Small Cell Clustering in HetNets

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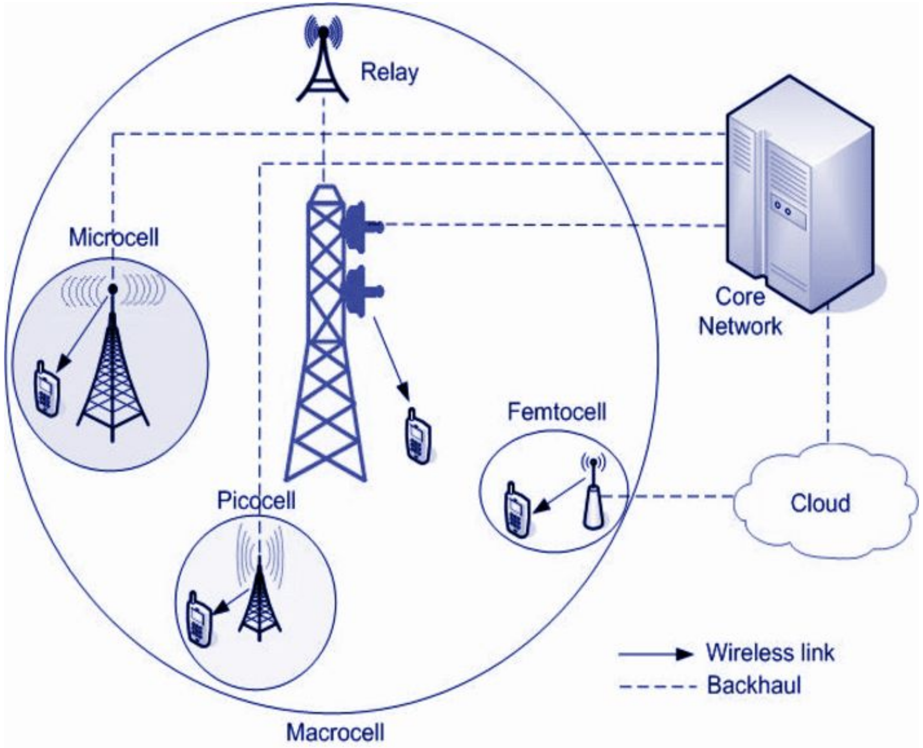
- Introduction to HetNets, Small Cells, 5G Network architecture and some more terminologies
- Why and How Machine Learning required for small cell clustering in HetNet
- Approaches and discussions

Introduction to Terminologies

HetNets



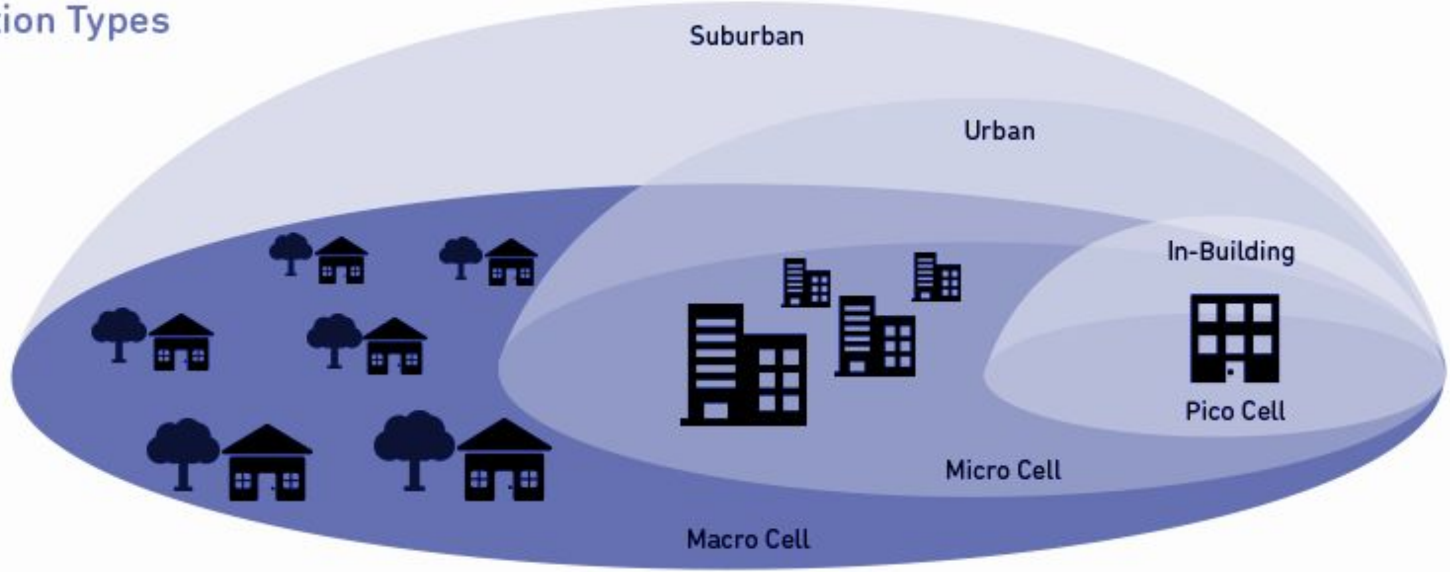
Heterogeneous networks (**HetNets**) are expected to play an important role in next generation telecommunication networks, i.e., fifth generation (**5G**) networks. A **HetNet** is composed of homogeneous cellular macro base stations with high transmission power overlaid (or underlaid) with low power base stations.

