ADOPTING UE-BASED SMALL CELL CONCEPTS IN SUPPORT OF 5G: A PERFORMANCE EVALUATION USING AFFINITY PROPAGATION ALGORITHM

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ABSTRACT

The fifth generation of mobile networks is expected around 2020 and it has many ambitions, as it aims to support more than 50 billion connected devices and to offer one thousand times higher data rate. In order to meet its demands for higher spectral efficiency, better coverage, lower delays, greater coverage and less power consumption, it is essential that 5G should redesign the way the existing networks work. This thesis focuses on the innovating idea of the selection of a subset of user devices amongst many others eligible to behave as base stations and to serve the user devices located less than 10 meters away from them. This idea aims to offer increased coverage and spectral efficiency to ultra-dense networks.

More precisely, this thesis focuses on the effectiveness of this scenario, simulating different scenarios that represent a conventional cellular network and a network with activated VBSs (Virtual Base Stations). By comparing the results, it turns out that the scenario with the VBSs has a better performance and, among other improvements, an increase in overall capacity and data rates.

Moreover, based on these promising results, this thesis also studies the way the most suitable eligible VBSs will be selected to serve as Base Stations and how users can be clustered into virtual small cells in order to be served from their providers. For this, the Affinity Propagation algorithm was proposed. Consequently, the algorithm is demonstrated and evaluated using a number of synthetic datasets for a wide range of its parameters and the results are discussed.

In conclusion, the results are satisfactory but not optimal, since the algorithm does not work properly in cases with a large amount of user devices. Finally, it is proposed to use another algorithm to initially divide the users into smaller subsets and then use a modification of the Affinity Propagation algorithm to select the appropriate eligible user device that will serve as a base station in each virtual small cell.

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Chapter 1

Introduction

1.1 Evolution of Wireless Technologies

Since the early 1980s, wireless technologies have undergone a dramatic evolution and experienced enormous growth, with the common goal of the performance and efficiency of wireless mobile communications.

From 1G, the first generation of wireless networks, which only supported voice calls we are now anticipating the fifth generation of wireless networks that is expected to support up 50 billion connected devices by the end of 2020 [1].

1G cellular wireless network was introduced in initial 1980's and was based on analog transmission and circuit switching to provide speech services [2]. Advance Mobile Phone Service (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS) were the most well used standards that consisted 1G. First generation, also paved the way for mobility as it used licensed spectrum, frequency reuse and provided consistent access and mobility by integrating backhaul network [3]. However, 1G suffered from several limitations, such as poor voice quality, unreliable coverage and insecure and unencrypted transmission.

The Second generation (2G) replaced 1G in the 1990s, with the most notable upgrade of using digital transmission techniques. More precisely, 2G was based on two different multiplexing techniques in order to increase its capabilities, the Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Furthermore, General Packet Radio Service (GPRS), Code-Division Multiple Access (CDMA) and Enhanced Data rates for GSM Evolution (EDGE) are the most widely known technology standards used by 2G. In comparison with the first-generation wireless networks, these advances allowed 2G to offer more advanced roaming, better quality and capacity and higher spectrum efficiency. Moreover, 2G introduced mobile data services, such as text messages (SMS), Multimedia messages (MMS) and picture messages, but it is unable to handle more complex data such as videos, web browsing and multimedia applications [4].

During the attempt to mitigate these limitations, 2.5G emerged as a bridge between 2G and 3G. In contrast with its descendants, 2.5G was more efficient, since it implemented a packet-switching technique as well as circuit switching [5]. In addition, GSM improved and General Packet Radio Service (GPRS) was introduced as one of the most significant technologies of 2.5G, along with Wireless Application Protocol (WAP). Consequently, with this new technology, higher speeds were achieved and Internet communication was provided including services such as email and web browsing.

The 3rd generation of mobile networks was established around 2001 and was based on Wideband Code Division Multiple Access (WCDMA). 3G gave a new dimension to telecommunication industry as it provided significantly higher data rate speeds and improved voice quality. Due these enhancements, this generation of cellular networks was able to support a range of multimedia services such as improved audio and video streaming, 3D gaming, mobile TV, video conferencing and location-based services. Furthermore, the same as 2.5G, 3G used packet alongside circuit switching until 3.5G.

The fourth generation (4G) , also known as LTE, was introduced in 2008-2009 [1]. 4G LTE and LTE Advanced offer even higher data rates than 3G, higher network capacity and seamless handoff across Heterogenous Networks, in order to support superior mobile broadband experiences. However, this generation of mobile networks also suffers from a serious limitation, as it is not efficient to support an extensive amount of simultaneously connected devices.

	Standards	Technology	SMS	Voice Switching	Data Switching	Data Rates
1G	AMPS, TACS	Analog	No	Circuit	Circuit	N/A
2G	GSM, CDMA, EDGE, GPRS	Digital	Yes	Circuit	Circuit	236.8 kbps
3G	UTMS, CDMA2000, HSPDA, EVDO	Digital	Yes	Circuit	Packet	384 kbps
4G	LTE Advanced, IEEE 802.16 (WiMax)	Digital	Yes	Packet	Packet	*up to* 1 Gbps

Figure 1. Comparison of the 4 generations of wireless technologies

1.2 Fifth Generation of Mobile Networks

1.2.1 5G Desideratum

The development of wireless technologies through the years revolutionized the way people communicate, but, as mentioned above, the existing technologies from 1G to 4G have many limitations. As follows, current cellular networks are incapable to cope efficiently with the fast increasing and ever-changing demands for better connectivity and continuous coverage. Moreover, the rapid growth of wireless data services, the outburst of wireless mobile devices, as well as the needs for a greater quality of experience, reduced latency and less energy consumption [6] necessitate the research for the fifth generation of cellular networks (5G).

1.2.2 5G Objectives

In order to satisfy the continuously increasing requirements and ambitions of the future, ongoing technologies have to evolve and be redesigned in all of their aspects [5]. Fifth generation is expected to be launched beyond 2020 [7] and aims to overcome the restraints of its predecessors, as it will constitute a major change in the design and operation of cellular networks. In addition, since scientists predict that by 2020, with the rise of Internet of Things (IoT), 50 billion devices will be connected to mobile networks [8], as well as they anticipate a thousand-fold increase in data traffic [9], it is indisputable that 5G must provide significant enhancements in capacity and data rates.

Consequently, 5G challenges include greater network capacity and higher data rates, due to the demand of 1000 times higher amount of data. Also, include tremendous quantity of connected devices [10], seamless and ubiquitous connectivity, along with enlarged reliability and zero end-to-end latency, which are critical in real-time applications. Finally, fifth generation should improve data security and also be able to handle interference and high mobility alongside achieving cost effectiveness and higher efficiency [11] with low energy consumption.

