Universidad Carlos III de Madrid

5GEN: A tool to generate 5G infrastructure graphs

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A **R** package[1] to generate 5G network infrastructure graphs.

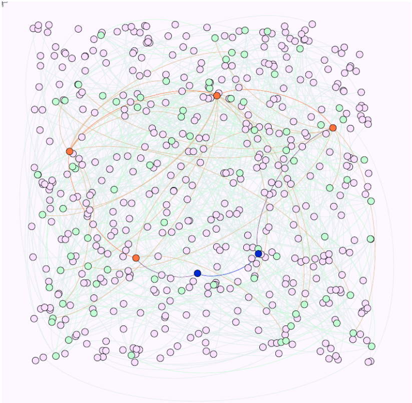

Figure 1: A graph generated by 5GEN.

[1] https://github.com/MartinPJorge/mec-generator/tree/5g-infra-gen

The network infrastructure **up to the core**.

- Active Antenna Units (AAUs);
- M1, M2 and M3 switches;
- Servers; and
- Fog nodes

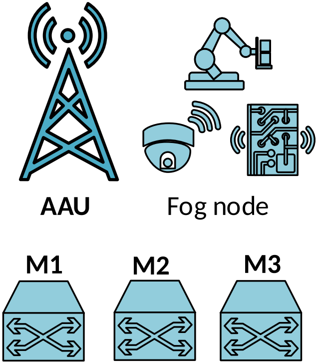

Figure 2: Some 5GEN graph components

To validate solutions for the Virtual Network Embedding (VNE) problem:

> "The problem of embedding virtual networks in a substrate network" ([1])

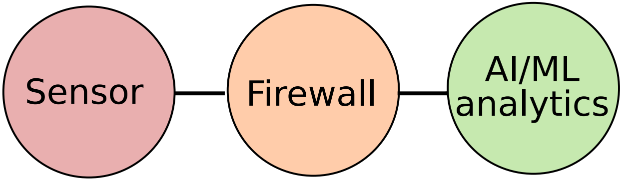

Figure 3: VNE example

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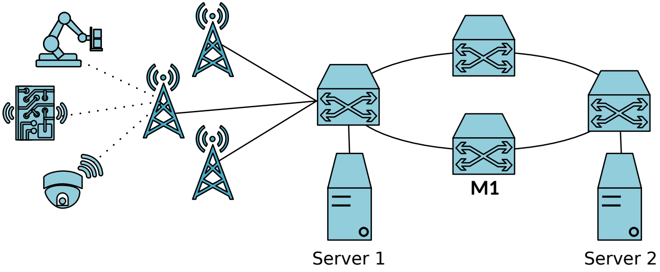

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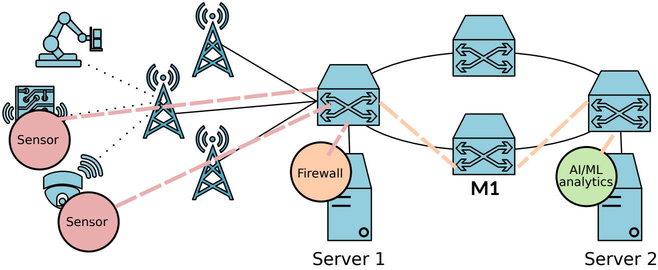

Figure 3: VNE example

Open questions:

- AAUs per switch?;
- Switches per "level"?;
- Interconnections; and
  - Hierarchical;
  - Ring; and
  - Redundancy;
- Traffic rates;

Use analysis in [2], based on ITU-T study group analysis [3]

