
Green Virtualization for Multiple Collaborative Cellular Operators: Benefits and 5G Challenges

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Relevant Publications

M. J. Farooq, H. Ghazzai, E. Yaacoub, A. Kadri, and M.-S. Alouini, “Green Virtualization for Multiple Collaborative Cellular Operators”, IEEE Transactions on Cognitive Communications and Networking (TCCN), accepted for publication.

H. Ghazzai, M. J. Farooq, A. Alsharoa, E. Yaacoub, A. Kadri, and M.-S. Alouini, “Green Networking in Cellular HetNets: A Unified Radio Resource Management Framework with Base Station ON/OFF Switching”, accepted for publication in the IEEE Transactions on Vehicular Technology, to appear 2017.

A. Taufique, M. Jaber, A. Imran, Z. Dawy, and E. Yaacoub, “Planning Wireless Cellular Networks of Future: Outlook, Challenges and Opportunities”, IEEE Access, Vol. 5, pp. 4821-4845, April 2017, doi: 10.1109/ACCESS.2017.2680318.

Z. Dawy, W. Saad, A. Ghosh, J. G. Andrews, and E. Yaacoub, “Towards Massive Machine Type Cellular Communications”, IEEE Wireless Communications Magazine, Vol. 24, No. 1, pp. 120-128, February 2017.

H. Ghazzai, E. Yaacoub, A. Kadri, H. Yanikomeroğlu, and M.-S. Alouini, “Next-Generation Environment-Aware Cellular Networks: Modern Green Techniques and Implementation Challenges”, IEEE Access, Vol. 4, pp. 5010-5029, September 2016, doi: 10.1109/ACCESS.2016.2609459.



Collaborators



جامعة الملك عبد الله
للعلوم والتقنية
King Abdullah University of
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UNIVERSITY of HOUSTON



THE UNIVERSITY OF
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Green Virtualization for Multiple Collaborative Cellular
Operators: Benefits and 5G Challenges

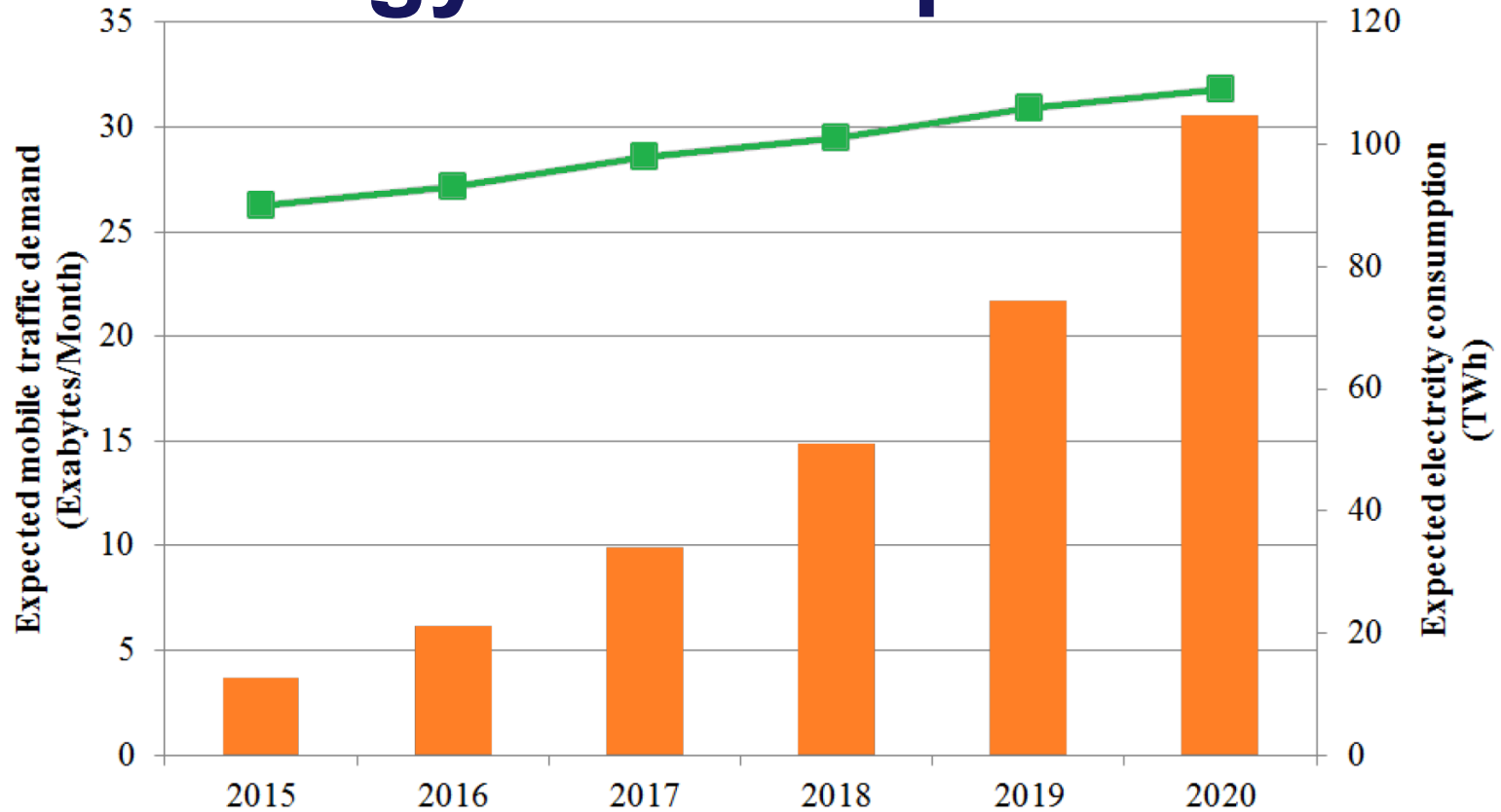
Acknowledgments

Thanks to: H. Ghazzai, M. J. Farooq, A. Alsharoa, A. Taufique, M. Jaber.

Collaborators: M.-S. Alouini, Z. Dawy, A. Kadri, A. Imran, H. Yanikomeroglu, W. Saad, A. Ghosh, J. G. Andrews.

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Mobile traffic is increasing, and so is energy consumption ...



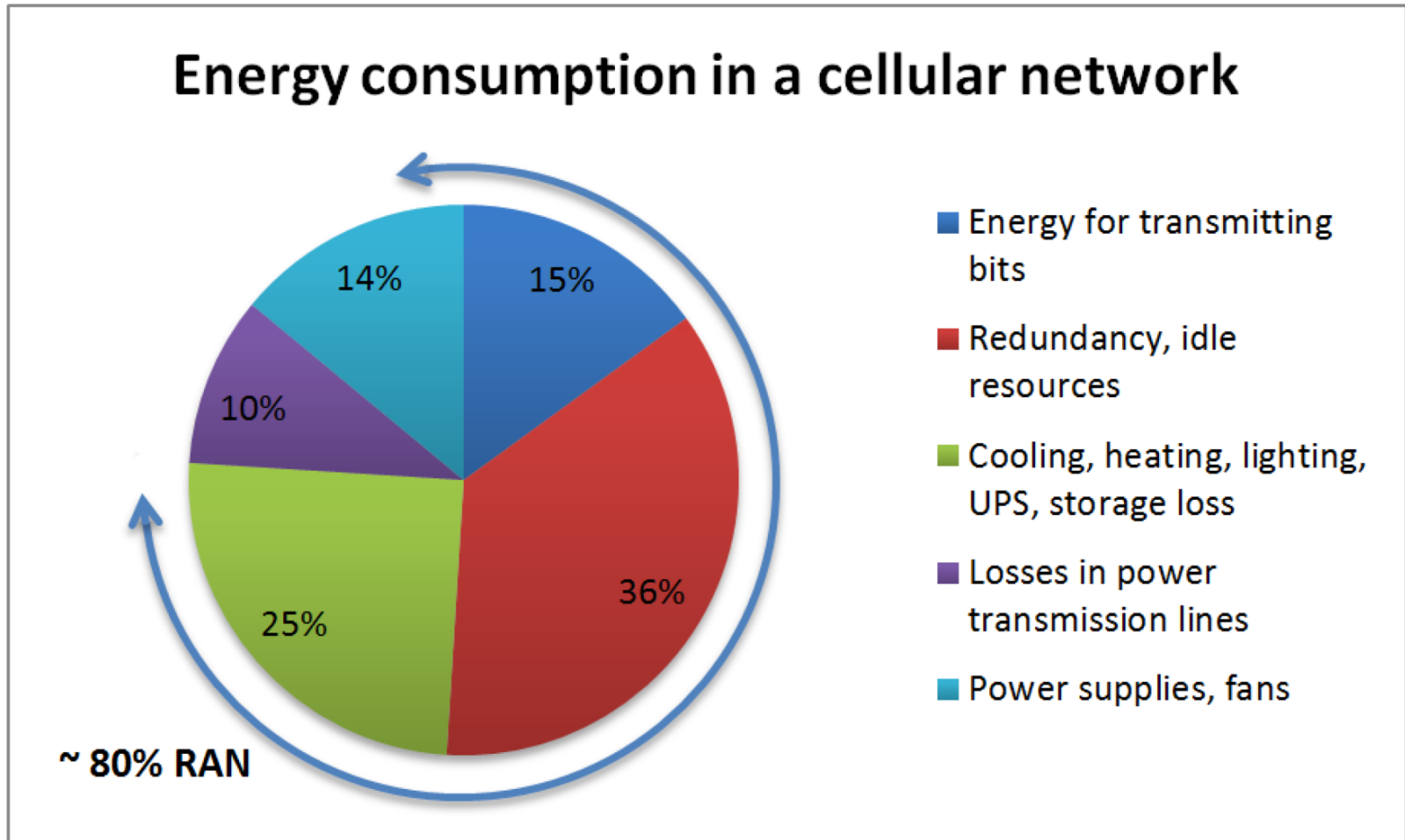
Data sources:

- Expected mobile traffic demand (bars): CISCO, "Cisco visual networking index: Global mobile data traffic forecast update," White Paper, February 2016.