Reasons to have HetNets:

1. Low Power Consumptions
2. Effective bandwidth Utilisation
3. Avoiding Interference between signals

Backhaul refers to the part of a satellite network that serves as an intermediate between the main network and the small networks used for distribution to other smaller channels

Base Station Types



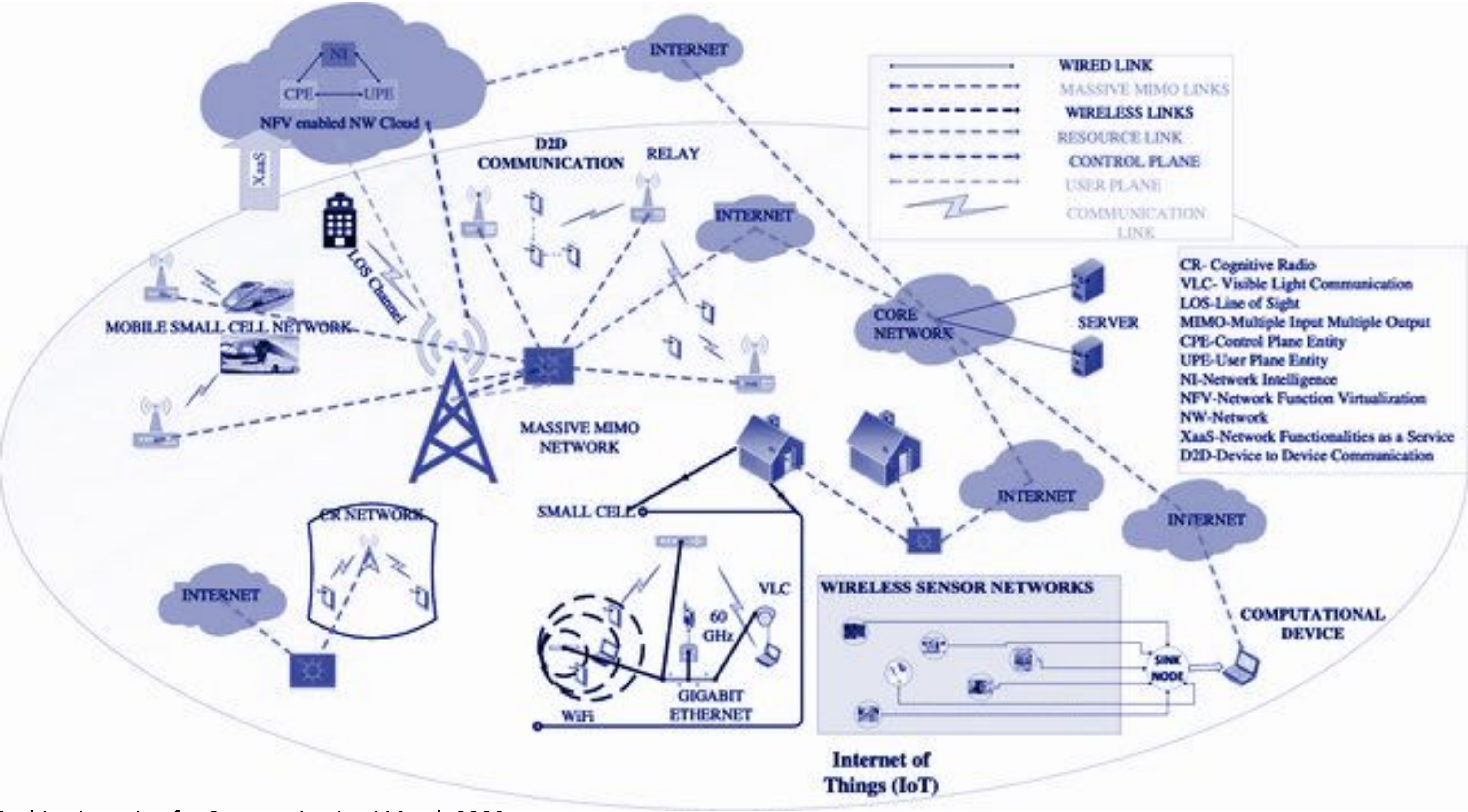
Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