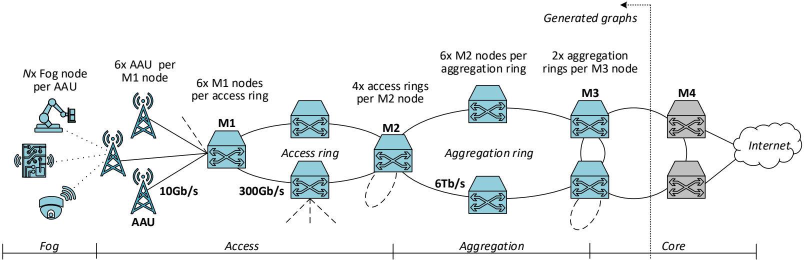

Figure 4: 5GEN reference topologies

1. Specify AAUs' locations;
2. Calculate required M1 switches and access rings;
3. Calculate required M2 switches and aggregation rings;
4. Derive how many M3 switches; and
5. Attach user-defined elements:
    - Fog devices;
    - Servers & where (M1, M2, M3);

5GEN assumes a set of AAUs distributed across an area, e.g., Granada.

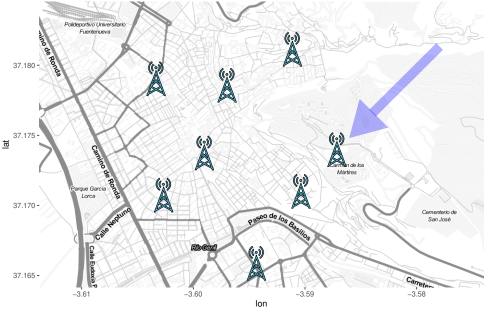

Figure 5: Location of an AAU in Granada

```
granadaCells[1,]$lat; granadaCells[1,]$lon
[1] 37.1716524
[2] -3.5932497
```

CSV with AAUs locations at `https://github.com/MartinPJorge/cscn19/granada-cells.csv`

- 12 AAUs/km^2
- 10m repulsion radius

$$\mathbb{E}\left[N(C)\right] := \int_C e^{-\int_{B(x,r)} \mathbb{1}(\lambda(u)>\lambda(x))\lambda(u)du}\lambda(x)\ dx \qquad (1)$$

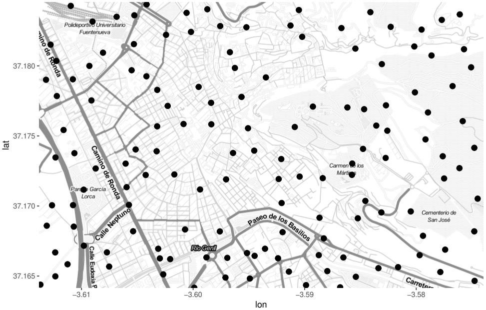

Figure 6: AAUs generated with a Matérn II PPP [4]

5GEN algorithm

Data: AAUs
Result: access and aggregation graph
levels = [AAUs, access, aggregation];
distances = [10km, 20km, 40km];
foreach *(l, d) in (levels, distance)* **do**

$$N = \begin{cases} AAUs, & \text{if } l = \text{AAUs} \\ M1, & \text{if } l = access \\ M2, & \text{if } l = aggregation \end{cases}$$

  H = hierarchical_clustering(N);
  C = cut_dendrogram(H, d);
  $R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor}$;
  if $l = AAUs$ **then**
    for $R_j \in R$ **do**
      $\mathrm{M1}_n = \min_{\mathrm{M1}} \sum_{r \in R_j} \text{Vicenty}(\mathrm{M1}, r)$;
      $\text{connect}(r, \mathrm{M1}_n),\ \forall r \in R_j$;
    end
  else
    $\text{connect}(r_i, r_{i+1 \mod 6}),\ \forall r_i \in R_j,\ \forall R_j \in R$;
    $g = 4$ if $l = \mathrm{M1}$ else 2;
    $G = \left\{ \{R_{i+gj}\}_{i=0}^{\min\{R-1-gj, g-1\}} \right\}_{j=0}^{\lfloor R/g \rfloor}$;
    for $G_i \in G$ **do**
      upper=M2 if l =M1 else M3;
      $\text{connect}'(R, \text{upper}),\ \forall R \in G_i$;
    end
  end
end

Algorithm 1: build5GScenario

It executes clustering to:

- Group AAUs;
- Create the access ring; and
- Create aggregation ring.