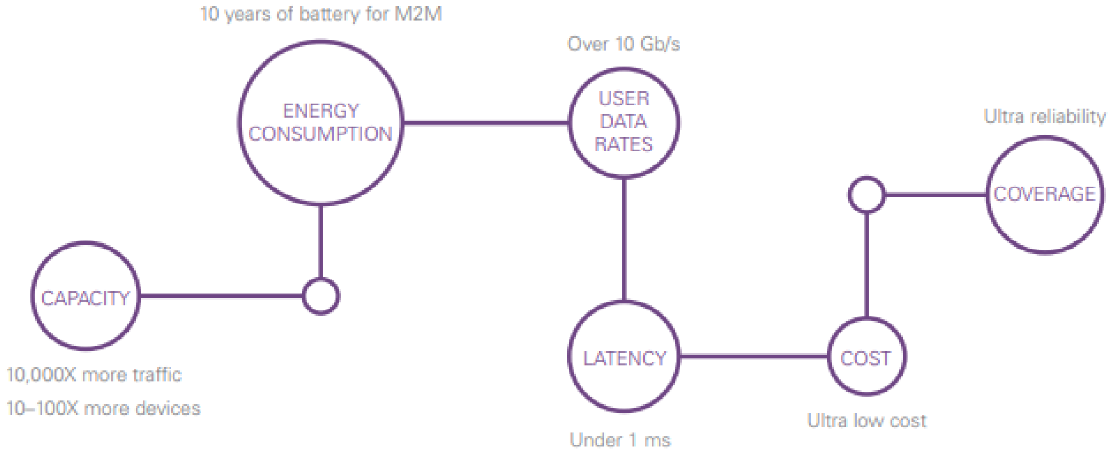


Figure 2. Challenges of 5G [8]

1.3 5G Architecture Vision

In order for 5G to address the above demands and challenges that is expected to, it is clear that the existing network infrastructures need to be remodelled. Furthermore, the conventional networks set-up need a significant change in the design [7] and the addition of some new techniques [5] that will enable 5G to fulfil its purpose.

Figure 3. 5G Enabling Technologies [12]

These new technologies include the Wireless Software-Defined network (SDN), the Millimeter Wave Spectrum, the Massive MIMO, the Network function virtualization (NFV), the Device-to-Device (D2D) communications, the Big data-driven network intelligence, Ultra-densification and the Cloud Radio Access Network (C-RAN).

5G objectives	*5G Possible Technologies*
Greater network capacity and higher data rates (~1000x higher amount of data 4G, user data rates in the order of Gbps)	Spectrum reuse and use of different band (e.g., mmWave communications) Ultra-densification C-RAN Massive MIMO
Reduced latency (1 millisecond end-to-end latency)	Big data and mobile cloud computing C-RAN D2D communication
Network densification (50 billion connecting devices)	Massive MIMO SDN Mobile cloud computing

Seamless and Ubiquitous connectivity	Ultra-densification D2D communications SDN
Higher energy efficiency (~10 times longer battery life for devices)	Wireless charging Ultra-densification D2D communications
Improved security	Big data and mobile cloud computing SDN

Table 1. 5G Objectives and Possible Technologies for each objective [12], [13]

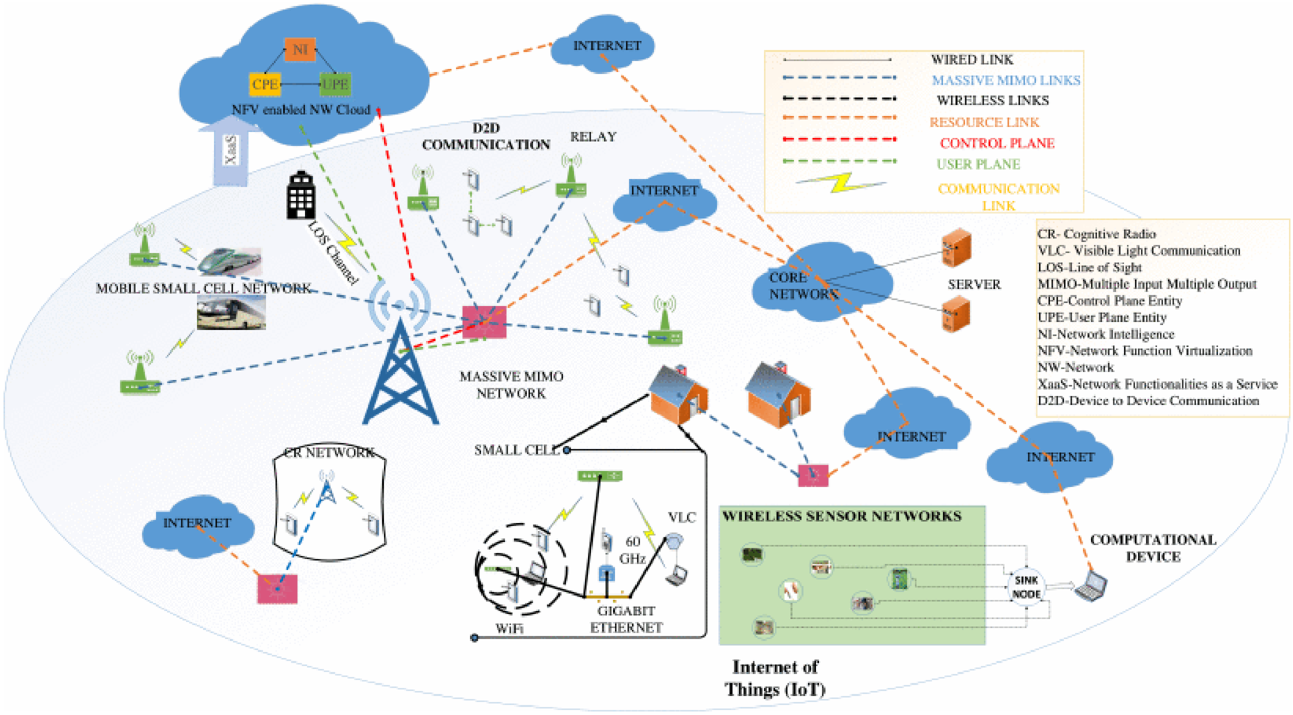


Figure 4. 5G Cellular Network Architecture [5]

1.4 Small cells as a possible part of the solution

1.4.1 The concept of small cells

According to Small Cells Forum [14], small cells are defined as "*low-power wireless access points that operate in licensed spectrum, are operator-managed and feature edge-based intelligence. They provide improved cellular coverage, capacity and applications for homes and enterprises as well as metropolitan and rural public spaces.*". Small cells have a scope between ten meters and a few hundred meters, while a typical macro-cell has a range of up to several tens of kilometers. The utilization of small cells is promising to raise the traffic data rate on mobile networks significantly. Using this method, a macro-cell or a hot spot is divided into smaller cells so users are able to connect to small cell BSs [15]. Hence, less users are connected to each station with a reduced distance than that of the macro-cell BSs and bandwidth can be reused or used for intra-small cell communications. As a result, small cells increase the macro-cell's edge data capacity, speed and overall network efficiency.