- Energy consumption (line): A. Fehske, G. Fettweis, J. Malmudin, and G. Biczok, "Energy cooperation in cellular networks with renewable powered base stations," IEEE Transactions on Wireless Communications, vol. 13, no. 12, pp. 6996–7010, Dec. 2014.



... with RAN consuming around 80%

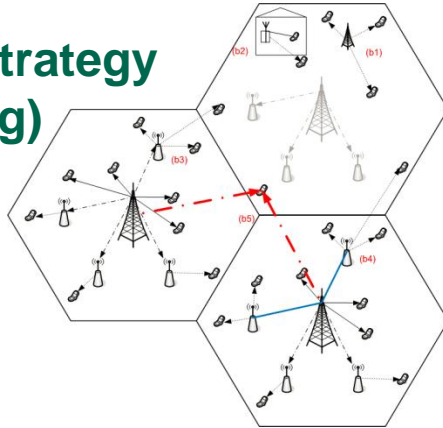


Data Sources:

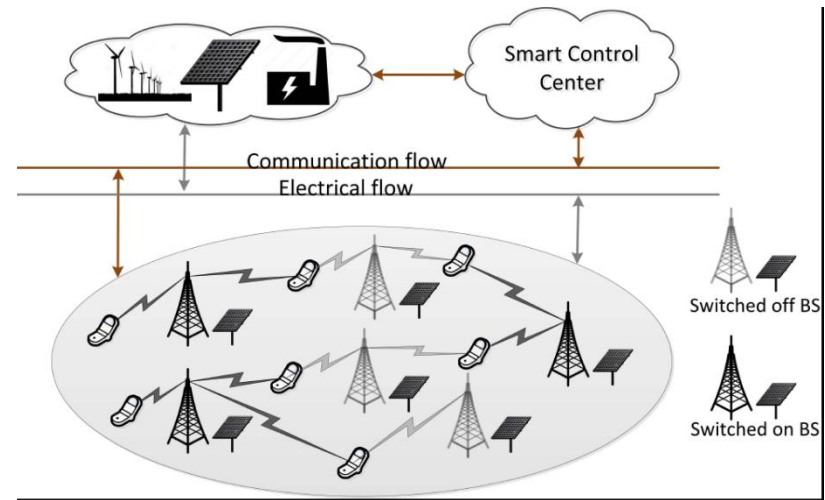
- Nokia Solutions and Networks, "Technology vision 2020 flatten network energy consumption," White Paper, Dec. 2013.
- Ericsson, "Ericsson mobility report: On the pulse of the networked society," White Paper, November 2015.

Several methods can be used to decrease energy costs:

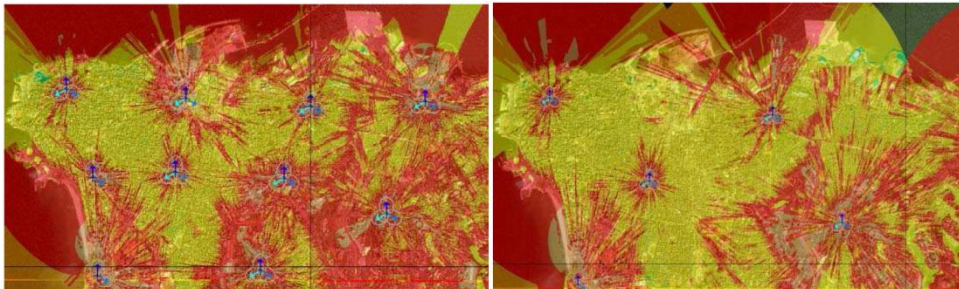
1. BS Sleeping Strategy (On/Off Switching)



2. Using Renewable Energy or optimized energy procurement from the smart grid to power BSs

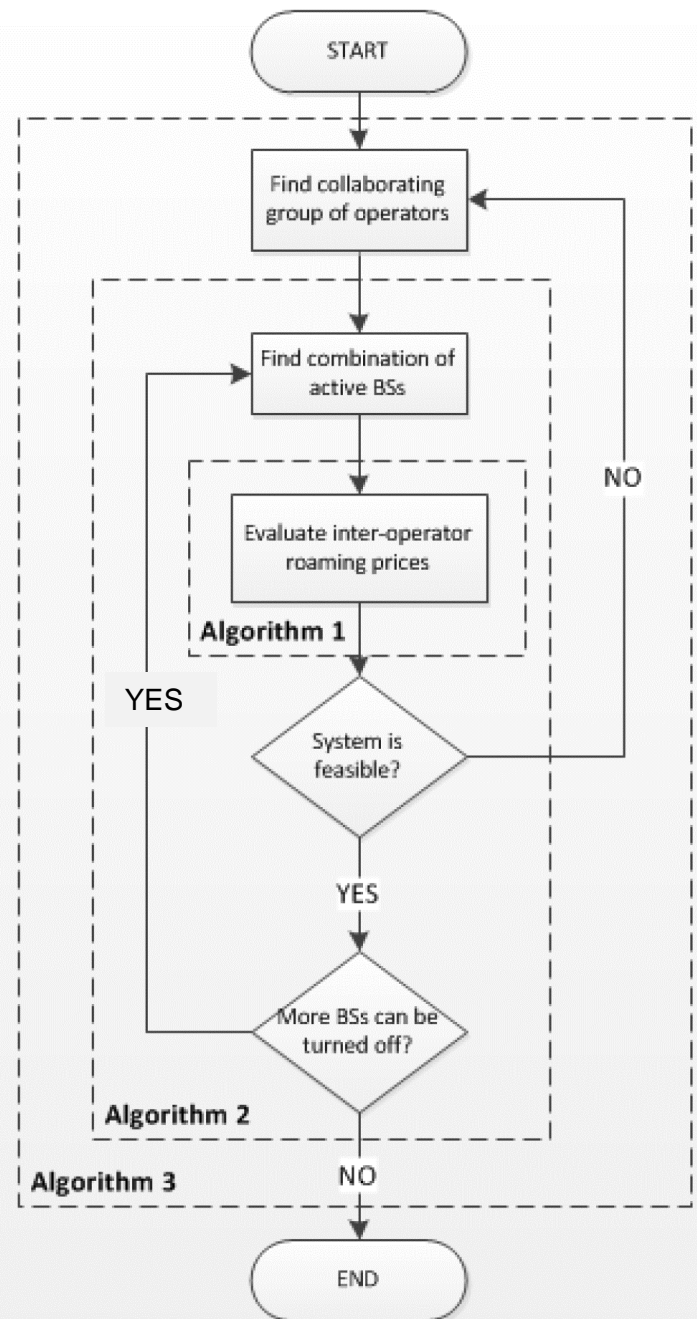


3. Collaboration between Mobile Operators, e.g. Network Sharing



Or....
A Combination of these Methods!

1. At the start, assume all operators can collaborate and all BSs are active
2. Evaluate inter-operator roaming prices
3. Based on these prices, find groups of collaborative operators
 - a. All operators can collaborate
 - b. None of the operators can collaborate together
 - c. Disjoint groups of collaborative operators can be found
 - d. Overlapping groups of collaborative operators can be found: form disjoint groups
4. Implement BS on/off switching while keeping the system feasible
5. Iterate by going back to 2.



Algorithm 1 Iterative Algorithm for Solving the MOLPP

1: $t = 0$; Let $\Psi = \{1, \dots, N_{\text{op}}\}$ be the set of operators in the game and $d^{(l)}[t] \leftarrow \mathcal{P}_l^{(c)*}$, $\forall l = 1, \dots, N_{\text{op}}$.

2: $\delta_{\min}^{(l)} \leftarrow \mathcal{P}_l^{(u)}$, $\delta_{\max}^{(l)} \leftarrow \mathcal{P}_l^{(c)*}$.

3: **repeat**

4: $t \leftarrow t + 1$.

5: Solve the optimization problem in eqs. (21) to (23) to obtain $\hat{\lambda}$ and $\hat{\mathbf{p}}_r$.

6: Determine the individual achievement of aspirations of each operator $\lambda^{(l)} \leftarrow \frac{\hat{P}_l^{(c)}}{d^{(l)}}$, $l = 1, \dots, N_{\text{op}}$.