R package **mecgen** performs everything underneath inside function **build5GScenario**.

AAUs assignment to M1s

uc3m

H = hierarchical_clustering(N);

C = cut_dendrogram(H, d);

$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor}$;

for $R_j \in R$ **do**

  $\mathrm{M1}_n = \min_{\mathrm{M1}} \sum_{r \in R_j} \mathrm{Vicenty}\left(\mathrm{M1}, r\right)$;

  $\mathrm{connect}\left(r, \mathrm{M1}_n\right), \ \forall r \in R_j$;

end

$H = \text{hierarchical\_clustering}(N)$;
$C = \text{cut\_dendrogram}(H, d)$;
$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor}$;
for $R_j \in R$ **do**
  $\text{M1}_n = \min_{\text{M1}} \sum_{r \in R_j} \text{Vicenty}\left(\text{M1}, r\right)$;
  $\text{connect}\left(r, \text{M1}_n\right), \ \forall r \in R_j$;
end

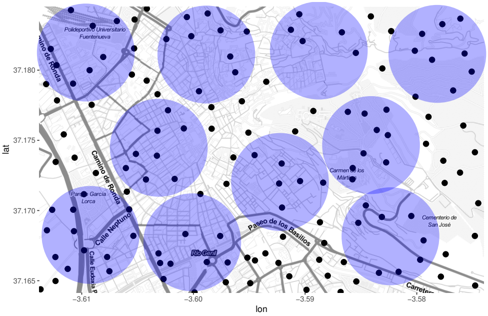

Figure 7: AAUs clustering representation[2]

[1]6 AAUs per cluster, none of them left out

AAUs assignment to M1s

H = hierarchical_clustering(N);
C = cut_dendrogram(H, d);
$R =$

$$\cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor};$$

for $R_j \in R$ **do**
  $\mathrm{M1}_n = \min_{\mathrm{M1}} \sum_{r \in R_j} \mathrm{Vicenty}(\mathrm{M1}, r)$;
  $\mathrm{connect}(r, \mathrm{M1}_n),\ \forall r \in R_j$;
end

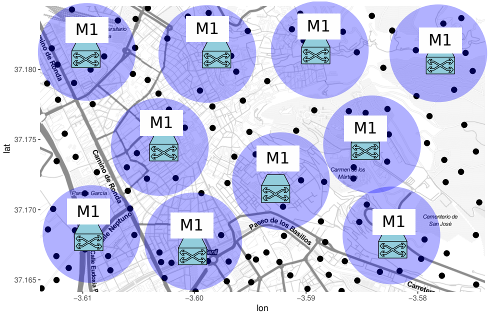

Figure 7: AAUs clustering representation[2]

[1] 6 AAUs per cluster, none of them left out

Creating the access ring

$$H = \text{hierarchical\_clustering}(N);$$

$$C = \text{cut\_dendrogram}(H,\ d);$$

$$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor};$$

$$\text{connect}\left(r_i, r_{i+1 \mod 6}\right),\ \forall r_i \in R_j,\ \forall R_j \in R;$$

Creating the access ring

$H = \text{hierarchical\_clustering}(N);$

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$\text{connect}(r_i, r_{i+1 \mod 6}),\ \forall r_i \in R_j,\ \forall R_j \in R;$

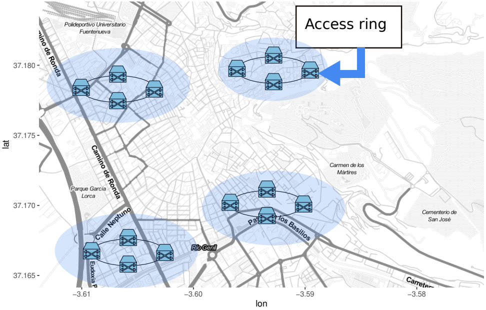

Figure 8: Access rings representation

Assignment of access rings to M2s

uc3m

$H =$ hierarchical_clustering(N);

