Energy-Aware Clustering for Multi-Cell Joint Transmission in LTE Networks

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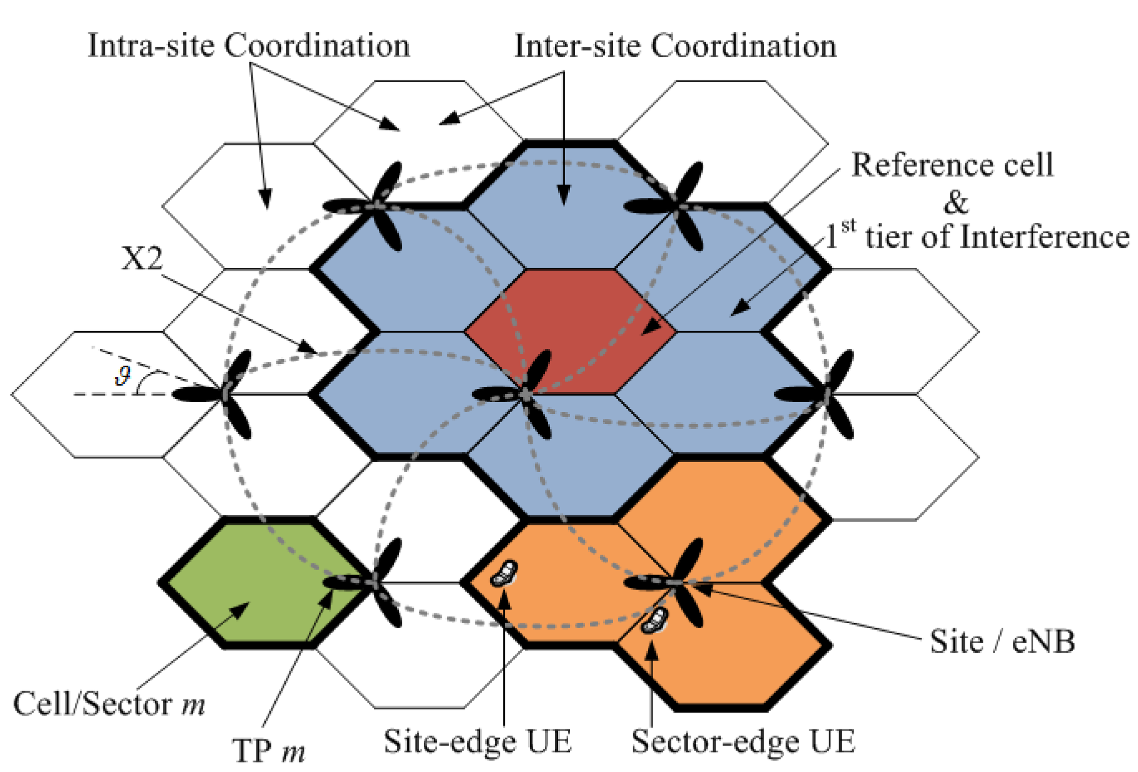
Main Points

- Focus of this work is on static (i.e. pre-decided and fixed over time) clustering deployments for LTE systems when joint signal precoding is employed at multiple base stations.
- We compare the overall energy consumption of various clustered cooperation layouts while considering different target performance metrics at user end.
- We demonstrate that properly planned clustering can provide the desired balance between network spectral and energy efficiency.
- Our evaluations for various inter-site distance deployments in a practical macrocell scenario unveil the individual parameters controlling the energy effectiveness of a clustering strategy.
- The choice of the optimum clustering layout depends on: 1) the specific service demands; 2) the network deployment density and; 3) the ability of base stations to jointly adjust transmit power.
- We provide a general framework for choosing the most appropriate cooperation set of base stations in energy-aware networks.