7: Calculate $l_{\max} = \underset{l \in \Psi}{\operatorname{argmax}} \lambda^{(l)}$ and $l_{\min} = \underset{l \in \Psi}{\operatorname{argmin}} \lambda^{(l)}$.

8: **if** $\lambda^{(l_{\max})} \geq 1$ **then**

9: Remove l_{\max} from the set Ψ .

10: **end if**

11: **if** $\Psi \neq \emptyset$ **then**

12: Update minimum achieved aspiration using the dichotomic search algorithm as follows:

13: **if** $\lambda^{(l_{\min})} < 1$ **then**

14: $\delta_{\min}^{(l_{\min})} \leftarrow d^{(l_{\min})}[t]$,

15: **else**

16: $\delta_{\max}^{(l_{\min})} \leftarrow d^{(l_{\min})}[t]$.

17: **end if**

18: $d^{(l_{\min})}[t + 1] \leftarrow \frac{\delta_{\max}^{(l_{\min})} + \delta_{\min}^{(l_{\min})}}{2}$.

19: **end if**

20: **until** $\lambda \geq 1$ or $\Psi = \emptyset$.

Start by assuming that all operators aspire to achieve their max. profit

Max. profit may not be achieved simultaneously for all operators. Alg1 attempts to select roaming prices to achieve a desired profit aspiration instead

Operators achieving their aspirations are removed from subsequent iterations

Adapt the aspiration levels so that the system might reach a feasible solution.

Decreased aspirations are never allowed to go below the profit in the non-collaborative scenario

Algorithm 2 Iterative Algorithm for BS Sleeping Strategy

```
1:  $t \leftarrow 0$ ; Assume all BSs are activated, i.e.,  $\epsilon[t] = [1, \dots, 1]$ .
2: repeat
3:    $t \leftarrow t + 1$ ;  $\Phi \leftarrow \emptyset$ .
4:   for  $j = 1, \dots, \sum_{l=1}^{N_{\text{op}}} N_{\text{BS}}^{(l)}$  do
5:     Turn off BS  $j$  if it is not already turned off.
6:     Check the BS power budget and number of served users
       constraints as expressed in (17) and (18), respectively, for
       all cells.
7:     if (17) and (18) are still satisfied for all cells then
8:       Add  $j$  to  $\Phi$  (i.e., BS  $j$  that belongs to the set of BSs that
       can be safely turned off) and compute  $\hat{\mathcal{E}}_l^{(c)}[t, j]$  from (13)
       and  $\hat{\mathcal{P}}_l^{(c)}[t, j]$  after solving the optimization problem in
       eqs. (19) and (20) for the given  $\epsilon[t, j]$  using Algorithm 1.
9:     else
10:      BS  $j$  cannot be turned off.
11:    end if
12:  end for
13:  Find BS  $\hat{j} \in \Phi$  such that, when it is turned off, the
       total energy consumption of the network is minimum:  $\hat{j} \leftarrow$ 
        $\underset{j \in \Phi}{\operatorname{argmin}} \sum_{l=1}^{N_{\text{op}}} \hat{\mathcal{E}}_l^{(c)}[t, j]$ 
14:  BS  $\hat{j}$  is completely and safely eliminated.  $\epsilon[t, \hat{j}] \leftarrow 0$ .
15: until No more BS can be turned off.
16:  $\mathcal{E}_l^{(c)}[t] \leftarrow \hat{\mathcal{E}}_l^{(c)}[t, \hat{j}]$ ,  $\mathcal{P}_l^{(c)}[t] \leftarrow \hat{\mathcal{P}}_l^{(c)}[t, \hat{j}]$ ,  $\epsilon[t] \leftarrow \epsilon[t, \hat{j}]$  for all
        $l = 1, \dots, N_{\text{op}}$ .
17:  $T \leftarrow t$ .
18: while  $\sum_{l=1}^{N_{\text{op}}} \mathcal{E}_l^{(c)}[T] \geq \sum_{l=1}^{N_{\text{op}}} \mathcal{E}_l^{(u)}$  or
        $\left( \sum_{l=1}^{N_{\text{op}}} \mathcal{E}_l^{(c)}[T] \leq \sum_{l=1}^{N_{\text{op}}} \mathcal{E}_l^{(u)} \text{ and } \mathcal{P}_l^{(c)}[T] \leq \mathcal{P}_l^{(u)}, l = 1, \dots, N_{\text{op}} \right)$ 
       do
19:    $T \leftarrow T - 1$ .
20:    $\mathcal{E}_l^{(c)}[T] \leftarrow \hat{\mathcal{E}}_l^{(c)}[T, \hat{j}]$ ,  $\mathcal{P}_l^{(c)}[T] \leftarrow \hat{\mathcal{P}}_l^{(c)}[T, \hat{j}]$ ,  $\epsilon[T] \leftarrow \epsilon[T, \hat{j}]$ 
       for all  $l = 1, \dots, N_{\text{op}}$ .
21: end while
22:  $\epsilon^* = \epsilon[T]$ 
```

Start by assuming that all BSs are switched on. Iterate over BSs. A BS is a candidate for switch off if the capacity and power budget constraints of all the other active BSs are not violated

Make sure that the BS elimination does not provoke a roaming price infeasibility by resorting to Algorithm 1

Switch off the BS that leads to maximum energy savings in the network

Check if either the total energy consumption in the network or the individual operator profit is improved as compared to the non-collaborative case.

Revert back by elimination in order to select the best BS combination.

Algorithm 3 Algorithm for Identifying Collaborating Groups

```
1: Complete  $\leftarrow 0$ ; Let  $\Xi = \{\Psi, E, \Pi\}$ , where  $\Psi = \{1, \dots, N_{\text{op}}\}$ 
   is the set of operators,  $E = [\mathcal{E}_1^{(u)}, \mathcal{E}_2^{(u)}, \dots, \mathcal{E}_{N_{\text{op}}}^{(u)}]$  is the set
   of non-collaborative energy consumption of the operators and
    $\Pi = [\mathcal{P}_1^{(u)}, \mathcal{P}_2^{(u)}, \dots, \mathcal{P}_{N_{\text{op}}}^{(u)}]$  is the set of non-collaborative profit.
   Let  $\Xi_i = \{\Psi_i, E_i, \Pi_i\}$ , where  $i$  denotes the  $i^{\text{th}}$  element in each
   set.
2: Let  $\xi = \emptyset$  be the set containing the disjoint groups of operators
   that can collaborate with each other.
3: while complete = 0, do
4:   Sort  $\Xi$  based on  $E$  in decreasing order.
5:   for  $i = 1$  to  $|\Xi|$  do
6:     for  $j = i + 1$  to  $|\Xi|$  do
7:       Find the set  $s_{ij} = \{\mathbf{p}_r \in \mathbb{R}^n : \mathcal{P}_l^{(c)} \geq \mathcal{P}_l^{(u)}, l = i, j\}$ 
       assuming all BSs are active. If  $s_{ij} \neq \emptyset$ , compute
       the corresponding collaborative energy consumption  $\mathcal{E}_{ij}^{(c)}$ 
       and profit  $\mathcal{P}_{ij}^{(c)}$  by solving the optimization problem in
       eqs. (15) to (18) using Algorithm 2.
8:     end for
9:      $s_{\text{opt}} = \{s_{ij} : \mathcal{E}_{ij}^{(c)} = \min_{\{j: s_{ij} \neq \emptyset\}} (\mathcal{E}_{ij}^{(c)}), \forall i, j\}$ .
10:    if  $s_{\text{opt}} \neq \emptyset$  then
11:      Combine Op.  $i$  and Op.  $j$  into a single virtual operator,
      denoted by Op.  $ij$ . Remove the  $i^{\text{th}}$  and  $j^{\text{th}}$  entry in
       $\Phi$  and add a new entry for the virtual operator  $ij$  i.e.,
       $\Xi = \Xi \setminus \{\Xi_i, \Xi_j\} \cup \{\Xi_{ij}\}$ , where  $\Xi_{ij} = (ij, \mathcal{E}_{ij}^{(c)}, \mathcal{P}_{ij}^{(c)})$ .
12:      Let Op.  $i$  denote the combined Op.  $ij$ .
13:       $i \leftarrow i - 1$ .
14:    else
15:      Op.  $i$  cannot collaborate with any other operator. Remove
      Op.  $i$  from the set  $\Xi$  i.e.,  $\Xi = \Xi \setminus \Xi_i$  and add  $\Xi_i$  to the
      set  $\xi$ .
16:    end if
17:  end for
18:  if  $i = |\Xi|$  then
19:    Complete  $\leftarrow 1$ .
20:  end if
21: end while
```

Initialize. Group operators in decreasing order of energy consumption. Start by trying to find collaborative groups for the most energy consuming operators, while increasing profit.

