Dynamically Adaptive Cell Clustering in 5G Networks

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***Abstract*—5G Networks is viewed as a key technology to provide seamless connectivity throughout the heterogeneous devices used in today's world. But seamless connectivity demands the 5G networks to be deployed in large scales and the current deployment methods are not suitable from the perspective of 5G. Frequency re-use with zero inter-cell interference is one such concept which can be achieved using clustering. Progressively the method of clustering in 5G should be an enhanced method so as to mitigate the issues raised due to the ultra-densified deployment. In this paper, a motivation on why to deploy 5G networks with clustering methodology and a brief on the metrics and pain points on using the clustering and the use of AI-ML algorithms in clustering is depicted.**

Keywords—ultra-dense networks; 5G; Frequency re-use; small cells;clustering

I. Introduction

Fifth Generation networks (5G) is designed to withstand the requirements of large data driven and massive bandwidth craving applications using the technologies such as Massive and Multi-user MIMO, Coordinated Multipoint transmission (CoMP), device to device (D2D) communication. Heterogeneity from the perspective of user equipment as well as the network deployment requires 5G to be most compatible and flexible with high stability and scalability. The design of 5G should be meticulously constructed predicting and analysing every nook and corner. One of such design objectives is to minimize the interference. Inter cell interference(ICI) mitigation is an important constraint from the start of mobile networking but the radius of impact of ICI on 5G is expected to be very high due to the ultra-dense network deployments.

To cater for higher spectral efficiency needs with minimum/optimized transmitting power, large numbers of base stations are to be deployed forming the ultra-dense networks. This huge deployment of base stations leads to ICI which in turn degrades the overall reliability and performance of the network. For reducing the interference in the MIMO type deployments, a technology called Interface Alignment (IA) is used which attempts to align the interfering signals in time, frequency or space. The receivers' co-ordinate with their transmitters using a linear pre-coding technique such that the interfering signals lies in the reduced sub-space. But the algorithm requires large amount channel state information (CSI) which significantly increases the signal overhead. One way to reduce the overall signal overhead is to group the cells into disjoint clusters of Base station and User Equipment pairs and apply IA to these clusters.

As the number of active UEs with high mobility per square area increases, it is necessary to cater to the network availability and bandwidth requirement of the UEs for which ultra-densification technology is used. In this scenario, small cells (Pico, femto cells etc.,) are deployed. These small cells have low power low range with high bandwidth parameters. When a user with high mobility is roaming across these small cell deployments, network outages are bound to happen. In order to mitigate these network outages, the small cells are grouped into clusters based on the parameters like distance, location etc. and each cluster is associated to a different base station based on the parameters like distance, power.

The rest of the paper is organized in the following way: Section II gives a brief on 5G and its key aspects, a brief on Artificial Intelligence (AI) and the convergence of 5G and AI to address the key issues/objectives in the next generation mobile deployments. Also the background on the concept of clustering and how clustering can benefit 5G deployments. Section III describes the deployment architecture of 5G using clustering with the terminology and working explained along the key metrics which are to be considered during the cluster formation. Section IV explains the conclusion derived from this paper and Section V provides the references used in writing this paper.

II. Background

Fifth Generation Networks (5G):

The main goal of introducing 5G networks is to provision to the heterogeneous needs of the users within low costs. 5G is expected to provide 1000x bandwidth per square unit with 100% coverage, 99.999% availability and an expected latency of 1ms. Apart from enhanced features of the traditional requirements like high speeds and higher coverage, 5G will be able to enable the key differentiating services like Machine to machine (M2M) communication, IoT applications etc. Lower power is a key area where 5G is expected to reduce 90% reduction in the network energy usage along with prolonged battery lives for devices like wearable sensors type devices. A number of key technologies are deployed in order to address different requirements of 5G some of which are multi user MIMO, CoMP, D2D Communication etc. Some of the key requirements and the technologies proposed to provide those requirements are provided in brief below:

A. Massive and multi User MIMO: To exploit the directional power of antennas, a large number of transmitter and receiver pairs are deployed both horizontally and vertically with each Tx-Rx pair to exchange narrower beams over different angles to provide a highly directional and non-interfering beams thus maximizing the network capacity and coverage area along with supporting multiple active users per square area. But on the dark side, there will be a massive increase in the computational overhead which can be significantly reduced by incorporating the concept of clustering. Clustering a group of transmitter antennas and enabling communication among the members of the cluster will significantly reduce the computational overhead raised by massive MIMO.

