Control Framework for Ultra-dense cellular networks

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Abstract. The current work focuses on the current network deployments and the transition to the 5G era, toward encompassing the proposed approaches in the network design. In this direction, the base station densification gain and the control/coordination of the Radio Access Network (RAN) are being taken into account. The densification gain (with respect to the Base Station density) represents the ability of the network to offer the desired data rate and comply with other important key performance indices for a 5G environment. Finally, load balancing and offloading techniques are discussed which are going to play an important role in the future networks. A coordination framework for the whole RAN infrastructure has been described by setting the criteria and the control mechanisms for the management of the network.

1 Motivation and Methodology

Currently, it is well known that traffic continues to grow rapidly with a forecast seen at (Figure 1) [1]. In addition, there are very demanding key performance indices for 5G technology which are provided in several documents and those are the ones that operators should consider when it will come to design the deployment of ultra-dense and multi-layer networks including 5G.

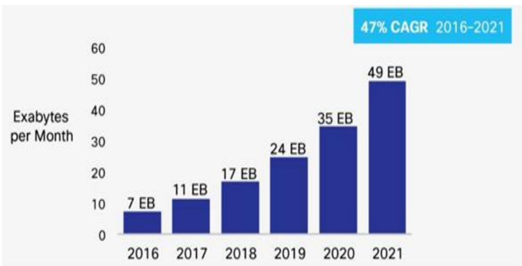

Fig. 1. Traffic forecast 2016-2021.

However, for the deployment of ultra-dense heterogeneous networks many challenges should be overcome. Firstly, there are key differences in the morphology of the existing dense networks with those of the future ultra-dense networks. Secondly, there is a difference in the philosophy of designing the deployment of the ultra-dense base stations in terms of the number to be deployed but also in terms of the physical topology.. Finally, the future networks will have different criteria for the control and coordination of the base stations, which is something currently approved in 3GPP. Therefore, the future networks will require and in depth study and analysis of techniques such as load balancing, user association and/or traffic modelling. The main parameters of the below analysis are based on our measurements in an existing 4G/4G+ network. This give us the opportunity to model the future networks not in theoretical base but on real cellular networks.

2 Network densification

2.1. Present cellular network: dense heterogeneous networks

Currently operators select a centralized architecture and deploy dense networks (Figure 1) mostly with macro Base Stations and some small cells (micro or femto Base Stations). Wi-Fi access nodes operate mostly independently from the cellular network and the frequencies in the cellular network are between 800MHz to 2600MHZ.

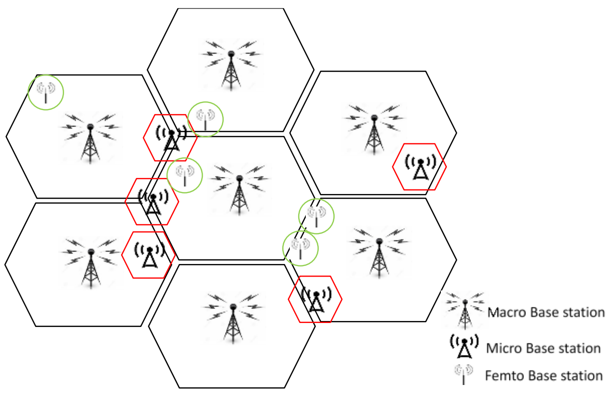

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Fig. 2. Dense Heterogeneous Network example (Macro, Micro and Femto)

Moreover, the macro Base stations and the micro Base stations are controlled by the core network. The coverage of the macro Base Station overlaps with the coverage of the micro Base Station and they are operated and controlled by separate core managers, without controlling the data exchange. Finally, this deployment cannot distribute the achievable data rates by considering the base station overweight at the denser areas of the network.

2.2 Future cellular networks: Ultra-Dense heterogeneous networks

The exponential growth of traffic and the 5G requirements bring new approaches for the network architecture. The Ultra-dense (Figure 2) network will be essential part for the network planning by the operators, who will have to design and execute the new deployments.