1.4.2 Types of small cells

Femtocell

A small, low-power, short range, self-contained base station, whose access node is referred to as Home eNB (HeNB) in LTE. Typically intended for residential homes or small business. The coverage range for a femtocell is less than 100 meters and the power typically ranges from 10 mW to 100 mW. A residential femtocell can support 4-8 users and an enterprise femtocell can support 16-32 concurrent users [16]. Key attributes include IP backhaul, self-optimization, low power consumption and ease of deployment [14]. The "plug and play" feature enables mobile operators to save the backhaul cost as the traffic of the femtocell can be carried via subscribers' broadband communication links to the core network. Backhaul links also help in offloading some of the traffic from the associated eNB, thus reducing traffic congestion at the eNB. A femtocell can operate in closed access mode, where only the UEs included in the cell's closed subscriber group (CGS) can connect, or open access mode, where all cellular UEs can connect [17]. An additional hybrid access mode allows all UEs to access the femtocell but a group of subscribers is prioritized. Moreover, femtocells can be assigned by mobile operator licensed bands of associated macro-cell or distinct spectrum bands.

Picocell

A low-power compact base station, which has a coverage range of about 200 meters or less. Picocells are used indoors and outdoors to provide hotspot coverage in enterprise or public areas like airports, stadiums and malls [17]. Their typical power for indoor use is 100-250 mW and for outdoor use is 1-5 W. Moreover, they can support 64-128 concurrent users [16] and they require some caution in selecting the number and location for indoor use. However, the self-optimizing features, borrowed from femtocell technology, minimize the amount of management required [14]. Their access is open to all UEs.

Microcell

An outdoor short-range base station that improves the users’ coverage where macro coverage is not enough [14]. The distance between two micro base stations is 500 meters or more, so it offers coverage to users in a wide range of area. A microcell can support 128-2568 concurrent users and its typical power ranges between 5 and 10 W [16]. Moreover, a microcell provides high mobility as a result of the reduced handover frequency. However, the data rate of this connection is low and unstable because of channel fading and traffic congestion [17].

Metrocell

Metrocells are small cells designed for high capacity metropolitan areas. They are typically installed on building walls and street furniture like lampposts and CCTV poles [14]. Moreover, they are used to provide additional capacity and they support more than 250 concurrent users. Their coverage range is hundreds of meters and their typical power is 10-20 W [16].

Relay Nodes (RNs)

The relay nodes are low-power base stations that enhance the coverage and capacity of macro-cells at the cell edge. RNs were defined in 3GPP Release 11 as one of the technologies supported by LTE-A systems. They have a typical transmit power of 1 – 5 W and coverage of a few hundred meters. A relay node is connected to its Donor eNB

(DeNB) via a wireless backhaul link [17]. UEs in some locations fail to communicate directly with a DeNB because the distance between them is greater than their transmission range. The deployment of RNs can overcome this issue effectively. Specifically, a RN receives the signals from the mobile users and retransmits them over the wireless backhaul link between the macro-cell and the RN [18] .Moreover, a RN can operate in inband and outband relaying modes. In inband relaying mode, the relay backhaul link and the relay access (RN-UE) link share same carrier frequency. On the other hand, outband relaying employs different carrier frequencies for the backhaul and access links [19]. Furthermore, to bypass the interference from a RN transmitter to its own receiver, the multicast-broadcast single-frequency network allows only backhaul transmissions between the RN and its associated DeNB [19]. Another point is that RNs offer additional flexibility in backhaul where wireline backhaul is unavailable or not economical [20].

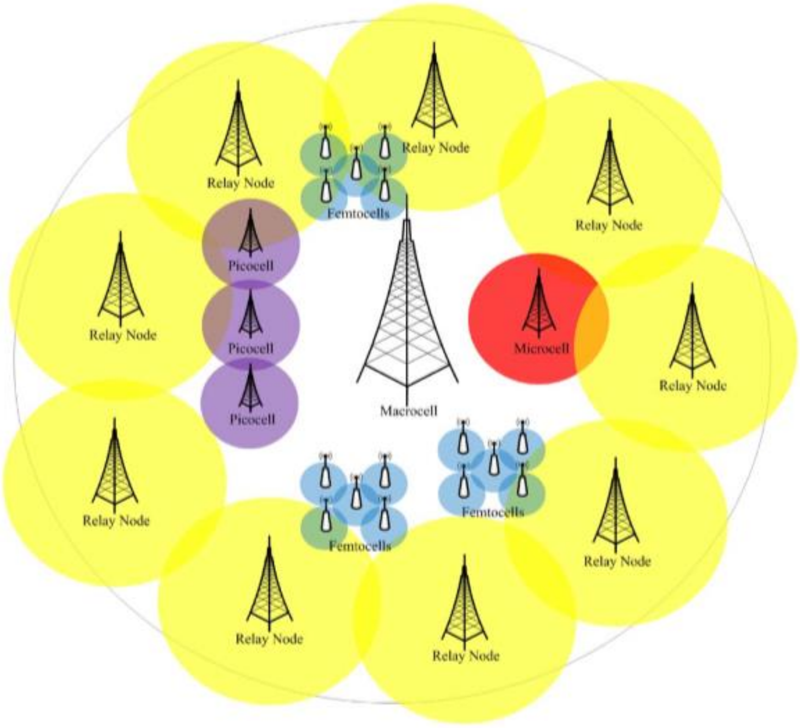


Figure 5. Small Cells Deployment [5]

1.4.3 Heterogeneous networks

Traditional network deployment approach

Before LTE-A, cellular systems were typically homogeneous. A homogeneous framework utilizes a macro-centric planning process where the locations of the macro-BSs are carefully chosen and the settings of each BS are configured to maximize the coverage and minimize the interference between them. All the BSs are similar in terms of transmit power, backhaul connectivity, power requirements, coverage range, antenna patterns etc. Furthermore, all the BSs serve approximately the same number of UEs. This approach is no longer sustainable as the wireless cellular systems have advanced to a point where a network with just one macro-BS reaches near optimal performance. Hence, the next generation leap will come from an evolved network topology [20].