Find the two operators whose collaboration leads to maximum energy savings in the network while increasing their own profits

Merge collaborating operators into a single virtual operator in the set of operators, and iterate in order to increase the subset of collaborating operators

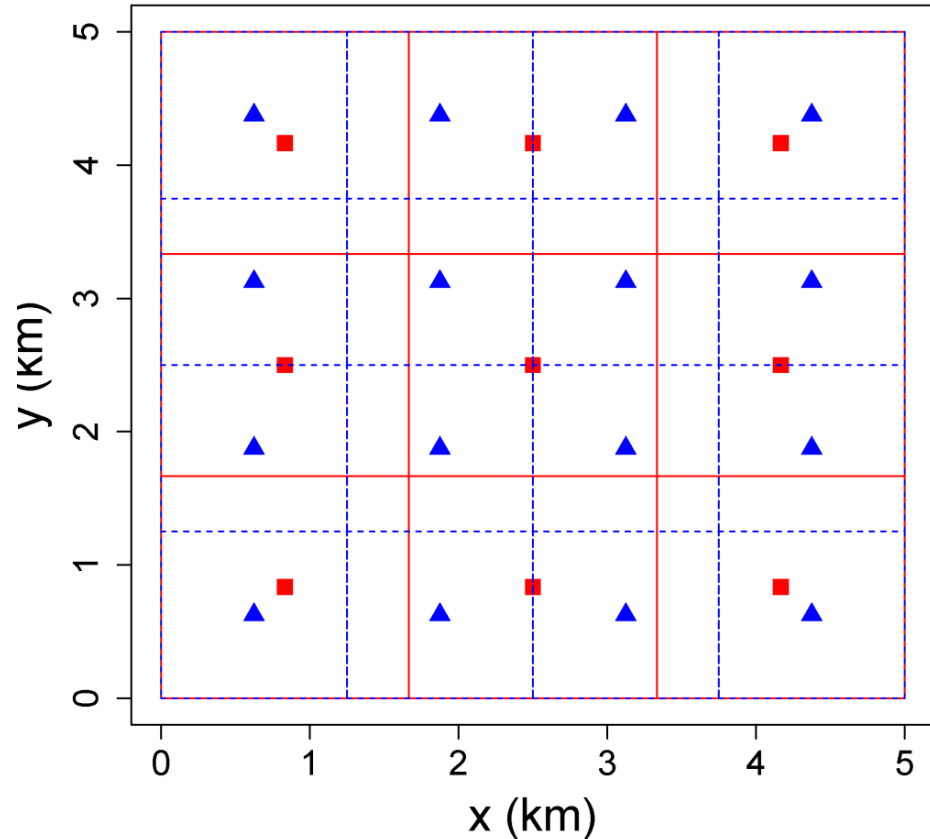
When (additional) collaborators cannot be found for an (virtual) operator, this (virtual) operator is excluded from the search, which continues on the other operators

Results: Voronoi Tessellation

Non-Cooperative Case

BSs of **Op1**
(red squares)
and **Op2** (blue triangles)

Operator	Nb of BSs	Nb of Users
Operator 1	9	200
Operator 2	16	150

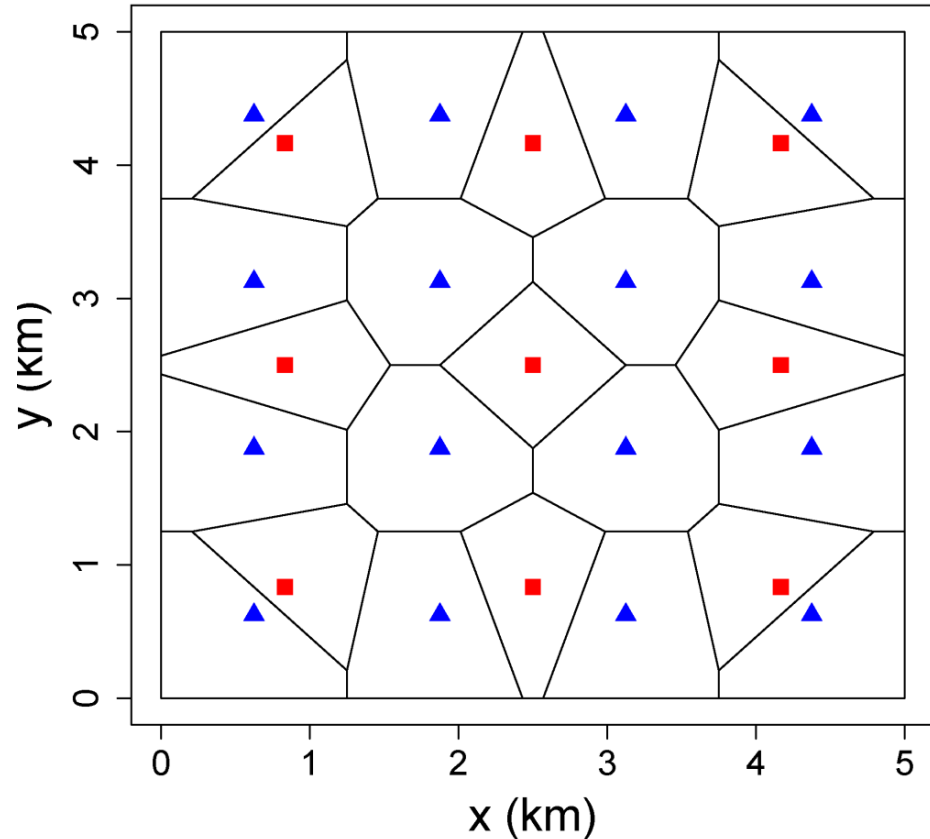


Results: Voronoi Tessellation

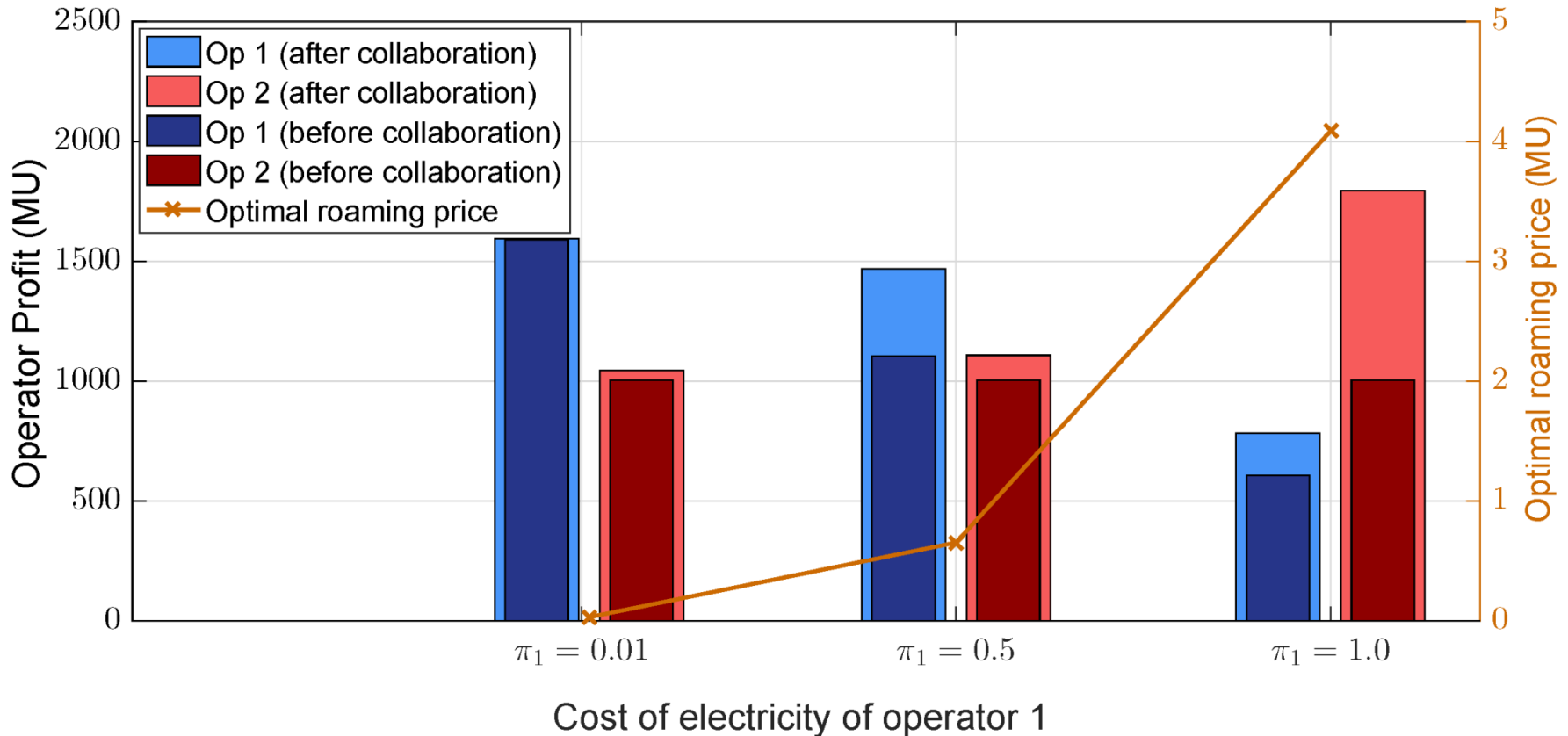
Cooperative Case

BSs of **Op1**
(red squares)
and **Op2** (blue triangles)