Small Cells

Small cells are low-powered **cellular** radio access nodes that operate in licensed and unlicensed spectrum that have a range of 10 meters to a few kilometers. Recent FCC orders have provided size and elevation guidelines to help more clearly define **small cell** equipment.
Small cells may encompass femtocells, picocells, and microcells.

FCC: Federal Communication and Commission

5G Architecture (Overview)



Contd.

Some more Areas for Machine Learning

- **Cognitive Radio:** A cognitive radio is a radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity to avoid user interference and congestion.
- **D2D Communication:** Device to Device Communication
- **Mobile Small Cell Network**
- **NFV(Network Function VIrtualisation):** Network functions virtualization is a network architecture concept that uses the technologies of IT virtualization to virtualize entire classes of network node functions into building blocks that may connect, or chain together, to create communication services.
- **Internet of Things**
- **Network Intelligence:** It will proactively integrate AI with the cloud technology to explore the road to **intelligent** operations in a **5G network**. The target of **network intelligence** is to implement a closed-loop self-organizing, self-healing, self-optimizing **network** that can significantly improve **network** operational efficiency
- **Visual Light Communication:** Li-Fi
- **Wireless Sensor Networks**
- **MIMO Technologies**

and Many More….

Applications

- ## Radio Resource Allocation (RRA)

  Small Cell Cluster-Based Resource Allocation for Wireless Backhaul in Two-Tier Heterogeneous Networks With Massive MIMO
  (IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 67, NO. 1, JANUARY 2018)

- ## Energy Saving

  Energy Savings in Heterogeneous Networks with Clustered Small Cell Deployments
  (2014 11TH INTERNATIONAL SYMPOSIUM ON WIRELESS COMMUNICATIONS SYSTEMS (ISWCS))

- ## Small Cell Clustering

  Dynamic Small Cell Clustering and Non-Cooperative Game-Based Precoding Design for Two-Tier Heterogeneous Networks With Massive MIMO
  IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 66, NO. 2, FEBRUARY 2018

- ## Small Cell Offloading

  Small Cell Offloading Through Cooperative Communication in Software-Defined Heterogeneous Networks
  IEEE SENSORS JOURNAL, VOL. 16, NO. 20, OCTOBER 15, 2016

and many more……..

Small Cell CLustering

Ref.

Dynamic Small Cell Clustering and Non-Cooperative Game-Based Precoding Design for Two-Tier Heterogeneous Networks With Massive MIMO
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Why Small Cell Clustering Required

- To **reduce interference** among different Small Cells(SC).
- To **maximize the downlink sum rate** of SC users (SUs) subject to the power constraint of each SC BS (SBS), while mitigating inter-cluster, eliminating inter-tier, intra-cluster and multi-macro user (MU) interference.

An interference graph-based dynamic SC clustering scheme is proposed by this paper.