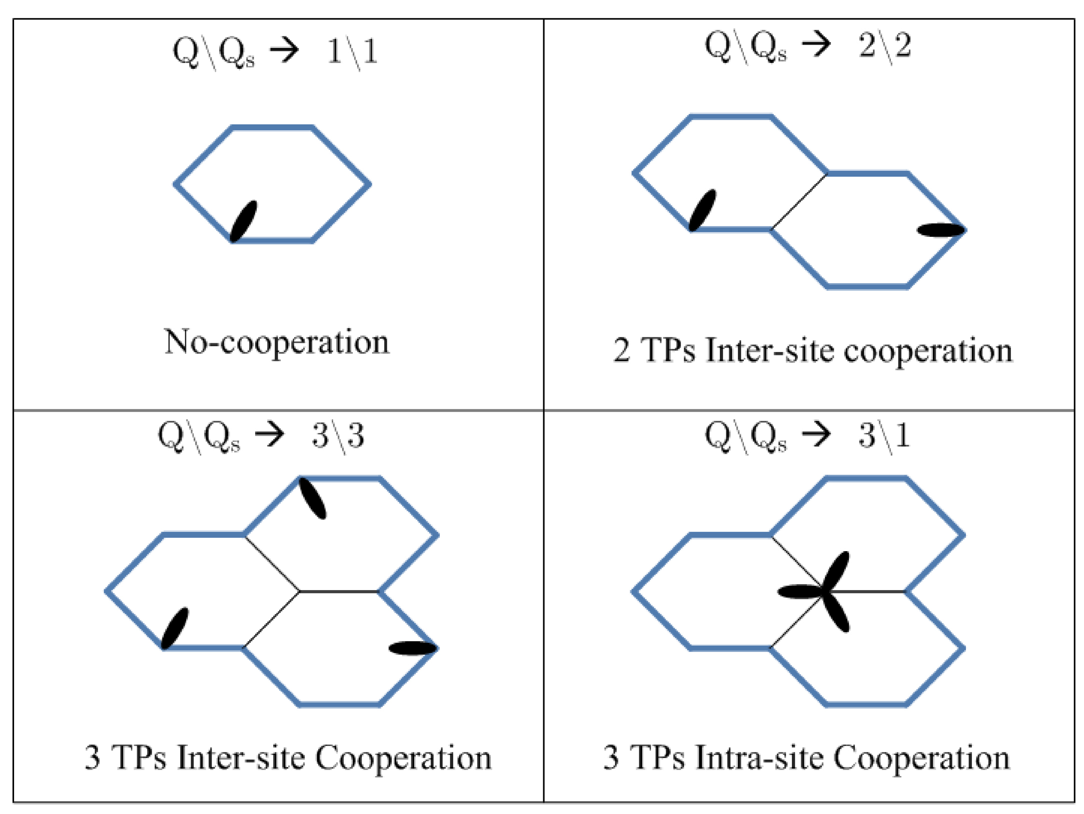
System Model

-Tri-sectored cellular downlink.
- Joint Transmission (JT) scheme: Signals from multiple Transmission Points (TPs), forming a coordination cluster, are jointly pre-processed.
-Intra-site coordination: almost zero latency and infinite capacity.
- Inter-site coordination: information has to be exchanged through X2 interface connecting eNBs. We acknowledge and evaluate the energy consumption of these multiple backhaul links.