B. The number of active users per unit square area increases, deployment of small cells is proposed. Small cell is a base transmitting system with very low coverage and low power requirements but provides very high bandwidth to the users within the coverage area. But as highly mobile users roam across the small cells, frequent handovers are expected along with very frequent network outages. Thus in order to provide seamless connectivity to the users, the small cells are deployed in such a way that co-operative communication among the network cells need to be enabled in order to minimize the inter cell interference as well provide seamless connectivity to the users. But the cooperative communication requires exchange of channel state information (CSI) among the network cells thus increasing the computational complexity and signalling overhead which increases the bandwidth requirements further. In order to address this issue, clustering method can be proposed. Disjoint clusters of small cells can be formed within which co-operative communication can be enabled thus decreasing the computational complexity, signalling overhead and bandwidth requirements significantly due to exchange of CSI.

C. Dynamic Channel Allocation: In order to efficiently utilise the under-utilized channels including the mmWave bands, channel sensing information to be constantly exchanged among the UEs to dynamically select the channel based on the frequency range, bandwidth requirements of the user application and availability of the channel. Exchange of channel state information among the UEs increases the computational complexity and signalling overhead. In this case clustering of UEs can be proposed to enable communication among the UEs thus localizing the CSI exchange and significantly reducing the overhead.

Convergence of 5G with AI:

Artificial Intelligence is a key next generation technology that is used based on the Machine learning algorithms (ML) and neural network deployments. Sensors in different locations based on their measurement and monitoring collect data from different states and behaviours of humans, workflows or processes. This sensor data may be big or small need to be understood, analysed to provide further actions. A ML algorithm is a mathematical procedure based on which the algorithm observes and learns the patterns and trends which leads to the implementation of AI. This in short can be termed as learning from experience.

Deployment of 5G includes cooperative communication among the network components as well as the sensors involved in the key service IoT requires processing of massive amount of data and also learning from the experience is very much required for an efficient deployment. Clustering mechanism is one such example where AI can be used in the deployment of 5G key processes. ML algorithms are used to group the nodes into disjoint clusters based on certain constraints and also to manage the election process within the cluster for the election of cluster head (CH).

III. DEPLOYMENT MODEL/ARCHITECTURE:

The deployment scenario of clustering and its terminology will be briefed in this section.

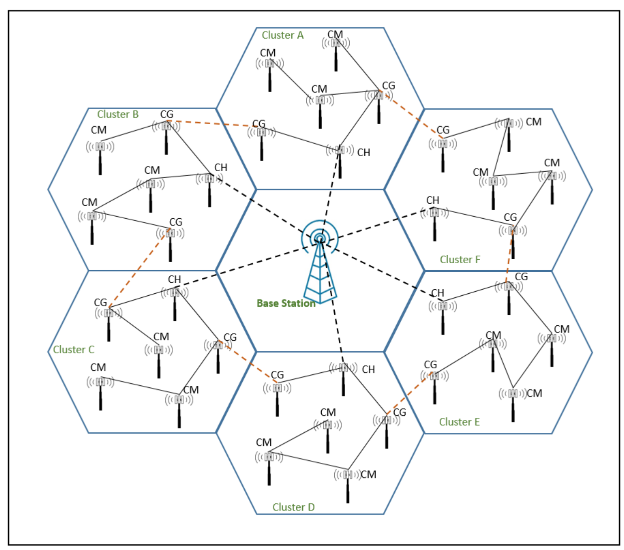

Figure-1: Clustering Deployment Architecture

In the Figure-1, a macro cell is ultra densified with small cells during the 5G deployment. These small cells are grouped into a number of clusters based on the distance and location constraints. The constraints are briefed below:

A. Distance: Based on the physical location nodes are grouped together to decrease the number of hops required for intra cluster communication. Physically nearby nodes can be clustered together which significantly reduces the overhead, computational complexity.