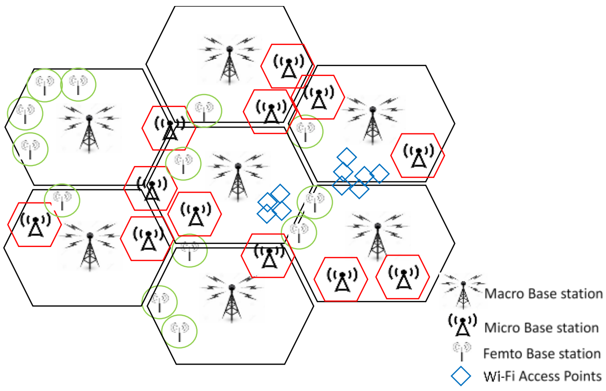

Fig. 3. Ultra-Dense Heterogeneous Network example (Macro, Micro, femto, Wi-Fi)

The massive deployment of small Base Stations will create an ultra-dense environment with cost efficiency. The operational expenses for micro and femto Base station are much more lower than the ones required by the Macro Base Stations. In this architecture licensed and unlicensed spectrum work together mostly by the aggregation of the Wi-Fi and focusing at the 5Ghz spectrum, frequencies bands are the same and higher because of the introduction of mmWave. Finally, the coordination and management of the network is centralized and distributive which allows the network to cooperate between the different infrastructures[2].

2.3 Densification Gain

Above section explains the importance of the network densification and the approach of an efficient ultra-dense network. On this section we want to define the densification gain (1) and the relation of this with the data rate and Base Station density [3].

$$G = \frac{(R_2 - R_1)/R_1}{(\lambda_2 - \lambda_1)/\lambda_1} \qquad (1)$$

G: Densification Gain, R_1= Existing data rate (Mbps), λ_1=Existing Base station density (BSs/km^2), R_2= Higher data rate (Mbps), λ_2=Higher Base station density (BSs/km^2)

As a starting point for defining the densification gain we will take the Base station density (λ1) and according to our measurements in a real 4G+ network we will set the existing data rate (R1) 25.5Mbps. We set the higher data rate of 300Mbps (according to 5G KPIs) and the higher Base station density (λ2) we will increase it from 17 to 250BSs/km2

So the formula 1 now becomes:

$$G = \frac{(300 - 25.5)/25.5}{(\lambda_2 - 17)/17} \qquad (2)$$

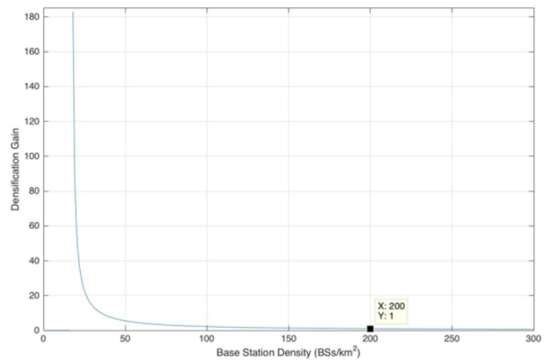

Fig. 3. Ultra-Dense Heterogeneous Network example (Macro, Micro, femto, Wi-Fi)

The results from formula 2 have been introduced in the Figure 3, according to the obtained results while the Base station density has increased and the densification gain has decayed. Ideally the best scenario for the densification of the network is when G≈1, which according the formulas 3 and 4 the ISD is dsite=132m[ ].

$$\lambda_2 = \frac{1}{A_{cell}} = 200BSs/km^2 \qquad (3)$$

A_{cell}=dominance area of a cell

$$d_{site}[km^2] = \frac{\sqrt{3}}{6}(d_{site})^2 \qquad (4)$$

Our example describes and proves the effective and immediate effective of the densification in the network capacity. The number of the Base Stations could be any Radio Access Technology (micro, femto, Wi-Fi). However, this approach and the densification in general cannot give the desirable and theoretical results by its own. The orchestration, the centralized management and the distributed management is vital for the success. The small cells tend to remain in light load and the macro cells serve the higher amount of the traffic.