Heterogeneous network deployment approach

A Heterogeneous Network (HetNet) is a network where a mixture of macro BSs, small cells (such as microcells, picocells, femtocells and RNs) and sometimes Wi-Fi access points, are deployed together to provide a complete coverage with handoff capabilities among them [14]. This multi-tier architecture aims to serve users with different QoS requirements in a cost, spectrum and energy-efficient manner. The small cell-based HetNets mechanism was specified by 3GPP (Third-Generation Partnership Project) in LTE-A cellular communications.

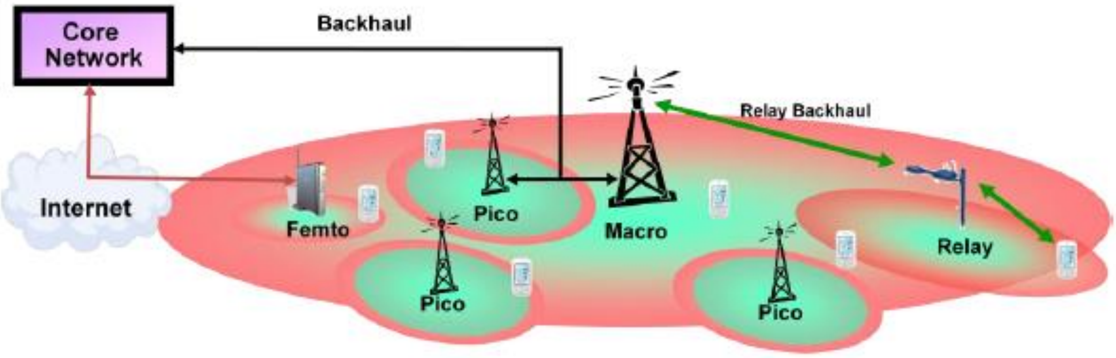


Figure 6. Heterogeneous Network utilizing macro, pico, femto and relay base stations [20].

Small cells are usually placed in key positions to fill coverage holes within the macro-cell and to expand the capacity in high-populated areas. This avoids the deployment of additional costly eNBs which requires careful network planning [19].

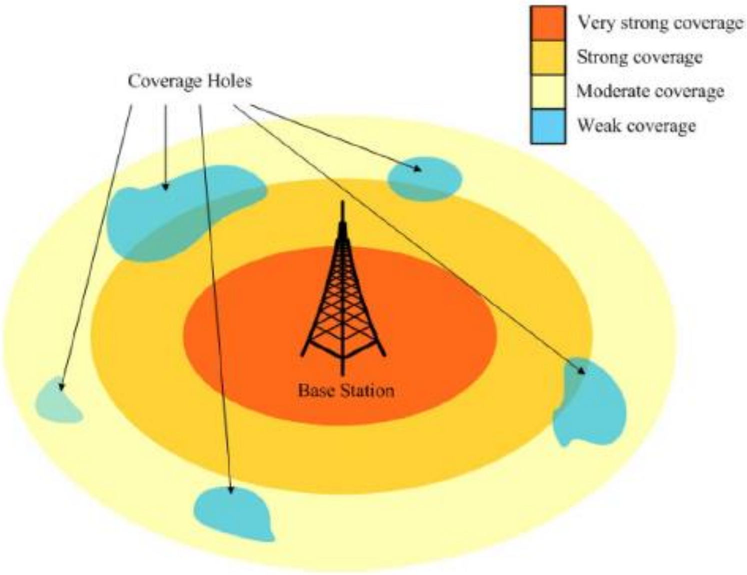


Figure 7. Coverage holes in a macro-cell [19].

Dense networks

Traditional deployments of small cells uniformly divide a macro-cell into smaller regions each covered by a small cell. On the other hand, dense networks radically raise the number of cells per unit area. More specifically, a massive number of heterogeneous, low-power nodes are deployed in opportunistic positions and are activated on demand [21]. Network densification has the ability to linearly increase the capacity of the network proportionally to the number of deployed cells via spatial spectrum reuse, and is believed to be the key facilitator to deliver high capacity gains in the next generation of networks [22].

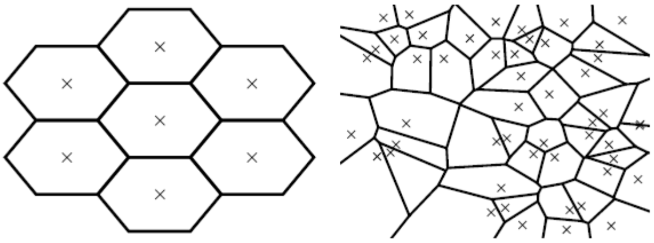


Figure 8. Traditional deployment on the left; Dense deployment on the right [21].

1.4.4 Benefits of small cells

By utilizing small cells, an ever-increasing number of users can be served by the wireless cellular network, particularly with enhanced connection quality. More users can be offloaded from the macro-stations to small-cells, thereby reduce traffic congestion and free up more resources for the users connected to the macro-station. Since a small cell BS typically serves a small number of UEs, more resources can be allocated to each UE providing the users better QoS. In addition, there are many scenarios where a user can be better served by a small cell instead of a macro cell. For example, the signal from a MBS usually attenuates in indoor environments due to high indoor building penetration losses. However, the deployment of small access nodes in close proximity to the users invariably provides superior indoor coverage [19]. Another example is the coverage blind spots created by obstacles like a tall corporate tower where users can have better coverage by outdoor small cells. Moreover, building enough macrocells to meet the demand for ubiquitous high-speed connectivity is financially prohibitive considering the expensive installation and careful planning required for MBS deployment [14]. On the other hand, small cells are a cost-effective solution with reduced CAPEX and OPEX for the network operators. What is more, moving the BSs closer to the UEs results in a higher-quality air interface and efficient spectral reuse. Additionally, the lower transmission power requirements of small cells save energy at BSs and battery life at UEs. More throughput can be achieved because with the higher signal quality of small cells, more bits can be transmitted at the same time. Furthermore, deploying RNs at cell-edge enhances coverage and throughput performance and offers more balanced load distribution between cell-center and cell-edge areas [19]. Together with the combination of new spectrum, mMIMO, mmWave and other technologies of 5G the goal for 1000x capacity increase can be accomplished (10x performance, 10x more spectrum, 10x more cells) [23].

1.4.5 Challenges of small cells - HetNets

In spite of the fact that the small-cells innovation is advantageous to wireless cellular networks, many substantial challenges emerge. In 3G/4G, the system designs are primarily based on the contexts and requirements of macrocells. However, 5G ultra-dense HetNet is not a simple upgrade of its predecessor networks. The densification and randomness of small access node deployment creates a new operational environment, where many issues arise in terms of interference mitigation, backhaul connectivity, radio resource utilization, user scheduling, mobility management, fairness, complexity and QoS.