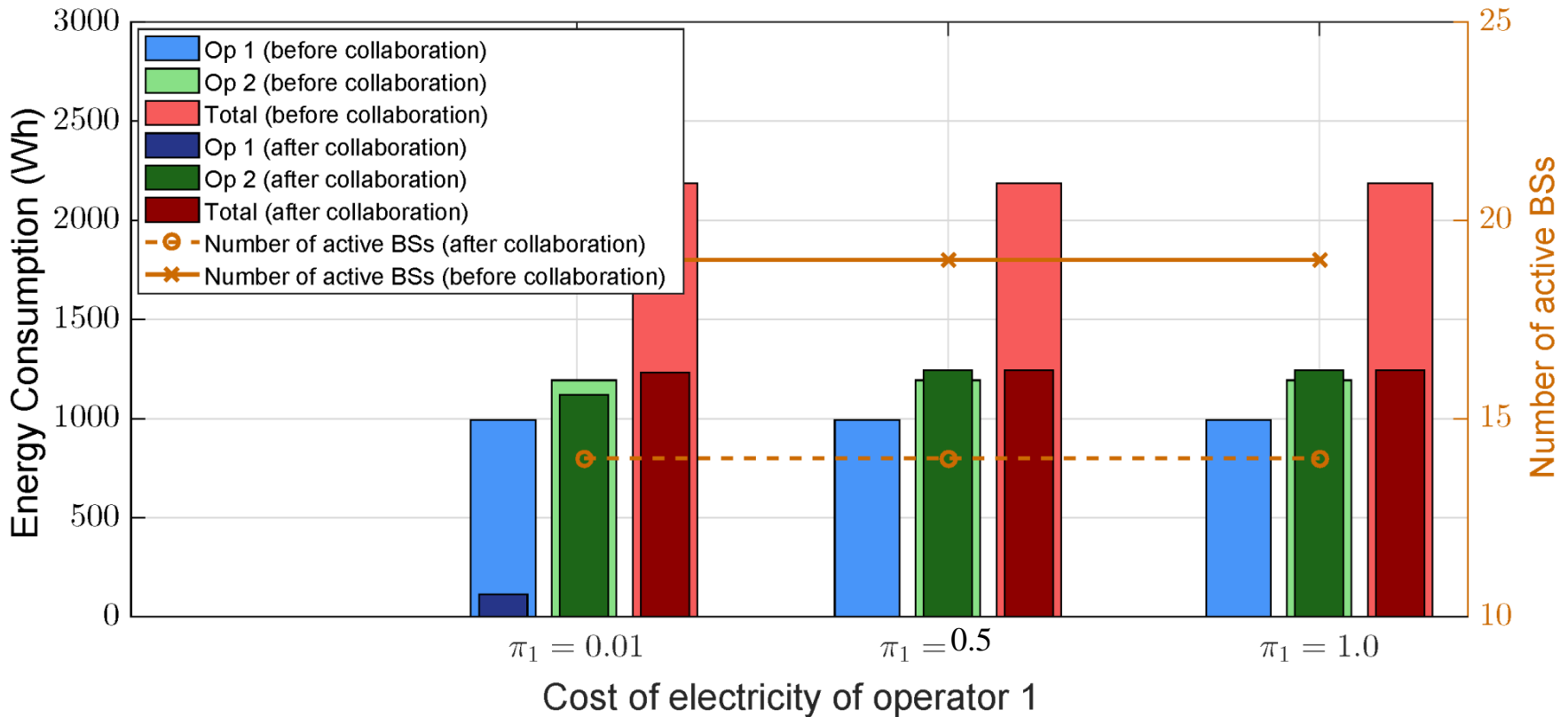
Operator	Nb of BSs	Nb of Users
Operator 1	9	200
Operator 2	16	150



Results: Operator Profitability vs. Varying Cost of Electricity



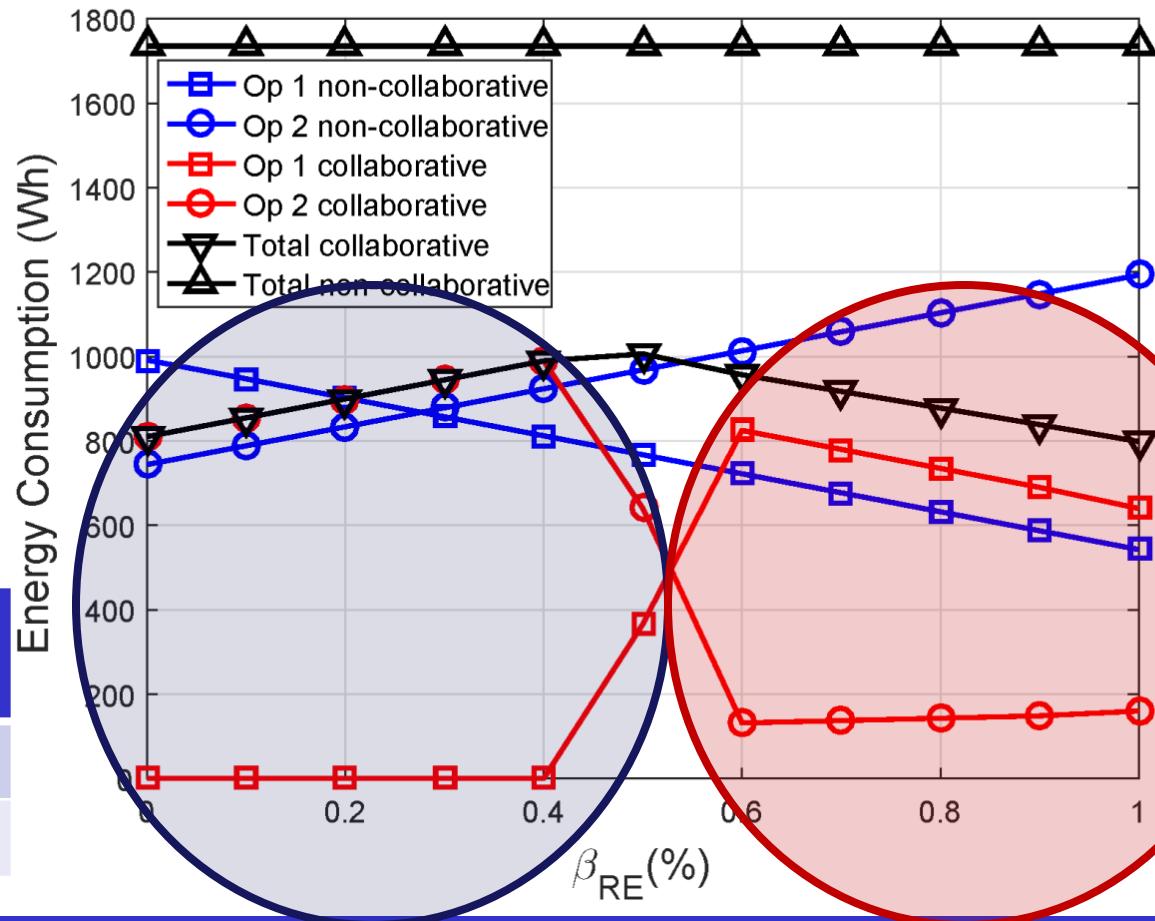
Results: Energy Consumption vs. Varying Cost of Electricity



Results: Energy Consumption vs. Distribution of Green Energy

Op2 dominant in using renewable energy. Op1 BSs switched off.

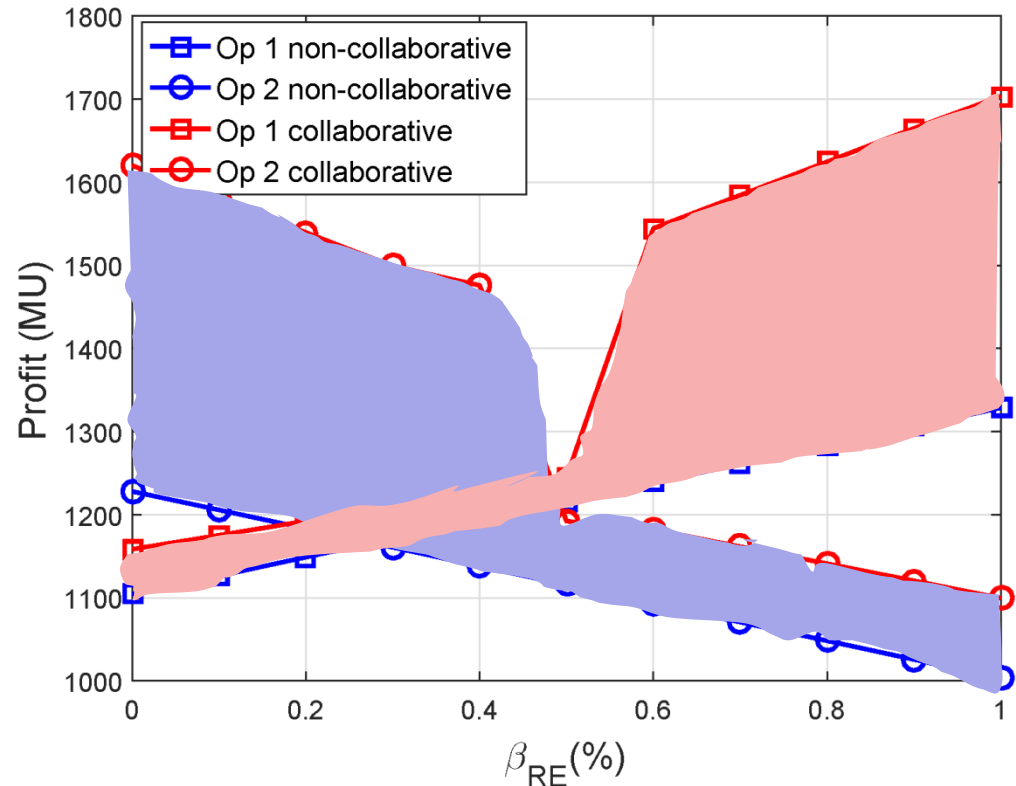
Op1 dominant in using renewable energy. Op1 BSs switched on and offload Op2 traffic.