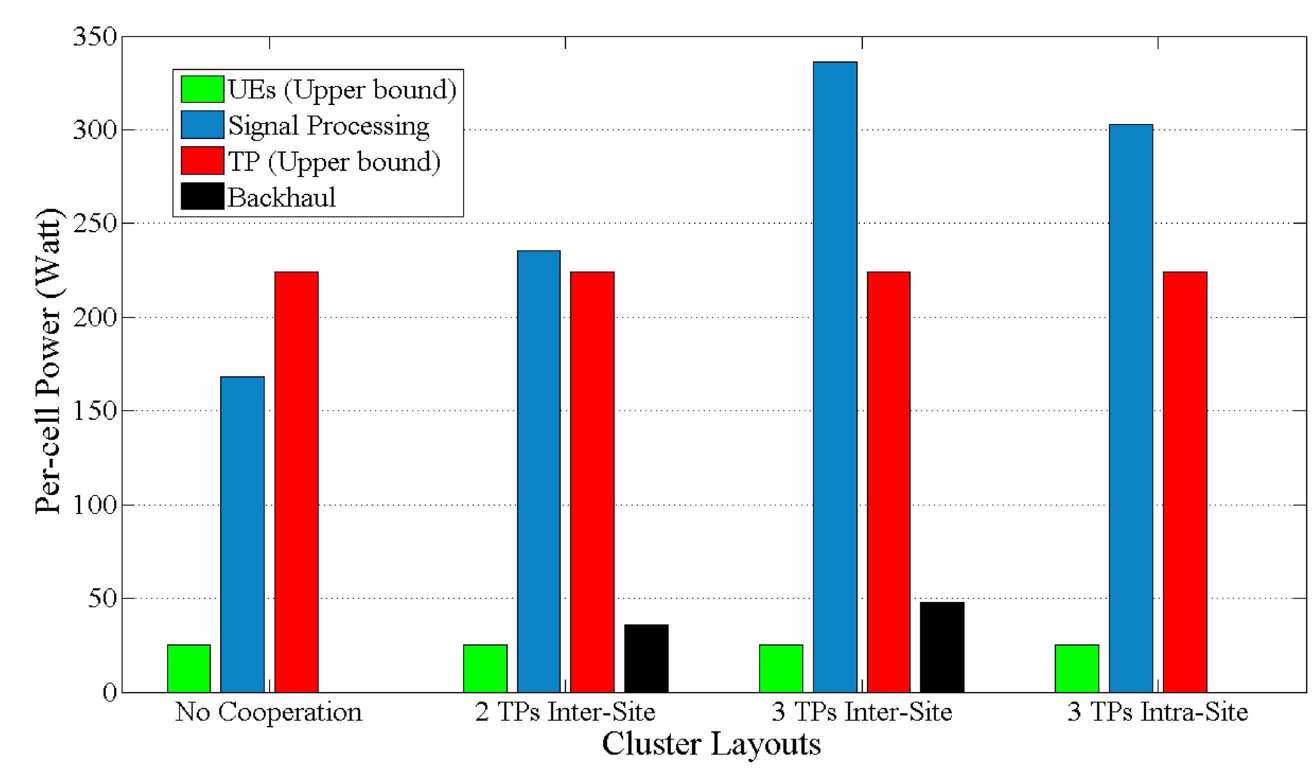
Cluster Layouts

- Macro cellular environment: 1-tier inter-cell interference
- Maximum cluster size of 3
- Centralised coordination: Local Processor for each cluster.
- Idealistic pre-processing exploits perfect CSIT and calculates appropriately precoding matrices for each cluster so as the ICLI is removed completely while the maximum power diversity gain is achieved for each UE



QoS & Energy Consumption

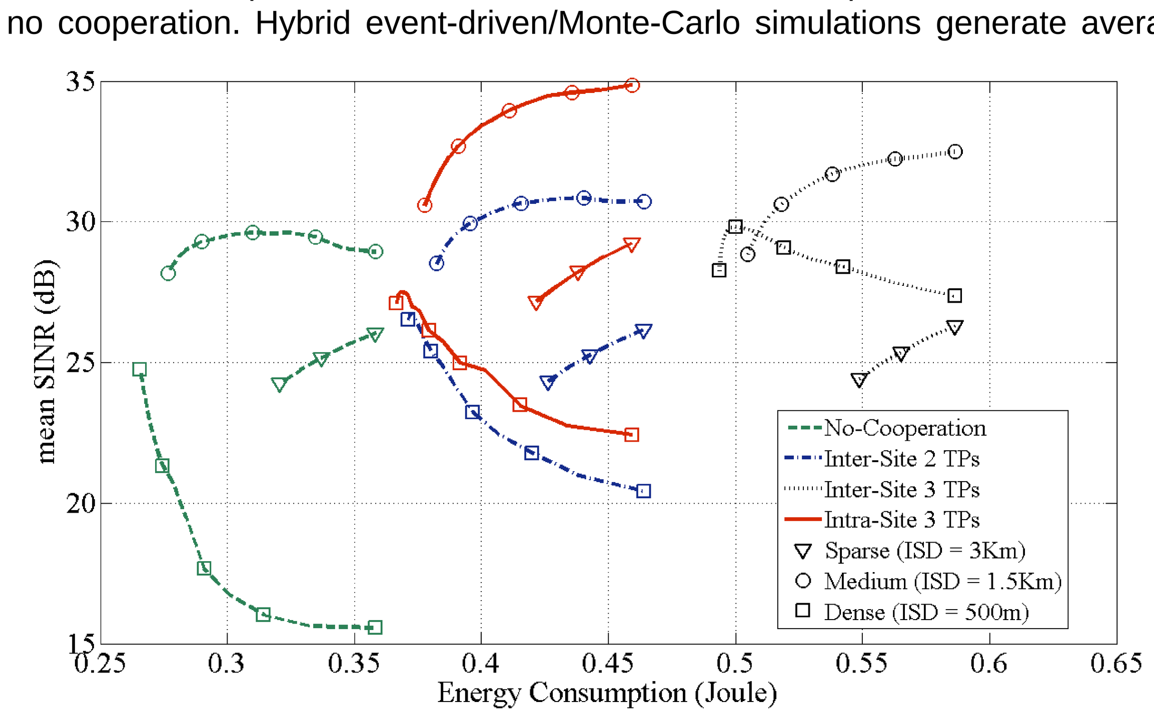
- Two distinct QoS-related metrics:
1) *Mean per-cell SINR* of all potential UE;
2) *Outage cell SINR*, i.e. percentage of potential UE locations that do not achieve a certain minimum SINR value.
-Holistic Power Model (per cluster). Tractable power models for:
1) TPs power usage related with the radiated power from antennas; 2) per-TP signal processing power; 3) cluster power needs for backhaul; 4) average power usage at the active UEs served by the cluster TPs.