Interference

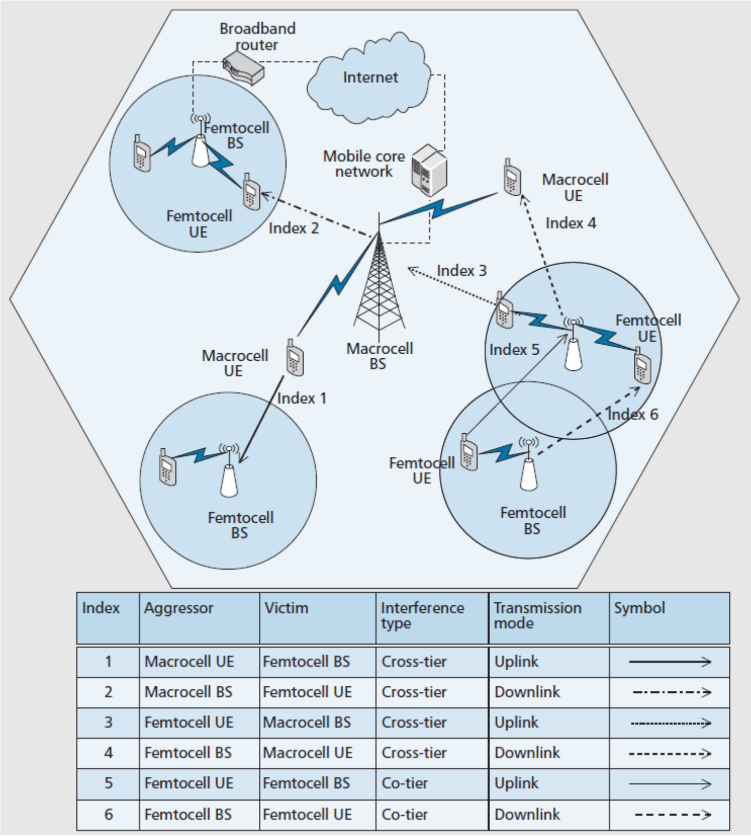
One of the major challenges is interference management between neighboring small cells and between small cells and macrocells. The heterogeneity and density of wireless devices, the different transmit powers of various BSs as well as the cooperation among BSs further complicate the dynamics of the interference. Also, the conventional strategies for interference management (e.g., channel allocation, power control, cell association) in single-tier networks may not be efficient in a HetNet, thus new research on the interference mitigation problem is needed [24].

Co-tier interference

Co-tier interference appears among network nodes that belong to the same tier in the network. In the case of femtocells, this happens when neighboring femtocells have coverage overlaps between them. For instance, a femtocell BS (FBS) (aggressor - the source of interference) causes downlink co-tier interference to the neighboring femtocell UEs (FUEs) (victims). Whereas, a FUE (aggressor) causes uplink co-tier interference to the neighboring FBSs (victims). In OFDMA (orthogonal frequency division multiple access) systems, the co-tier interference occurs only when the aggressor and the victim use the same set of PRBs (in OFDMA, the channel bandwidth is divided into small radio resources known as physical resource blocks - PRBs). Thus, efficient allocation of PRBs can reduce this type of interference in OFDMA-based HetNets [25].

Cross-tier interference

This type of interference is generated between network elements that belong to different tiers of the network (e.g., between femtocells and macrocells). For instance, FUEs and MUEs cause uplink cross-tier interference to the serving MBS and the adjacent femtocells, correspondingly. On the other hand, the serving MBS and femtocells cause downlink cross-tier interference to the FUEs and nearby MUEs, respectively. Equally, in OFDMA-based networks, cross-tier interference occurs only when both the aggressor and the victim share the same set of PRBs [25]. The Interference between the eNB and FUEs is virtually negligible when femtocells are deployed in coverage holes [19].

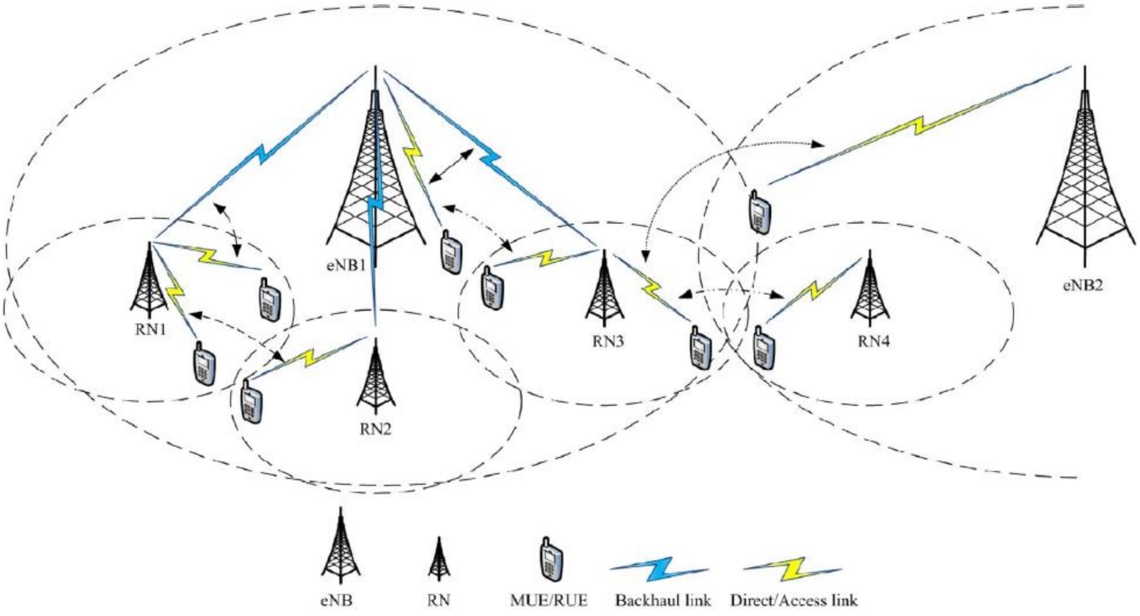


Index	Aggressor	Victim	Interference type	Transmission mode	Symbol
1	Macrocell UE	Femtocell BS	Cross-tier	Uplink	———→
2	Macrocell BS	Femtocell UE	Cross-tier	Downlink	-·-·-·→
3	Femtocell UE	Macrocell BS	Cross-tier	Uplink	··········→
4	Femtocell BS	Macrocell UE	Cross-tier	Downlink	---------→
5	Femtocell UE	Femtocell BS	Co-tier	Uplink	———→
6	Femtocell BS	Femtocell UE	Co-tier	Downlink	- - - - - →

Figure 9. Interference scenarios in OFDMA-based femtocell networks [25]

Relay Node Interference

There are three types of interference in relay-based networks: Inter-cell interference, Intra-cell interference and Inter-RN interference. Inter-RN interference arises when two neighboring RNs use the same set of PRBs even if the RNs are associated with two different DeNBs. Inter-cell is generated when a RN in a macrocell and an adjacent MUE or a RN associated with a neighboring macrocell use the same set of PRBs. Intra-cell interference occurs when the direct links, backhaul links and access links utilize the same set of PRBs [19].