Approaches Till Now

- A game-based **distributed power control strategy to coordinate the interference.**
- A **Stackelberg game** is formulated to study the joint utility maximization of the Macro cell Users and Small cell Users subject to a maximum tolerable interference power constraint at Macrocell Base Stations(MBS). Formulating a Stackelberg game between MBS and SBSs, where the MBS acts as a leader and all SBSs act as follower. By setting the interference price at MBS, the SBS can determine its transmit power to achieve its optimal utility.
- Developing a **transmit power adaptation method with a non-cooperative game to reduce the inter-cell interference**.

Limitation of Previous Methods

- Those works **only considers the single antenna systems.** The extension to multiple-antenna systems is not trivial.
- A few works considering MIMO-based non-cooperative game among base stations where each base stations is equipped with multiple antennas. However, s**mall cell has only a role of a Base Station, which limits interference coordination capability among Small cells**, especially for ultra-dense Small cells.

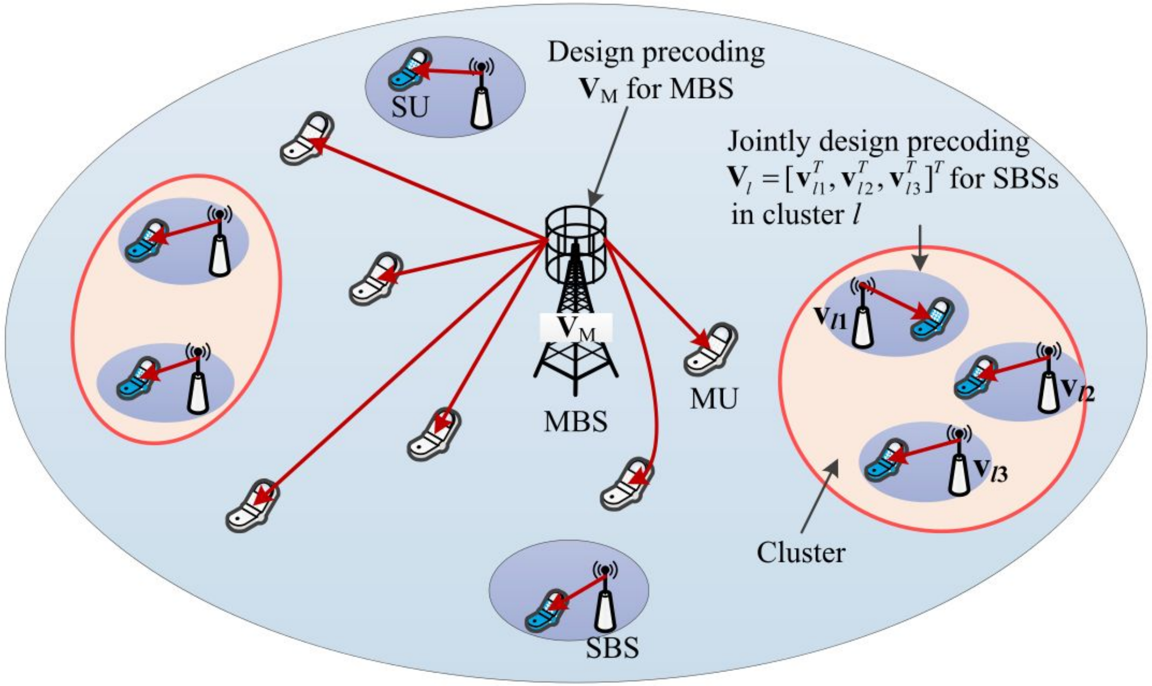
Proposed Method

- A new **SC clustering strategy** and their **precoding designs** for maximizing downlink sum rate of Small cell uses in two-tier mMIMO-HetNet.
- To reduce the interference among SCs, **an interference graph-based dynamic SC clustering scheme is proposed**, where SCs are grouped into multiple SC clusters according to their interference channel strength. On this basis, the SUs' signals are jointly designed in each cluster. **Singular Value Decomposition(SVD) to remove the intra-cluster interference**.
- **Coordinating inter-cluster interference** for maximizing the downlink sum rate of SUs

Architecture of **two-tier** heterogeneous networks (**HetNet**)

A typical **two-tier** heterogeneous networks consist of one macro-basestation (MBS) and several small-basestations (SBS). Both macro- and small-cells adopt Orthogonal Frequency Division Multiple Access (OFDMA)

System model for small cluster-based two-tier downlink mMIMO-HetNet



System model for small cluster-based two-tier downlink mMIMO-HetNet.