Operator	Nb of BSs	Nb of Users
Operator 1	9	200
Operator 2	16	150

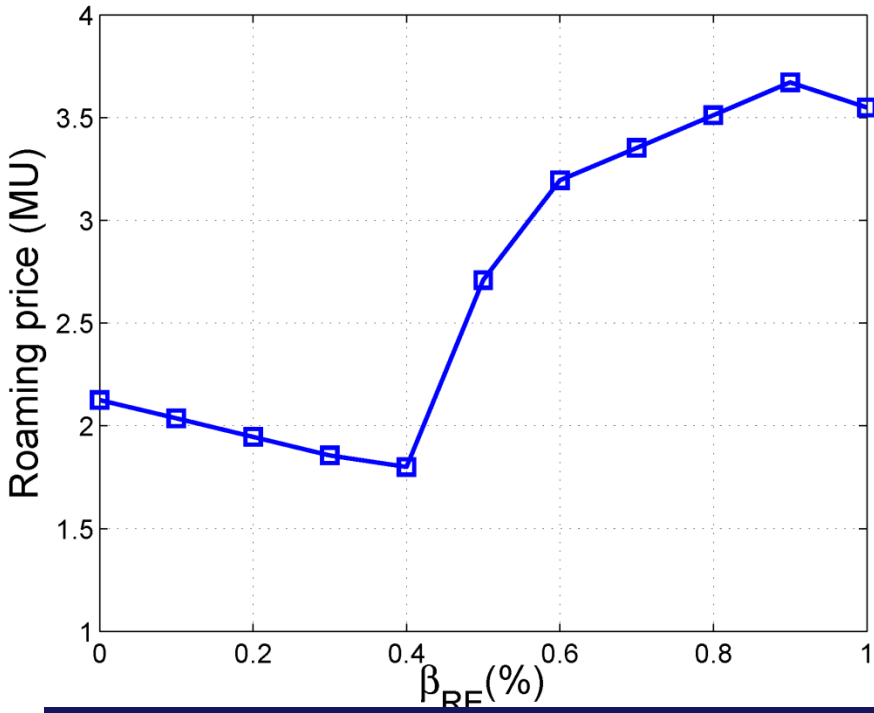
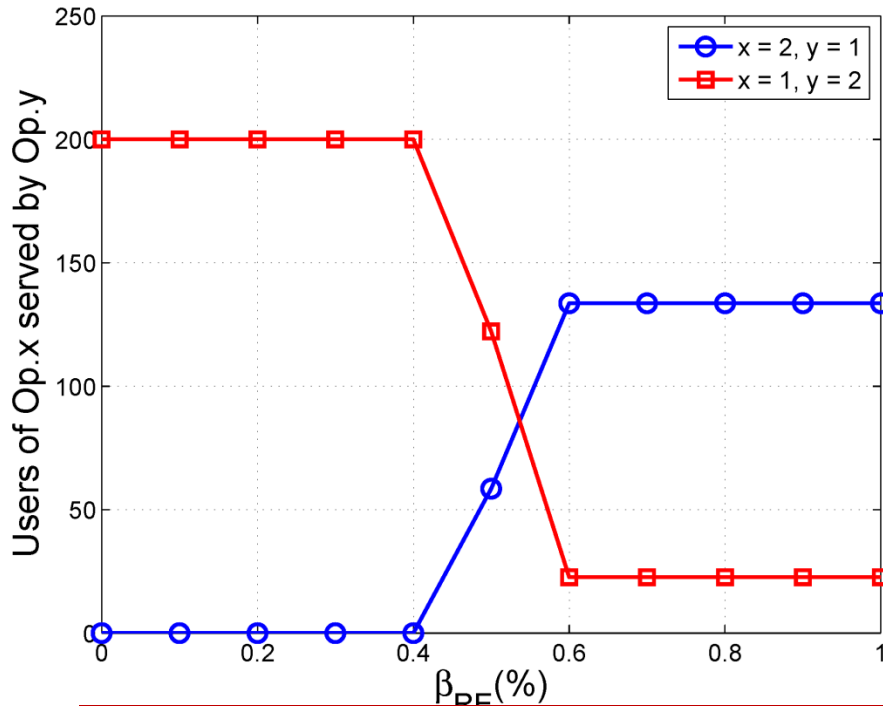
Results: Operator Profit vs. Distribution of Green Energy

Op1 and **Op2** profits increase with the increased use of renewable energy by each operator



Operator	Nb of BSs	Nb of Users
Operator 1	9	200
Operator 2	16	150

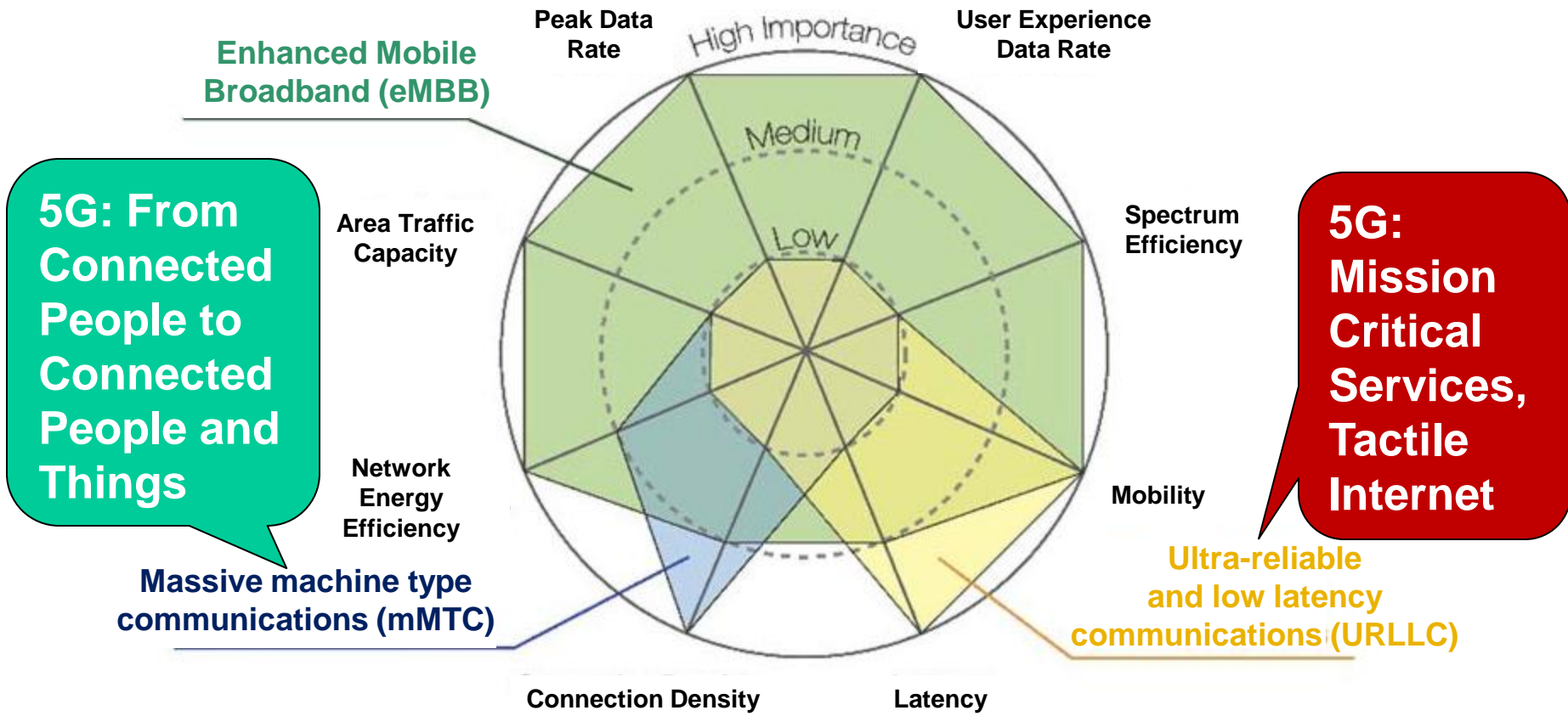
Results: Roamed Users and Roaming Price vs. Distribution of Green Energy