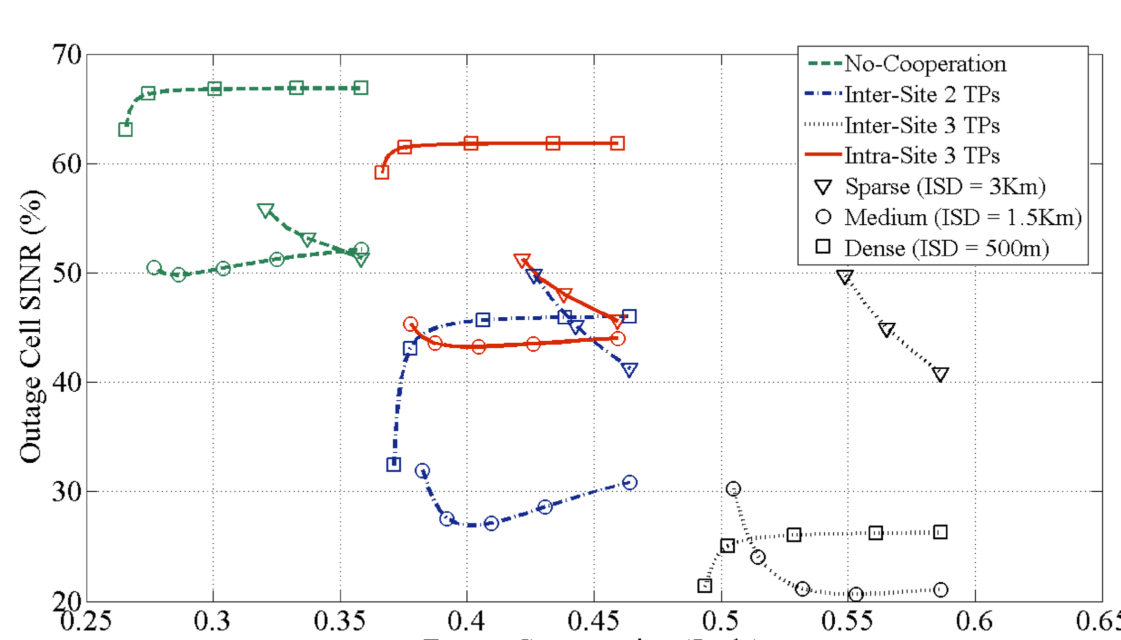


Results for real-world cellular network scenario

System Setup:

- LTE-based system model and propagation parameters suggested by 3GPP are chosen as an example for establishing the relation of the various system modelling parameters with practical ones. Path loss coefficients are fitted to respective ``Urban Macro - LOS'' empirical scenario. A minimum TP transmit power is considered as a function of ISD, so as any cell-edge UE can achieve a minimum SINR target under no cooperation. Hybrid event-driven/Monte-Carlo simulations generate averaged numerical results.





Key Observations

Optimum Transmit Power Strategy

- ICI-limited dense deployments (e.g. ISD=500m): Optimal to transmit with minimum power
- Noise-limited sparse deployments (e.g. ISD = 3 Km): Optimal to transmit with maximum power
- Medium density deployments (e.g. ISD = 1.5 Km): Non-monotonic SINR-EC relationship. TPs transmit power can be adjusted to obtain a satisfactory balance.