- **Two-Tier**:A typical **two-tier** heterogeneous networks consist of one macro-basestation (MBS) and several small-basestations (SBS). Both macro-cells and small-cells adopt Orthogonal Frequency Division Multiple Access (OFDMA)

- **MIMO**:In radio, multiple-input and multiple-output, or MIMO, is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation

- **Densification** : Densification of the network means deploying lots of small cells to enable more overall users, lower latency, better mobile device battery life, and expanded coverage.

- Combination of **massive MIMO and Densification** of small cells are collectively called **Two-Tier HetNet**.

- **Stackelberg Game theory** is used between Macro and Small cells to assign the energy efficient radio resource. MBS: Leader, SBS: Follower

- By setting the interference price at MBS, the SBS can deteRmine its transmit power to achieve its optimal utility

Input to the Small Cell User Equipment(UE)

$$
\begin{aligned}
y_{lk} &= \sum_{i=1}^{C} \sum_{j=1}^{K_i} \mathbf{h}_{ilk} \mathbf{v}_{ij} x_{ij} + \sum_{m=1}^{K_{\mathrm{M}}} \mathbf{h}_{0lk} \mathbf{v}_{0m} x_{0m} + n_{lk} \\
&= \underbrace{\mathbf{h}_{llk} \mathbf{v}_{lk} x_{lk}}_{\text{Desired signal}} + \underbrace{\sum_{j \neq k}^{K_l} \mathbf{h}_{llk} \mathbf{v}_{lj} x_{lj}}_{\text{Intra-cluster interference}} + \underbrace{\sum_{i \neq l}^{C} \sum_{j=1}^{K_i} \mathbf{h}_{ilk} \mathbf{v}_{ij} x_{ij}}_{\text{Inter-cluster interference}} \\
&\quad + \underbrace{\sum_{m=1}^{K_{\mathrm{M}}} \mathbf{h}_{0lk} \mathbf{v}_{0m} x_{0m}}_{\text{Inter-tier interference}} + \underbrace{n_{lk}}_{\text{Noise}}, \qquad (1)
\end{aligned}
$$

Input to the Macro Cell User Equipment(UE)

$$y_{0k} = \sum_{m=1}^{K_{\mathrm{M}}} \mathbf{h}_{00k} \mathbf{v}_{0m} x_{0m} + \sum_{i=1}^{C} \sum_{j=1}^{K_i} \mathbf{h}_{i0k} \mathbf{v}_{ij} x_{ij} + n_{0k}$$

$$= \underbrace{\mathbf{h}_{00k} \mathbf{v}_{0k} x_{0k}}_{\text{Desired signal}} + \underbrace{\sum_{m \neq k}^{K_{\mathrm{M}}} \mathbf{h}_{00k} \mathbf{v}_{0m} x_{0m}}_{\text{Intra-tier interference}} + \underbrace{\sum_{i=1}^{C} \sum_{j=1}^{K_i} \mathbf{h}_{i0k} \mathbf{v}_{ij} x_{ij}}_{\text{Inter-tier interference}}$$