$C =$ cut_dendrogram$(H,\ d)$;

$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor}$;

$\text{connect}(r_i, r_{i+1 \mod 6})\,,\ \forall r_i \in R_j,\ \forall R_j \in R$;

$g = 4$ if $l =$ M1 else 2;

$G = \left\{ \{R_{i+gj}\}_{i=0}^{\min\{R-1-gj,g-1\}} \right\}_{j=0}^{\lfloor R/g \rfloor}$;

for $G_i \in G$ **do**

  upper=M2 if l =M1 else M3;

  $\text{connect'}(R, \text{upper})\,,\ \forall R \in G_i$;

end

```
H = hierarchical_clustering(N);
C = cut_dendrogram(H, d);
R = ∪_{C'∈C} { {C'_{i+6j}}_{i=0}^{min{C'−1−6j,5}} }_{j=0}^{⌊C'/6⌋};
connect(r_i, r_{i+1 mod 6}), ∀r_i ∈ R_j, ∀R_j ∈ R;
g = 4 if l = M1 else 2;
G = { {R_{i+gj}}_{i=0}^{min{R−1−gj,g−1}} }_{j=0}^{⌊R/g⌋};
for G_i ∈ G do
    upper=M2 if l =M1 else M3;
    connect'(R, upper), ∀R ∈ G_i;
end
```

$$H = \text{hierarchical\_clustering}(N);$$
$$C = \text{cut\_dendrogram}(H, d);$$
$$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor};$$
$$\text{connect}(r_i, r_{i+1 \bmod 6}),\ \forall r_i \in R_j,\ \forall R_j \in R;$$
$$g = 4 \text{ if } l = \text{M1 else } 2;$$
$$G = \left\{ \{R_{i+gj}\}_{i=0}^{\min\{R-1-gj,g-1\}} \right\}_{j=0}^{\lfloor R/g \rfloor};$$

for $G_i \in G$ **do**

  upper=M2 if l =M1 else M3;

  connect'(R, upper), $\forall R \in G_i$;

end

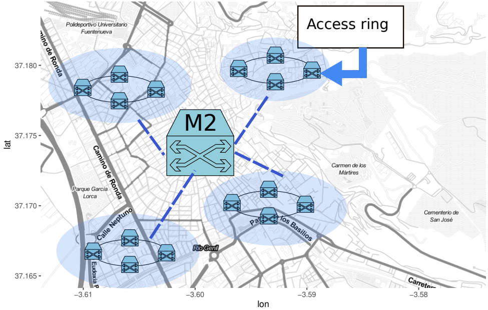

Figure 9: M2 switch handling x4 access rings' traffic

H = hierarchical_clustering(N);

C = cut_dendrogram(H, d);

$R = \cup_{C' \in C} \left\{ \left\{ C'_{i+6j} \right\}_{i=0}^{\min\{C'-1-6j,5\}} \right\}_{j=0}^{\lfloor C'/6 \rfloor}$;

connect$(r_i, r_{i+1 \mod 6})$, $\forall r_i \in R_j$, $\forall R_j \in R$;

$g = 4$ if $l =$ M1 else 2;

$G = \left\{ \{R_{i+gj}\}_{i=0}^{\min\{R-1-gj, g-1\}} \right\}_{j=0}^{\lfloor R/g \rfloor}$;

for $G_i \in G$ **do**

  upper=M2 if l =M1 else M3;

  connect'(R, upper), $\forall R \in G_i$;

end

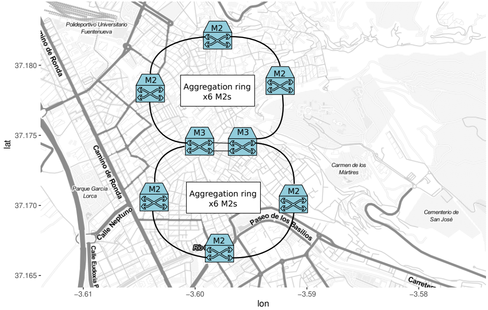

Figure 10: Aggregation rings' representation

Just invoke **build5GScenario** with AAUs' locations

```
granadaCells <- read.csv('granada-cells.csv')
assocs <- build5GScenario(lats = granadaCells$lat,
                          lons = granadaCells$lon)
```

assocs contains dataframes with:

- AAUs to M1s;
- M1s to M1s;
- Access rings to M2;
- M2s to M2s; and
- Aggregation rings to M3s.