The operator generating more renewable energy can serve more roamed users

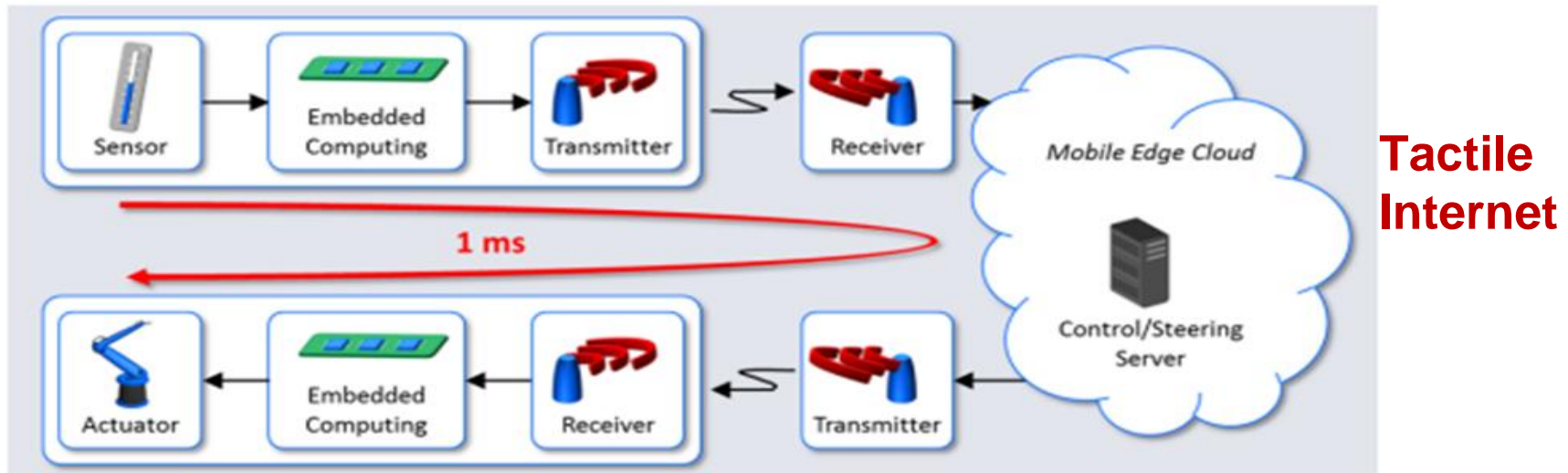
Roaming price is higher when Op1 generates more renewable energy since it has more users and less BSs than Op2

Can these gains be sustained in 5G Networks?



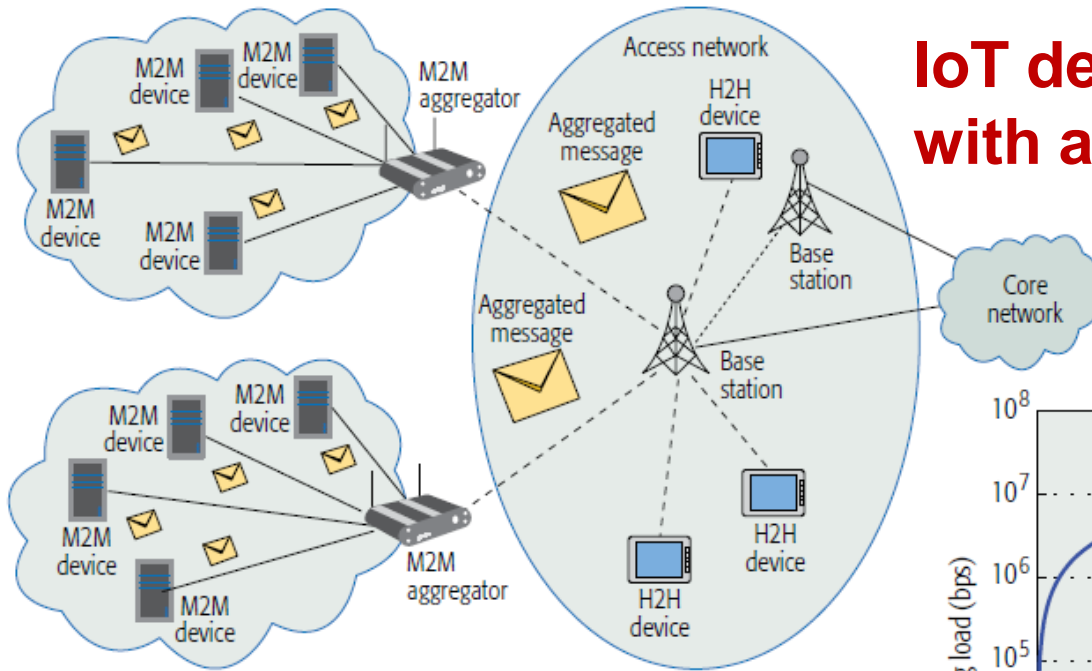
Source: ITU-R M.2083

Can BSs be switched off while ensuring QoS for IoT and Tactile Internet?

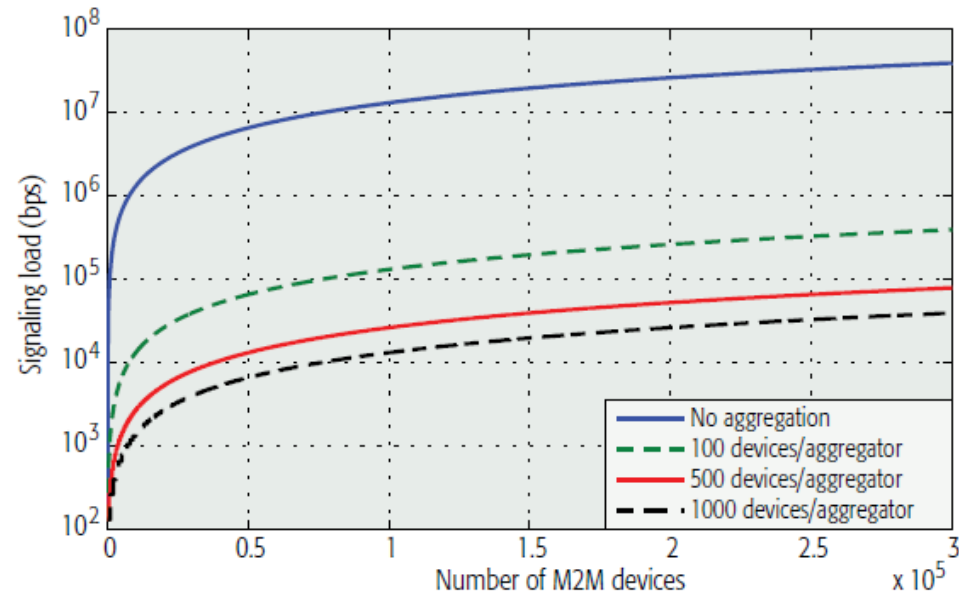


Source: ZeitgeistLab.ca

BS On/Off Switching with mMTC and URLLC



IoT devices can communicate with an aggregator

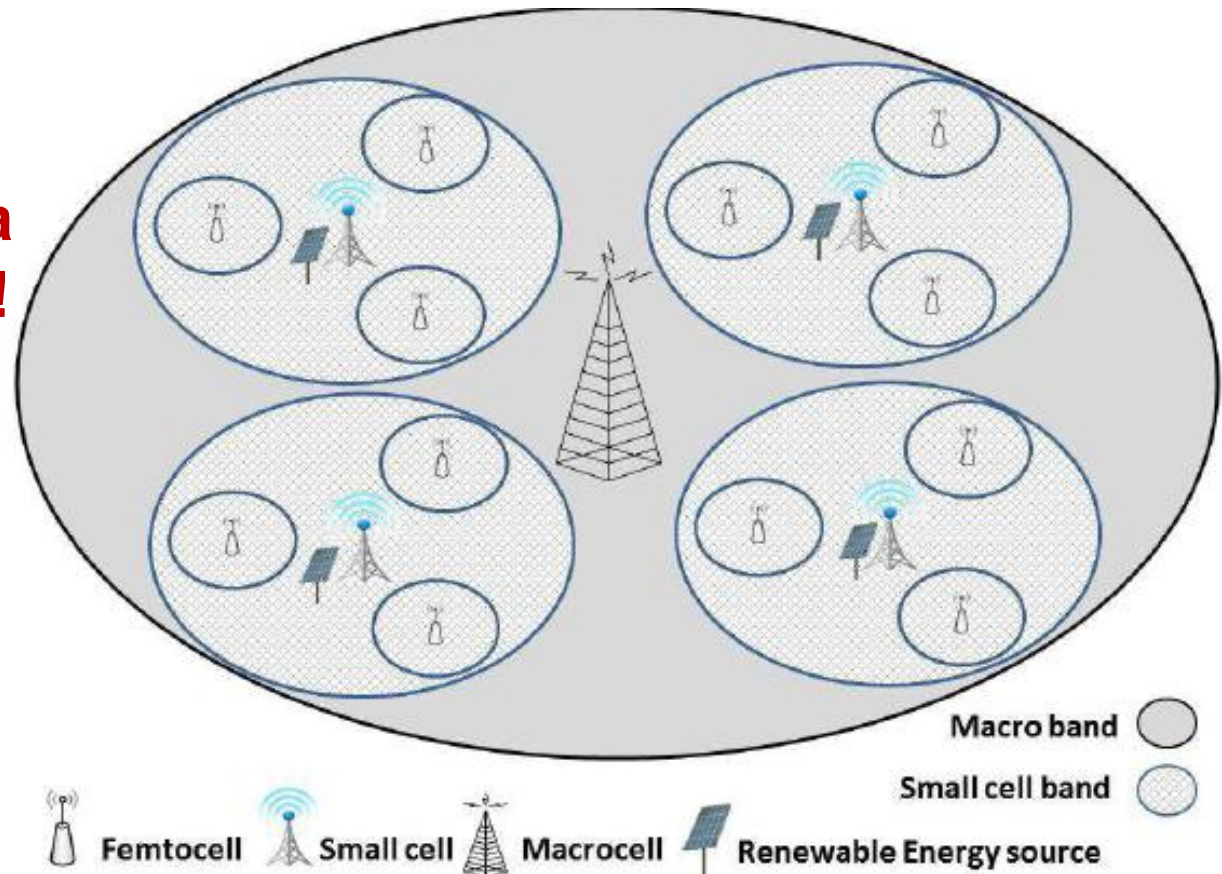


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BS On/Off Switching with mMTC and URLLC