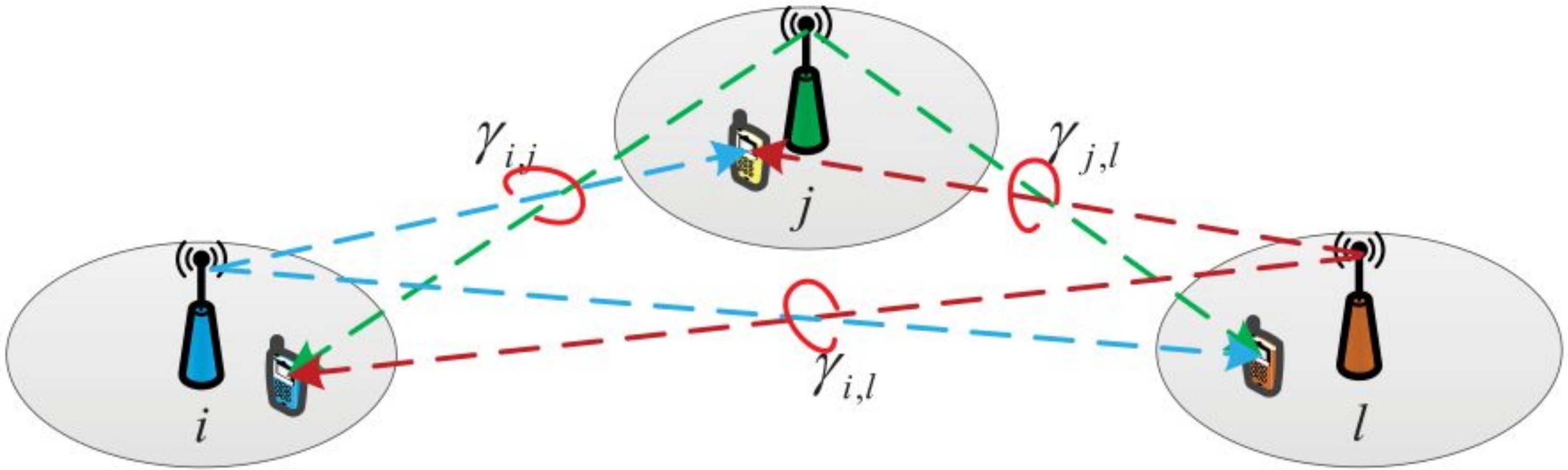
$$+ \underbrace{n_{0k}}_{\text{Noise}}, \qquad (2)$$

Average Interference channel strength between 2 Small Cells

$$\gamma_{i,j} = \frac{1}{NK_{\mathrm{T}}} \sum_{k=1}^{K_{\mathrm{S}}} \left(\|\bar{\mathbf{h}}_{ijk}\| + \|\bar{\mathbf{h}}_{jik}\| \right), \qquad i,\ j = \{1, \ldots, C\},$$

N: Total Number of antennas in Small Cell Base Station
K_T:Total number of Small Cell Users in Small Cells
K_s: Total Number of Single Antenna
h: Downlink interference channel from the ith Small Cell to the kth Small Cell User in the j th Small Cell