Interference	Interfering Links	Symbol
Intracell	eNB1 - RN3 eNB1 - MUE	⟷
Intracell	eNB1 – RN1 RN1 - RUE	←–→
Intracell	eNB1 - MUE RN3 - RUE	←·-·→
Inter-RN	RN1 - RUE RN2 - RUE	←--→
Intercell	RN3 - RUE eNB2 - MUE	←······→
Intercell/Inter-RN	RN3 - RUE RN4 - RUE	←··→

Figure 10. Interference scenarios in relay-based networks [19].

Backhaul connectivity

When small cells were firstly embedded in cellular networks, their number was limited. Hence, the limited burst backhaul traffic created by small cells was forwarded into the core network by traditional backhaul link [26]. However, with the utilization of mMIMO and mmWave technologies in 5G ultra-dense networks, the small cells are expected to provide more than 1 Gbps throughput which has to be forwarded into the core network by the backhaul. Hence, the backhaul network capacity will be a bottleneck [27]. Consequently, the need for backhaul evolution which will maintain connectivity at satisfactory capacity and QoS arises. Nonetheless, the implementation of efficient and economical backhauling solutions for ultra dense small cell deployment is a challenging problem. Surveys demonstrate that 96% of the network operators acknowledge backhaul amongst the most critical issues in small cell deployments [22]. Moreover, the backhaul requirements differ depending on the target QoS, the location, the cost and the traffic load, therefore there is no optimal solution. The small cell backhaul links are used to forward/receive the user data to/from the core network and exchange information between different small cells. The backhaul connections for 5G small cells will be both wired and wireless. While wired solutions guarantee high data rates and reliability, they are costly. In addition, this kind of backhaul connectivity may not be mandatory for the small cells that are ordinarily serving less traffic load compared to a macrocell [28]. Thus, wireless backhaul links will regularly be chosen as a lower-cost solution. For example, mmWave, non-line of sight (NLOS), standard microwave will usually be selected. What is more, new frequency bands are being examined for wireless backhaul such as 3.5 GHz, 60 GHz, and 80 GHz [23].

Mobility

In a multi-tier HetNet architecture handover failures and radio link failures may be too frequent if small cells are used when devices are highly mobile, causing signaling overhead and robustness downgrade. Hence, highly mobile UEs should be handed over to the macrocell tier and low mobility or static UEs should be kept in the small cell tier. New mobility management solutions are needed, where accurate mobility of the UEs is estimated and each UE is connected to the corresponding cell tier according to its speed. Moreover, slicing the transmission of control and data planes will yield to a more robust mobility, by assigning the transmission and management of control/mobility traffic to the macrocell BSs and the data traffic to the small BSs [22]. Furthermore, as simulations for the impact of small cell deployments on mobility performance implied, the handover optimization technique can effectively reduce the handover failure rate [26].

Chapter 2

Background Knowledge

2.1 Related Work

2.1.1 CelEc framework for reconfigurable small cells

Cella Ecosystem (CelEc) [29] is an innovative suggestion on 5G, that it aims to evolve and supplement the Mobile Radio Network. This proposal introduces the cella cell, the smallest and portable small cell, that is expected have coverage up to 10 meters in range and its purpose is to provide massive mobile device support, when the network is stressed. The basic concept is to use the crowd's densely distributed UEs, as computing elements which will offer their networking functionalities, computing and storage resources. More precisely, the idea targets especially towards outdoor places where the network usage is high. Furthermore, it allows the users to have full access to these portable small building blocks and units of network CelEc Devices (CelDes), if it is necessary, at any time and at any location. Finally, this reconfiguration of the infrastructure of mobile network, intents to bridge coverage gaps, improve the uplink and downlink network capacity, and also to increase data rates, throughput and spectral and energy efficiency.

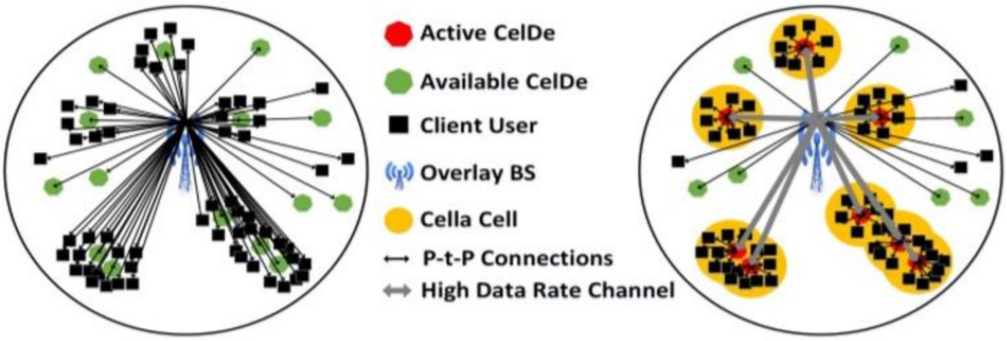


Figure 11. Representation of a current Small Cell concept on the left and Representation of a CelEc concept on the right [29].

2.1.2 Virtual Small Cells Formation in 5G Networks

Similarly with CelEc Framework, Virtual Small Cells Formation that is proposed in [15] is also an innovating solution for 5G Networks. In this approach a group of users will serve other users as base stations of virtual small cells, in order to connected them to the microcell base stations. By employing this approach, the number of communication links that are needed to connect the users to the macrocell base stations or the small cells is decreased and it is almost proportional to the logarithm of the density of the UE. Due to this, the overall network capacity can significantly increase. Moreover, the cellular network spectrum will be released for macrocell to small cell communications, the bandwidth will be used more efficiency, the signaling overheads will be offloaded from the macrocell BSs to the small cell BSs and finally it will reduce the complexity and cost of implementing massive MIMO systems.

2.1.3 Selection of VBSs using Affinity Propagation Clustering

To implement the concept of a UE acting as a BS and serving other UEs, it is essential to choose a clustering technique that will properly select which UEs will serve as UE-VBSs (UE Virtual small cell Base Stations) every time and in every location. More specifically, it is required to cluster the eligible UE-VBSs and select the active UE-VBS, which is the cluster center. Affinity Propagation Clustering technique [30] is the most suitable algorithm for the dynamic and optimal selection of the active UE-VBSs, because it doesn’t requires to select the number of clusters from the beginning, it doesn’t allow the random selection of the initial cluster centers and finally it chooses the cluster centers among the data points, which is extremely important because in the VBSs approach the cluster center must be a UE among the eligible UE-VBSs.