B. Based on the functionality performed by the nodes, clustering can be done. Nodes which provide similar requirements to the users can be clustered together so that the exchanged channel state information can be limited to that particular functionality, thus reducing the signalling overhead & computational functionality and utilizing the available resources efficiently and enabling load balancing to take place efficiently.

C. As per the node density, number of nodes per cluster can be determined. As the number of nodes per square unit increases, the number of members in the cluster increases which in turn increases the signalling overhead and computational complexity. Hence optimum number of members to be grouped into a cluster to increase the network performance and optimize the resource allocation.

D. Based on the node link connectivity, the cluster formation will have to take place to ensure inter cluster and intra cluster communication.

E. Based on the mobility of the users, number of handovers will be considered as a metric. Users with high mobility leaving one cluster and joining another cluster in a highly dynamic network, clustering can be done to optimize the number of handovers and decrease the network outages and packet loss.

F. Also the number of clusters into which certain coverage area is divided into is also an metric in cluster formation, as more number of clusters increase the computational overhead on the transceiver system.

Based on the above described clustering metrics, clustering formation will be done and the proposed algorithm can be continuously learning based on the metrics described. As these metrics change frequently, re-clustering takes place in a frequent manner.

The components of cluster as described in the Figure-1 are as below:

Cluster Head(CH): A reliable and locally less energy consuming node will be elected as a cluster head which maintains the information of all the members of that cluster and acts as a single point of contact with the transceiver system on behalf of that entire cluster. Cluster head election will also be based on the distance or number of hops from the transceiver system. Cluster head enables intra cluster communication and reduces the computational overhead on the base transceiver system.

In any case, cluster head becomes rogue or non-functional, re cluster election takes place. To avoid frequent election procedure within a cluster, a backup cluster head can be elected during the election process which acts as the cluster head in absence of the primary head.

Cluster Member (CM): All the nodes grouped into the cluster other than the cluster head are called cluster members. These cluster members communicate with each other and to the cluster head but not directly to the transceiver system under normal circumstances.

Cluster Gateway (CG): In a cluster, few nodes act as cluster gateway to communicate with the adjoining clusters, thus enabling inter cluster communication. This comes particularly handy during the handover scenario which can be described as below:

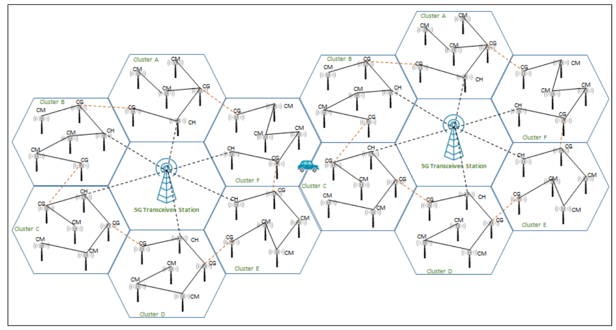

Figure-2: Handover Scenario

As the user moves from cluster F to Cluster C, handover takes place between the cluster gateways nodes of the respective clusters.

Pain Points of Clustering:

- Size of the cluster: As the cluster size increases based on the number of nodes, the resource allocation and computational overhead on the base transceiver system decreases but the burden on the cluster head increases in managing the members of the cluster.
- Dynamic Re-clustering: continuously changing requirements due to the heterogeneous devices within the coverage area require re-clustering to be done continuously which will lead to the wastage of resources for forming the clustering.
- Node to node connectivity will be another pain point where the communication among the clusters can hamper the existing cluster formed and will lead to new cluster formation.
- Grouping of nodes providing similar requirements to the users is difficult to perform locally and should be performed in a globalized manner. Thus learning should be enabled centrally to group these nodes based on considering other parameters like location and resource optimization.

IV. CONCLUSION:

Clustering mechanism is an important concept to be utilized in the deployment of 5G networks to address the issues raised due to incorporating different technologies like Massive MIMO, D2D communication, Co-operative communication among the network nodes etc. But precise design optimizations are required to cluster the ultra-densified nodes which can be possible only through continuous sensing and learning from the dynamically changing nodes. Algorithms possessing such monitoring and learning capability are to be used to perform clustering functionality. This paper highlights the motivations and metrics required for the clustering of network nodes in a efficient manner and the gives us the motivation to enhance or develop the learning algorithms.

V. References

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