E.g., add server nodes

```
...
graph <- attachServers(nodes = graph$nodes,
                       links = graph$links,
                       numServers = 3,
                       bandwidth = 12,
                       bandwidthUnits = "Mbps",
                       distance = 0,
                       distanceUnits = "meter",
                       switchType = "m2",
                       idPrefix = "dell",
        properties = list(cpu=2, mem=20, disk=100))

```

Servers are equally distributed across the switches they are attached to.

Fog nodes generation inside an area

```
graph <- attachFogNodes(..., numNodes = 100,
                             latB = plazaNuevaLatB,
                             latT = plazaNuevaLatT,
                             lonL = plazaNuevaLonL,
                             lonR = plazaNuevaLonR, ...)
```

Other methods:

- Modify/add graph nodes (e.g., swithes or servers) properties: *addNodeProps()*; and
- Modify/add graph links (e.g., fiber) properties: *addLinkProps()*.

mecgen is being used by UC3M netcom research group:

- 5G-CORAL - fog oriented european Project;
- vRoute - FPTAS algorithm[3];
- Ongoing research:
  - closed loop 5G orchestration; and
  - mobility orchestration scenarios (ETH, BME + UC3M).

[3] submitted to INFOCOM2020

VNE algorithms of 5G-CORAL OCS (Orchestration system), on top of volatile fog architecture (generated with **5GEN**)

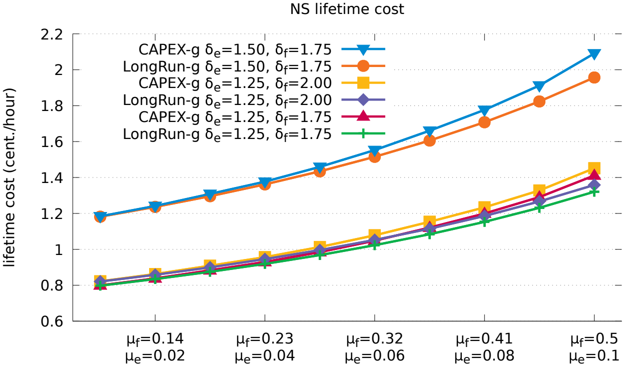

Figure 11: Evaluation on VNE on top of **5GEN** graph

- stores the graph as GML (easy to parse);
- Arbitrarily big graphs;
- SDNlib has small reference abstracted graphs;
- it is based on ITU [3];
- open source: `https://github.com/MartinPJorge/mec-generator/tree/5g-infra-gen`; and
- Given the AAUs it creates the whole infrastructure.

uc3m

- A. Fischer, J. F. Botero, M. T. Beck, H. De Meer, and X. Hesselbach, "Virtual network embedding: A survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 4, pp. 1888–1906, 2013.
- L. Cominardi, L. M. Contreras, C. J. Bcrnardos, and I. Berberana, "Understanding QoS Applicability in 5G Transport Networks," in *2018 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, June 2018, pp. 1–5.
- ITU-T Study Group 15, "Consideration on 5G transport network reference architecture and bandwidth requirements."
- J. Martín-Pérez, L. Cominardi, C. J. Bernardos, A. de la Oliva, and A. Azcorra, "Modeling mobile edge computing deployments for low latency multimedia services," *IEEE Transactions on Broadcasting*, vol. 65, no. 2, pp. 464–474, June 2019.