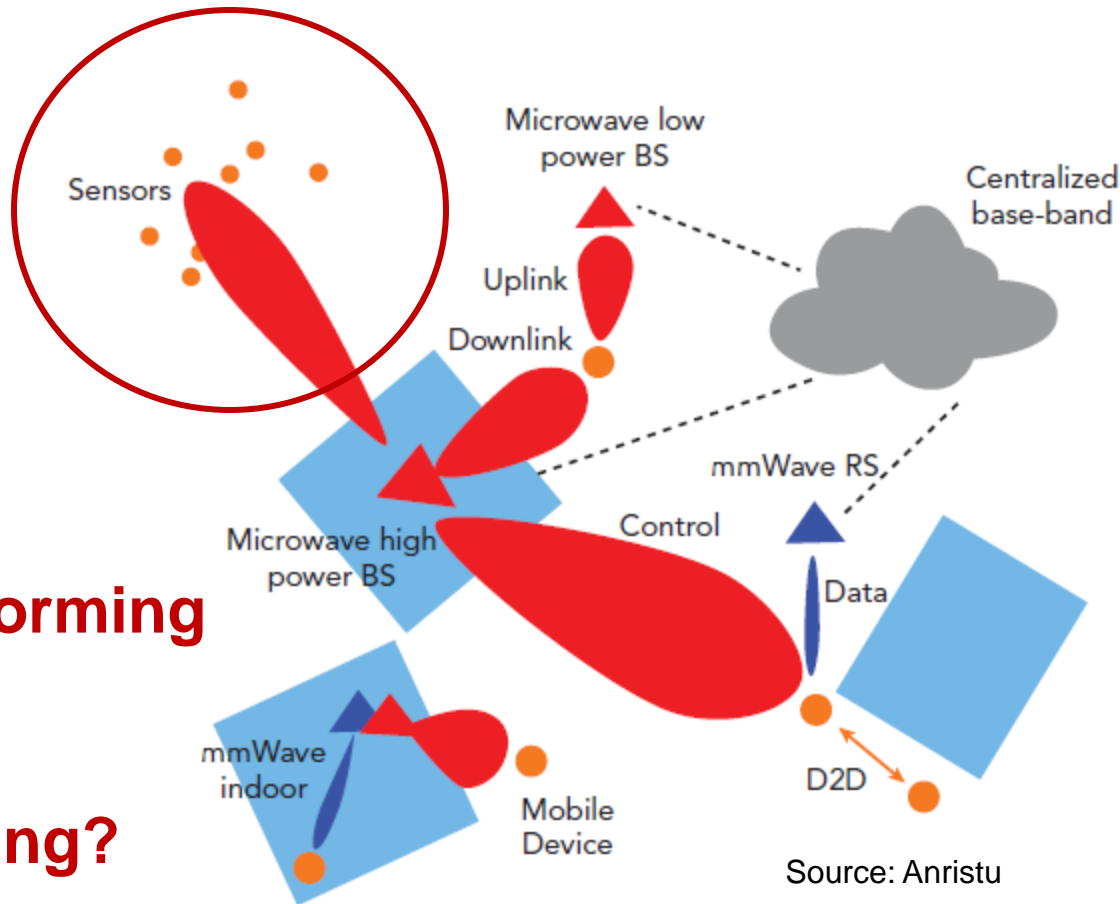
... that could be a HeNB/Femtocell !

Need to provide proper incentives for owners.



H. Ghazzai, M. J. Farooq, A. Alsharoa, E. Yaacoub, A. Kadri, and M.-S. Alouini, "Green Networking in Cellular HetNets: A Unified Radio Resource Management Framework with Base Station ON/OFF Switching", accepted for publication in the IEEE Transactions on Vehicular Technology, to appear 2017.

BS On/Off Switching with mMTC and URLLC

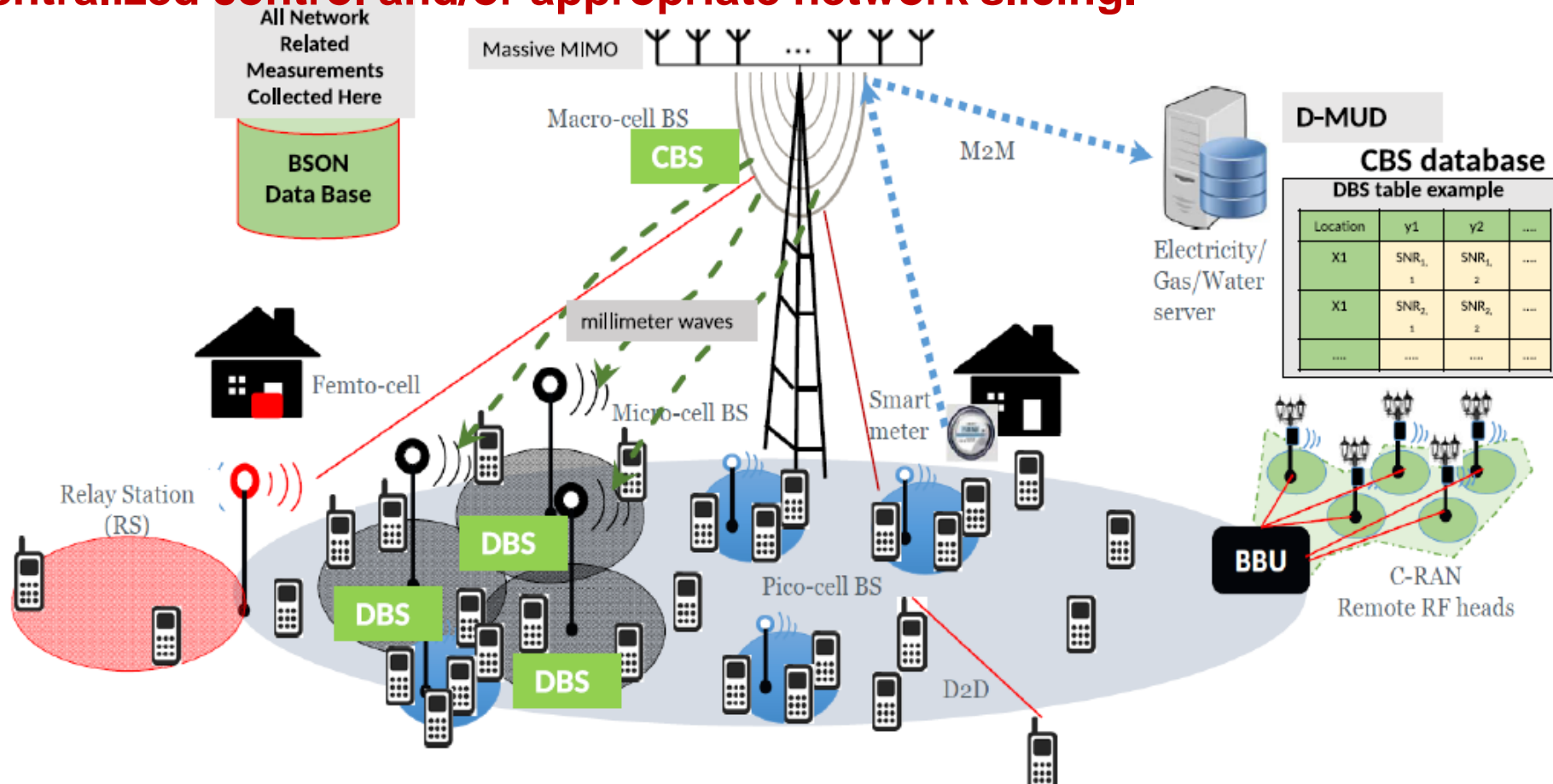


OR...

Massive
MIMO/Beamforming
can help
+
Network Slicing?

BS On/Off Switching with mMTC and URLLC

URLLC QoS/QoE can be guaranteed by resource reservation through centralized control and/or appropriate network slicing.



A. Tafique, M. Jaber, A. Imran, Z. Dawy, and E. Yaacoub, "Planning Wireless Cellular Networks of Future: Outlook, Challenges and Opportunities", IEEE Access, Vol. 5, pp. 4821-4845, April 2017, doi: 10.1109/ACCESS.2017.2680318.

Thank You