3 Load balancing and offloading

The load-balancing and the offload in a multi-layer Ultra-dense network it is not only part for the 5G technology but it is the key for the success of the network. The integration of different Radio Access Technology from the 5G user equipment in order to communicate and use unlicensed spectrum (Wi-Fi), LTE advances and the new 5G standards is extremely important for meeting key performance indices. The user should understand and interact with all these different RATs as a one. This approach leads to new network control methods and user association key features [4].

3.1 Control Mechanism

The dynamic control and monitor of a heterogeneous network can offer well-distributed load across the different types of Base Stations. As we mentioned before at the densification part, the small cells tend to remain lightly loaded compared to the macro Base Stations. This behavior will reduce the impact of the offered data rate in the network but also it is a proof for the importance of network control (Figure 4).

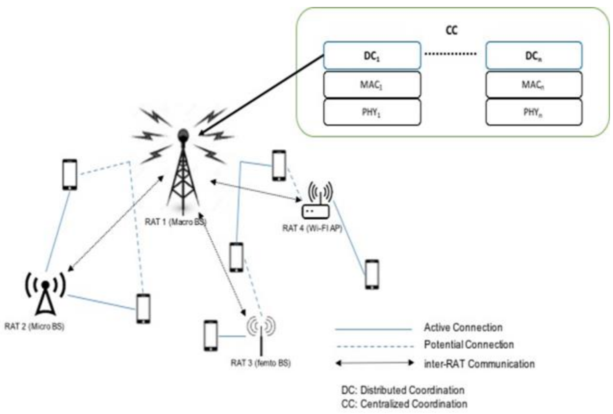

Fig. 4. Radio Access Network with Distributed and Central Controller

The proposed control mechanism splits the control decisions and the monitoring in two controllers. The distributed coordination and the centralized coordination, this hybrid type of control aspires to have dynamic coordination of the different RATs, real-time with really low latency and global view of the Users and the infrastructure (Figure 5).

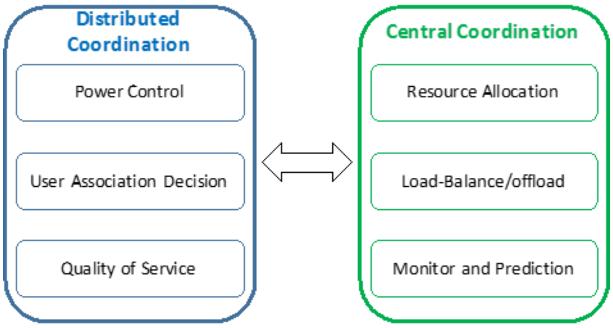

Fig. 5. Distributed and Central coordination framework

The distributed coordinator is located at the Macro Base Station, whose main task is to communicate with all of its elements. It is responsible for the power control of the Base Station, it can monitor and control the quality of service and it includes also the user association decision. However, the distributed controller communicates continuously with the central controller. The central coordination is the main "brain" of the network and communicates with more than one distributed controllers. Firstly, it is responsible to monitor the network, because of the global view of the network and with some machine learning and prediction entities can analyze the traffic and the load of the network. In addition, the controller manages the load balance and offloading algorithms in order to keep the traffic optimally distributed to different types of Base Stations and RATs.

3.2 Key features for User Association

Key factor for the successful balance of the load is the optimal user association with the different RATs. The disparity of transmit power lead the association of the most UEs with the macro cell instead of the small cells and this affects the equilibrium of the heterogeneous network. The optimal approach for user association demands the combination of different factors. Firstly, energy efficiency is the factor, the ratio of data rate and power consumption is important for power saving. Secondly the spectrum efficiency, which refers at the data rate as previous but now from the bandwidth side. Thirdly, the Quality of Service(QoS), is extremely important. The latency and the throughput which define the QoS is a primary concern for the delivery of the 5G application such as virtual reality and 4k streaming. Finally, the service classification helps the optimal user association, due to the change of the demand of the resources. For example, a user which demands video streaming has higher resources demand than a user who is browsing, this means that the "heavy" user should be associated with a Base Station with more available resources. This is an efficient traffic steering not from the network side but from users demand, which leads to fairness for user and network balance of the traffic.

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