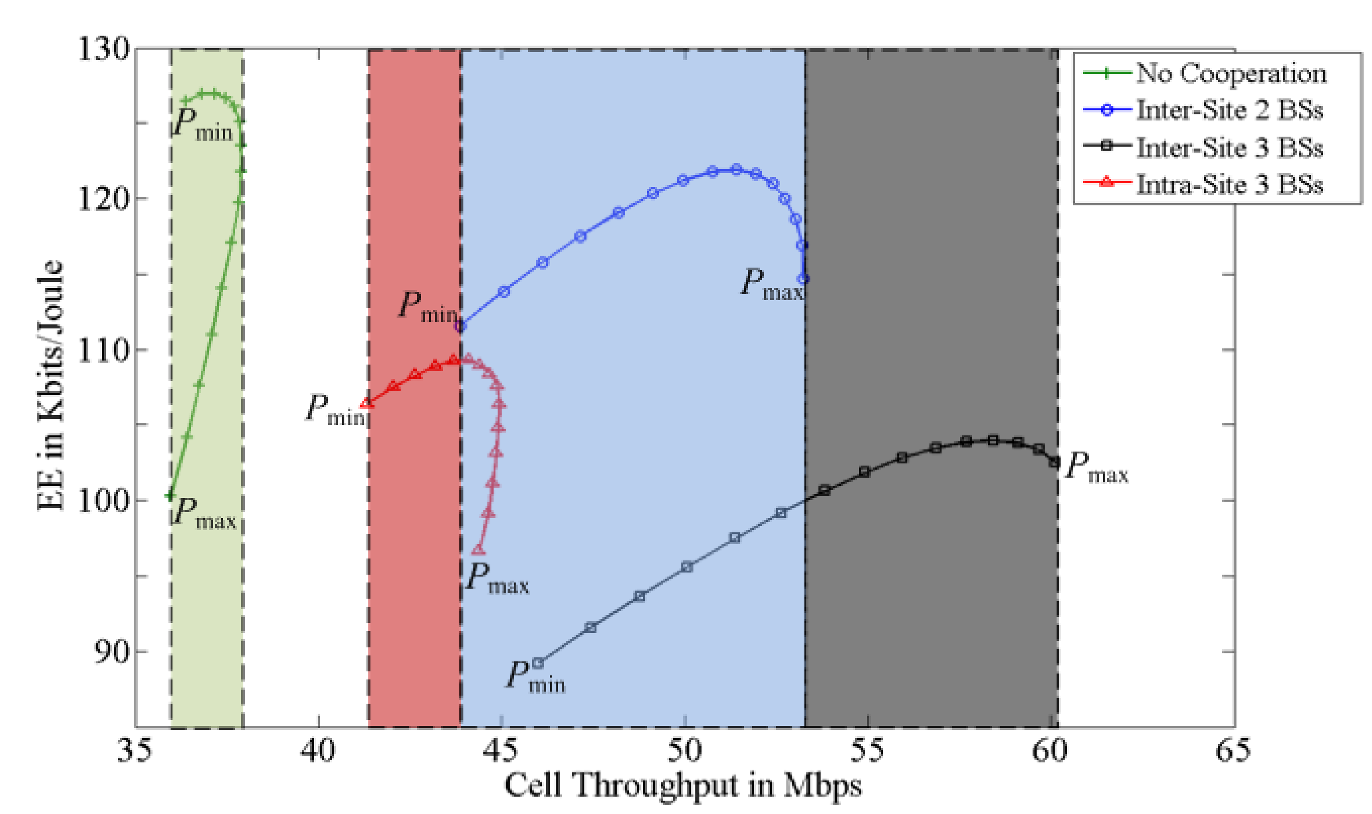
Optimum Cluster Layouts

- Sparse deployments:
  - Effects of cooperation become insignificant to site-edge UEs
    → no outage cell SINR improvement.
  - Sector-edge UEs can still benefit from cooperation
    → significant gain on mean per-cell SINR.
- Dense deployments:
  - Inter-site interference becomes severe for site-edge UEs
    → Cooperation among TPs in different sites is more effective. Especially for optimising outage cell SINR, inter-site TPs cooperation seems to pose as the only feasible solution

Framework for determining optimal energy-aware clustering

Step 1: Translated the SINR-EC analysis into Joule-per-bit EE versus cell throughput results.
(For illustrations we considered Shannon capacity per link)

Step 2: Obtain performance of the different cooperation schemes for variable TPs transmit power value



Energy Efficiency– Throughput Tradeoff

- Results reveal that although a no-cooperation scheme can be more energy efficient when TPs transmit with appropriate power, it cannot reach the high rates obtained by clustered cooperation.
- The differently shaded areas denote the optimal cluster layout that should be applied to achieve specific system throughput targets.

Basic Conclusions/Contributions:

- We provide a framework to identify if, when and which cells in the downlink of LTE cellular networks should cooperate to efficiently exploit the gains offered by CoMP techniques.
- Our analysis and evaluation results show that the decision on the most energy efficient cluster layout depends both on the QoS-based requirements and the deployment density.
- Regarding energy-aware average throughput optimisation, a significant gain can be achieved via intra-site coordination which favours sector-edge UEs.
- For optimising rate fairness, inter-site coordination favouring site-edge UEs is preferable. Inter-site coordination proves to be more effective especially for dense deployments, where the effect of inter-site interference becomes severe for site-edge UEs.
- System EE can be improved when TPs transmit with low power in the ICI-limited dense deployments. In sparser deployments, where noise and interference effects are of the same magnitude, TPs transmit power can be adjusted at higher level to optimise EE or obtain a satisfactory throughput-EC tradeoff performance.
- Introduced a general framework to show how the most appropriate energy-aware static clustered cooperation can be determined and employed to optimise system energy efficiency when specific network capacity targets need to be reached.