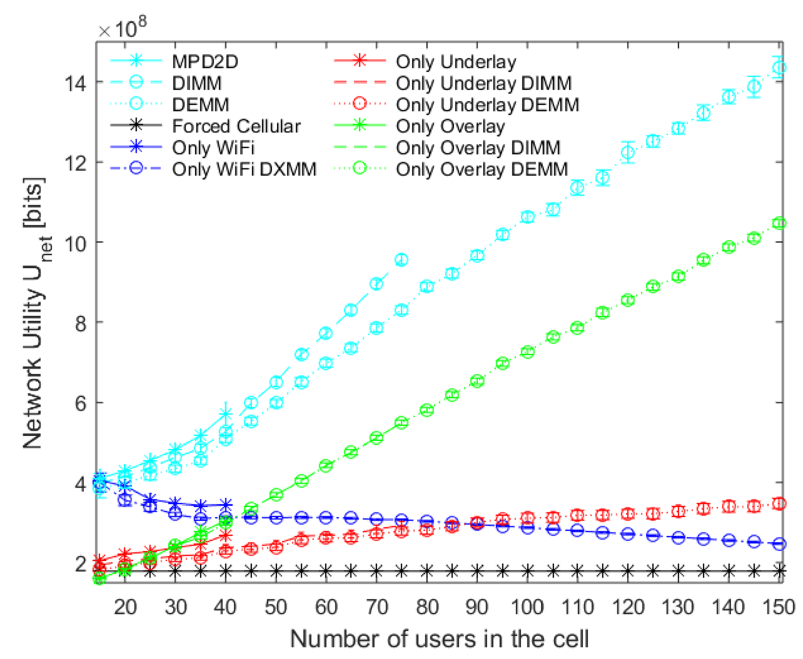
Heuristics & Results

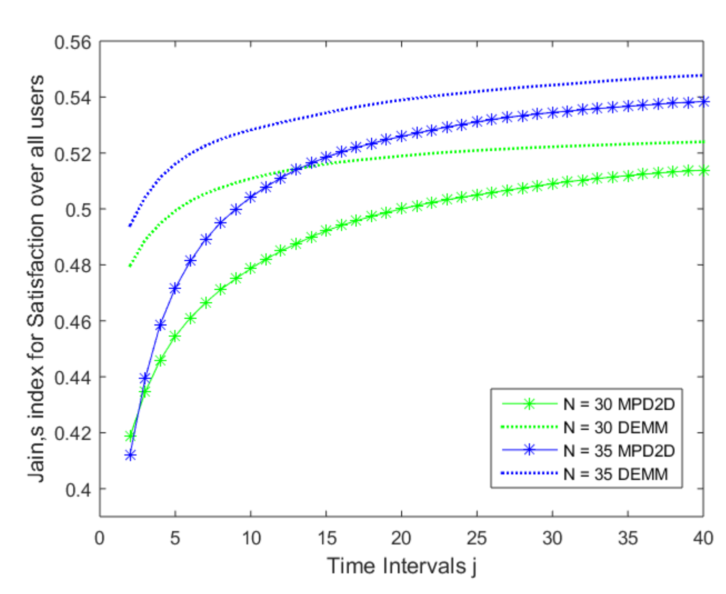
Algorithm 1 DIMM: D2D Instensive Multimode Multi-path

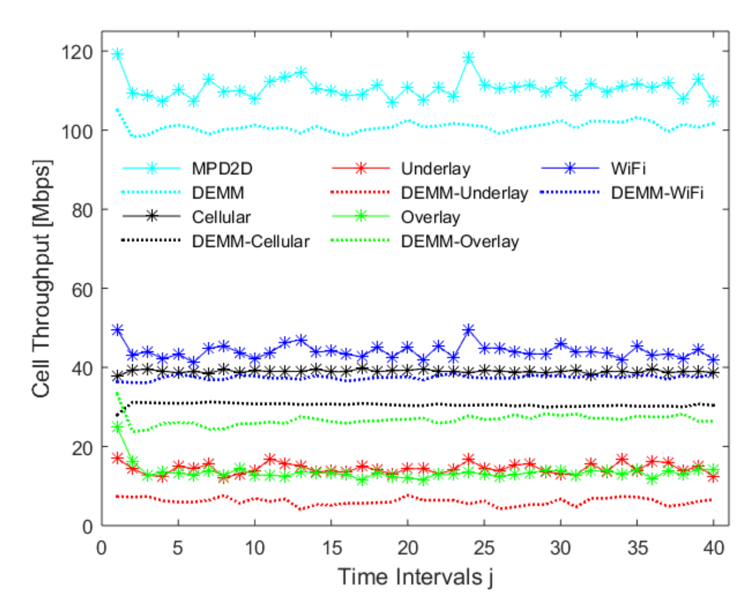
```
Input: 𝒩, ℒ, ℱ: Sets of users, links and flows.
{I^i_{n,m}}, {γ^i_{n,m}}: interference parameters.
Output: Y = {Y^i_{n,m}}: Set of decision variables.
Initialize: Y^0_{s,e} = Y^0_{e,d} = 1 ∀ (s,e),(e,d) ∈ ℱ
for (s,d) ∈ ℱ | s,d ∈ 𝒩 do
    Y^0_{s,e} = Y^0_{e,d} = 1
    if Y^3_{s,u} = Y^3_{u,d} = 0 ∀ u ∈ 𝒩 then
        Y^3_{s,d} = 1
Y^? = Y; max = z = U_net(Y).
while Y_old ≠ Y do  Y_old = Y
    for (n,m) ∈ ℒ^{D2D} do
        for i ∈ {1,2} do
            Y^{i,?}_{n,m} = 1;  Y^{k,?}_{n,m} = 0 ∀ k ∈ {1,2} − {i}
            Y^{k,?}_{n,u} = Y^{k,?}_{u,m} = 0 ∀ u ≠ n,m; ∀ 0 ≤ k ≤ 2
            z = U_net(Y^?)
            if z > max & SINR and Flows satisfied then
                Y = Y^?; max = z
            else
                Y^? = Y
            for i=3 do
                Y^{3,?}_{n,m} = 1; Y^{3,?}_{n,u} = Y^{3,?}_{u,m} = 0 ∀ u ≠ n,m
                z = U_net(Y^?)
                if z > max & Flows satisfied then
                    Y = Y^?; max = z
                else
                    Y^? = Y
```

Algorithm 2 DEMM: D2D Expeditious Multimode Multi-path

```
Input: 𝒩, ℒ, ℱ: Sets of users, links and flows.
{I^i_{n,m}}, {γ^i_{n,m}}: interference parameters. ρ ∈]0,1[.
Output: Y = {Y^i_{n,m}}: Set of decision variables.
for (n,t) ∈ 𝒩×𝒩 | I^1_{t,e} > ρ·γ^0_{n,e} do  θ^1_{t,r} = 0, ∀ r ∈ 𝒩
for (n,m) ∈ ℒ^{D2D} do
    for x ∈ 𝒩 − {n} | I^0_{x,m} > ρ·γ^1_{n,m} do   θ^1_{n,m} = 0
    if θ^1_{n,m} > 0 then
        for x ∈ 𝒩 − {n} | I^1_{x,m} > ρ·γ^1_{n,m} do
            θ^1_{x,r} = 0, ∀ r ∈ 𝒩
for (n,m) ∈ ℒ^{D2D} do
    for x ∈ 𝒩 − {n} | I^2_{x,m} > ρ·γ^2_{n,m} do
        θ^2_{x,r} = 0, ∀ r ∈ 𝒩
Do DIMM withouth SINR checking.
```







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