Interference graph model between



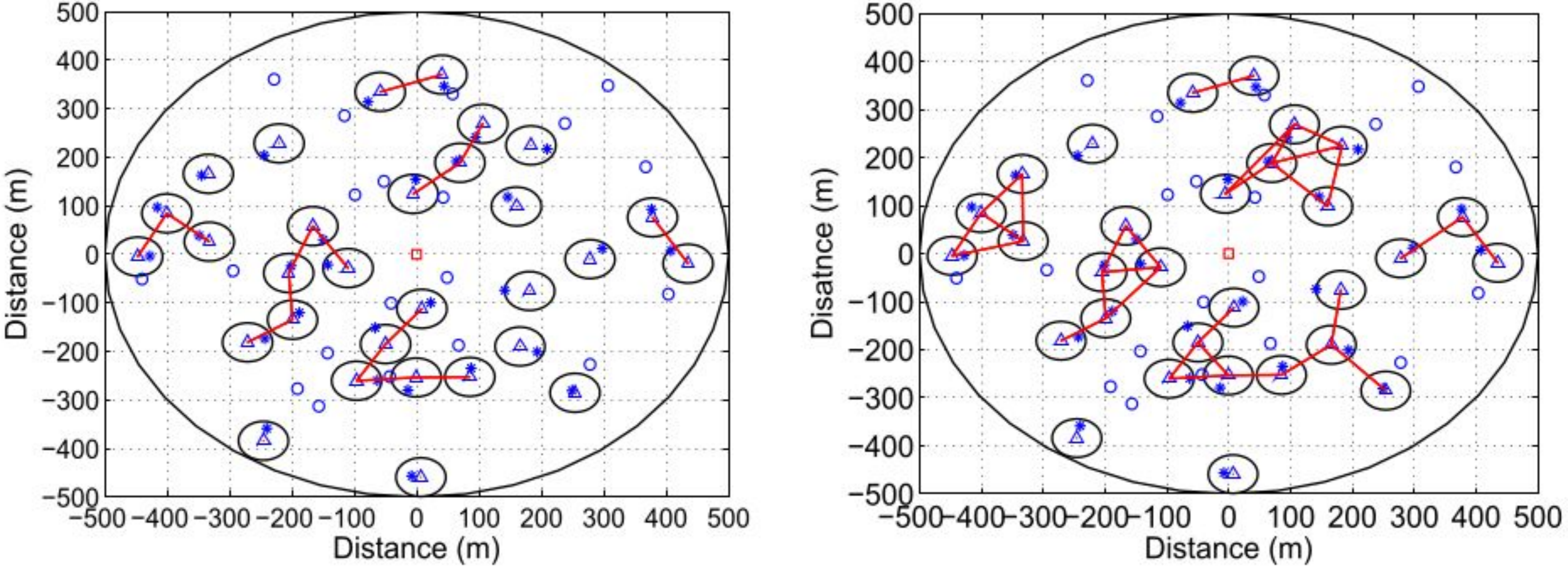
Clustering Algorithm

Algorithm 1 Interference Graph-Based Dynamic SC Clustering Scheme

Input : J, γ_{th}, $n = 1$.
Output: $\mathbf{C}$.
for $i = 1 : J$ **do**
  $\mathbf{C}\{n\} = \{i\}$.
  for $j = 1 : J \ (i \neq j)$ **do**
    Compute $\gamma_{i,j}$ according to (9).
    if $\gamma_{i,j} \geq \gamma_{th}$ **then**
      The SCs i and j form a new cluster, namely $\mathbf{C}\{n\} = \mathbf{C}\{n\} \cup \{j\}$.
      if The SC i or j has belonged to any other cluster n' **then**
        The SCs i, j and their all cluster members form a new cluster, namely $\mathbf{C}\{n\} = \mathbf{C}\{n\} \cup \mathbf{C}\{n'\}$, $n = n - 1$.
      end if
    end if
  end for
  $n = n + 1$.
end for

Note: Here, $\mathbf{C}$ should be a set consisting of several subsets. Each subset indicates a cluster and its elements represent SCs' index. Therefore, $\mathbf{C}\{n\}$ denotes the nth subset in set $\mathbf{C}$.