However, Affinity Propagation algorithm uses the similarity measure as a parameter but a modification of the algorithm is proposed in [30], which will better fulfill the requirements of the formation and selection of the virtual small cell. In this modification, the algorithm uses the power received by a UE from an eligible UE-VBS as a parameter and in addition, the messages are being passed only between the UEs and the eligible UE-VBSs, in contrast of the original algorithm where the messages are being passed among all the nodes.

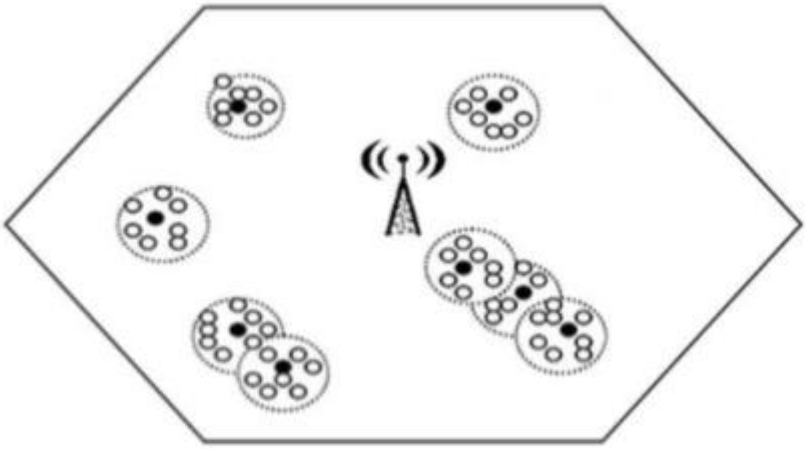


Figure 12. Representation of a Network consisting of one BS and nine clusters, each cluster containing UEs (white nodes) and an active UE-VBS (black node).

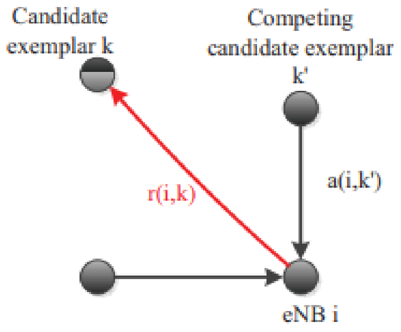
2.2 Affinity Propagation

2.2.1 Algorithm Description

Affinity Propagation [31] is a clustering algorithm that was devised by Brendan J. Frey and Delbert Dueck in 2007 and it is known and used due its simplicity, general applicability and performance. This algorithm organizes the data points into clusters considering the similarity between those data points. In contrast with other k-centers clustering algorithms that select the cluster centers (exemplars) randomly before the algorithm runs, AP (Affinity Propagation) considers that of all the data points could be possible exemplars and doesn't need to select the number of clusters and choose the initial set of points. Instead, AP takes as input the value s(k,k), that represents how possibly is for data points with bigger values than s(k,k) to become exemplars, also referred as "preferences". The similarity value s(i,k), represents how suitable the data point k is to be the exemplar for data point i. However, if all preferences have the same suitability to become exemplars, then a common value should be assigned to all the preferences. This value may be the median similarity or minimum similarity of the inputs. By using this technique, AP overcomes the problems that may cause with the k-centers technique, which include the rerun of the algorithms several times until a good exemplar is found and the precondition that the number of clusters must be small in order for the algorithm to run properly.

Additionally, AP, as it considers all data points as possible exemplars, iteratively exchanges messages between those data points until the optimum set of exemplars and clusters emerges. More precisely, the AP algorithm runs several iterations and each iteration has two types of message passing between the data points, the responsibility and the availability.

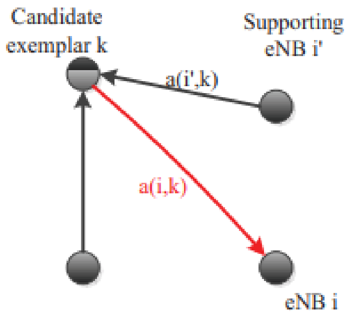
The responsibility r(i,k), is sent from data point i to the candidate exemplar k and represents the suitability of data point k to become the exemplar of data point i. In the beginning the availabilities are set to zero.



$$r(i,k) \leftarrow s(i,k) - \max_{k' \text{ s.t. } k' \neq k} \{a(i,k') + s(i,k')\}$$

Figure 13. Responsibilities r(i,k) are sent from data points to candidate exemplars on the left and responsibilities equation on the right [32].

The availability a(i,k), is sent from candidate exemplar k to the data point I and represents the suitability of the data point i to select point k as its exemplar. Self-availability a(k,k) is computed different.



$$a(i,k) \leftarrow \min\left\{0, r(k,k) + \sum_{i' \text{s.t.} i' \notin \{i,k\}} \max\{0, r(i',k)\}\right\}$$

$$a(k,k) \leftarrow \sum_{i' \text{s.t.} i' \neq k} \max\{0, r(i',k)\}$$

Figure 14. Availabilities a(i,k) are sent from candidate exemplars to data points on the left and availabilities and self-availabilities equations on the right [32].

Finally, the clustering procedure is completed, when after the message passing iterations, an unchanging set of exemplars emerges (convergence) or if a predefined number of maximum iterations is reached.

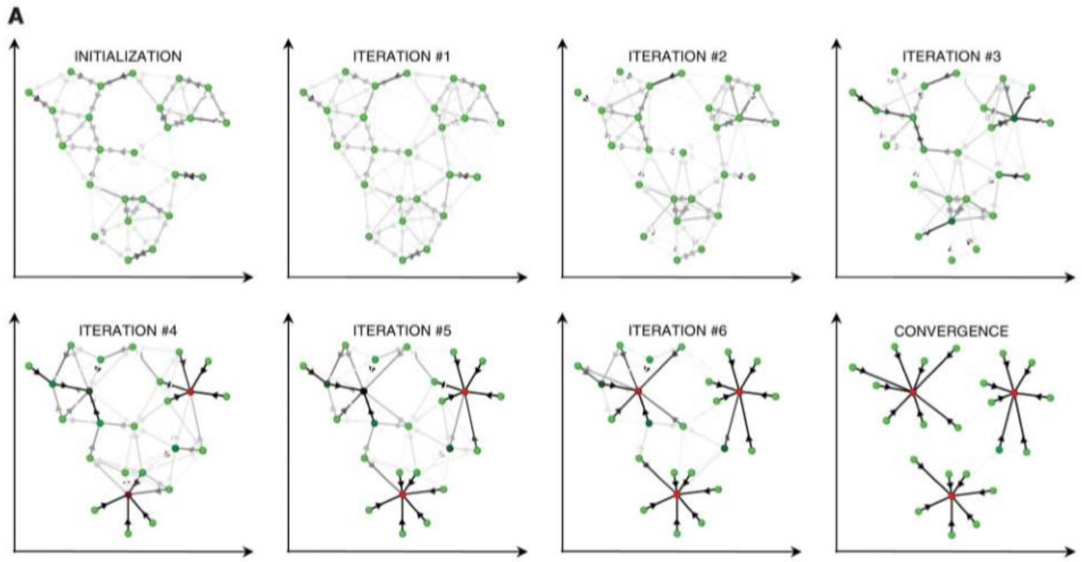


Figure 15. Affinity Propagation procedure from initialization until convergence [31].