Clustering with different avg. Interference channel strength



(a) γ_{th}=-100dB

(b) γ_{th}=-105dB

Results

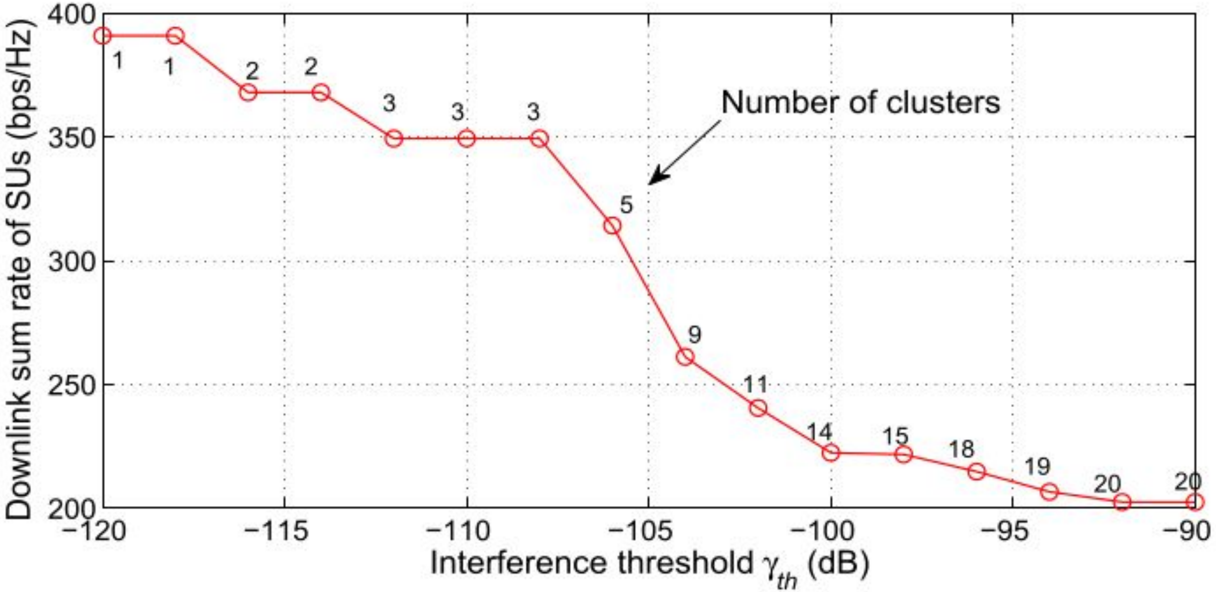
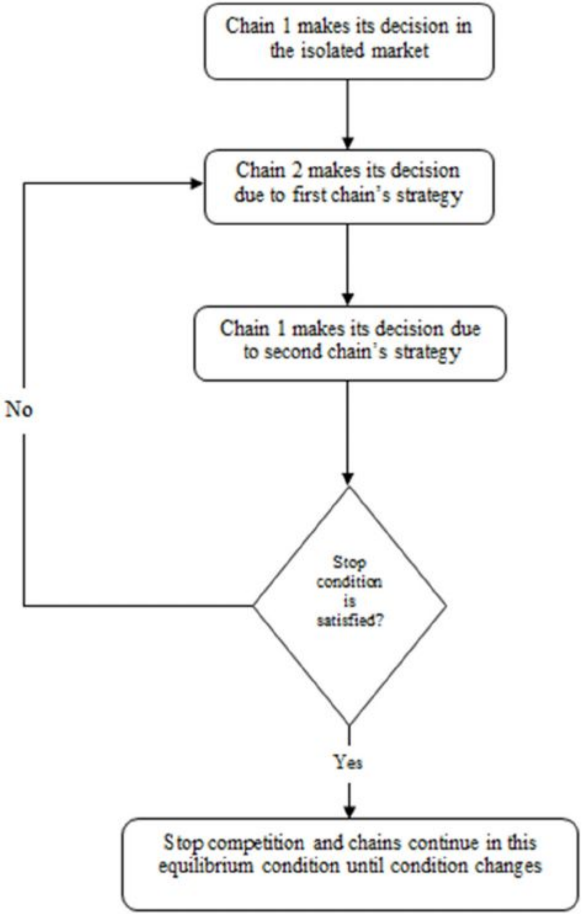


Fig. 6. Downlink sum rate of SUs versus interference threshold.



Stackelberg Game Theory

https://www.youtube.com/watch?v=eoF4c1Y9aEM

Inference from these Insights

- Machine Learning can be applied in the **Use equipment side for minimum energy utilisation**
- Machine Learning can be used in **clustering the small cell based on their inter-interference strength** provided the small cell strength associated with different small cell clusters
- Machine Learning can be used in **deciding the maximum number of small cells that can be accomodated in a cluster** provided the geographical conditions of the given location.

Where Machine Learning Can be used?

- **Interference coordination** is one of the main challenges
- In particular, macro users (MUs) and SC users (SUs) usually share the same time-frequency resource to improve the spectral efficiency, which requires robust **interference coordination scheme**.
- **A precoding scheme** has been proposed for mMIMO to suppress the impact on neighboring users (victims) through cooperation between macro base stations and small cell Base Stations..
- **Stackelberg game** between Macro-Base Stations and Small cell base stations
- **Small Cell Clusterings using nearest neighbour**
- To **eliminate the inter-tier interference** from MBS to SUs and multi-MU interference simultaneously, precoding scheme for MBS can be applied.

References

- **Small Cell Cluster-Based Resource Allocation for Wireless Backhaul in Two-Tier Heterogeneous Networks With Massive MIMO**

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- **Dynamic Small Cell Clustering and Non-Cooperative Game-Based Precoding Design for Two-Tier Heterogeneous Networks With Massive MIMO**

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- **Small Cell Offloading Through Cooperative Communication in Software-Defined Heterogeneous Networks**

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