2.2.2 Benefits and Drawbacks

Tested in many different clustering problems, such as clustering cities, micro array measurements and images of faces, it turned out that AP found clusters with considerably lower error and especially lower amount of time (less than one-hundredth), than other algorithms did. Nevertheless, it also turned out that AP is not the most suitable algorithm for big datasets, due to its complexity. The algorithm’s complexity is in the order of $O(N^2T)$ and the memory complexity is in the order of $O(N^2)$ if a dense similarity matrix is used, where N is the number of data points and T is the number of iterations until convergence.

Chapter 3

Problem Simulation and Formulation

3.1 VBS Scenario Simulation

3.1.1 Simulation Using OPNET Opnet modeler

Opnet Network simulator is a tool that is used for simulating the performance and behavior of any network, both in academic and industry fields. It is widely known and used because of its capability to function as a research and a network analysis tool. Opnet’s main advantage over the other simulation tools is that is very powerful and versatile and also supports the simulation of wireless and fixed networks.

3.1.2 Problem Definition

The main concept of this simulation is to evaluate the performance of an existing wireless network in contrast to a network that uses VBSs. More specifically, a VBSs is a UE which will have functions of the ENodeB and will be able to serve other UEs which are at a distance of 10 meters from this VBSs. The aim is to verify that the results of the scenarios that use VBSs contribute to better results than the scenario with no VBSs, as far as the fifth generation of mobile networks is concerned. Some of the performance statistics that I collected are the increase of throughput, the reduce of the delay, the pathloss and so on.

3.1.3 Scenarios Description

I simulated 3 different scenarios: The first one is a conventional cellular network, the second one contains 2 active VBSs and the third one contains 3 active VBSs. All of the scenarios contain one ENodeB, 30 UEs equally divided in 3 randomly distributed clusters and two more individual UEs. Additionally, in the second scenario, there are two active VBSs in two of the clusters and the one in the third cluster is inactive, whereas in the third scenario each cluster has one active VBS. Moreover, in these two scenarios, the two individual UEs (Outlier_UE_1 and Outlier_UE_2) are directly connected with the ENodeB. In the scenarios two and three, where there are 2 and 3 active VBSs respectively, the UEs within the clusters are all less than 10 meters away from the VBSs.

The attributes used for the ENodeB are as follows:

- Antenna Gain: 15dBi
- Battery Capacity: Unlimited
- Maximum Transmission Power: 5.0 W
- Number of Receive Antennas: 2
- Number of Transmit Antennas: 2
- Operating Power: 20
- PHY Profile: LTE 20 MHz FDD
- Pathloss Model: Urban Microcell (3GPP)

The attributes used for the UE are as follows:

- Antenna Gain: 2.0 dBi
- Battery Capacity: 11
- Maximum Transmission Power: 1.0 W
- Multipath Channel Model (Downlink): LTE OFDMA ITU Pedestrian A
- Multipath Channel Model (Uplink): LTE SCFDMA ITU Pedestrian A
- Number of Receive Antennas: 2
- Number of Transmit Antennas: 2
- Pathloss Model: Urban Microcell (3GPP)

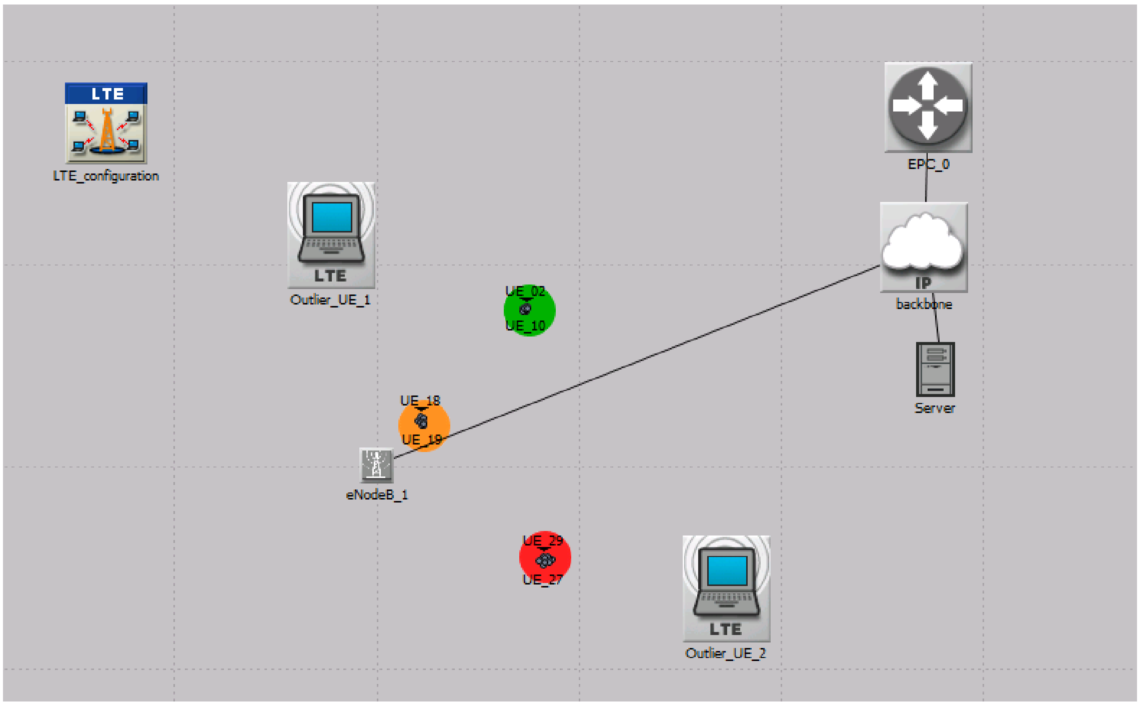


Figure 16. Scenario Topology

3.1.4 Simulation Results

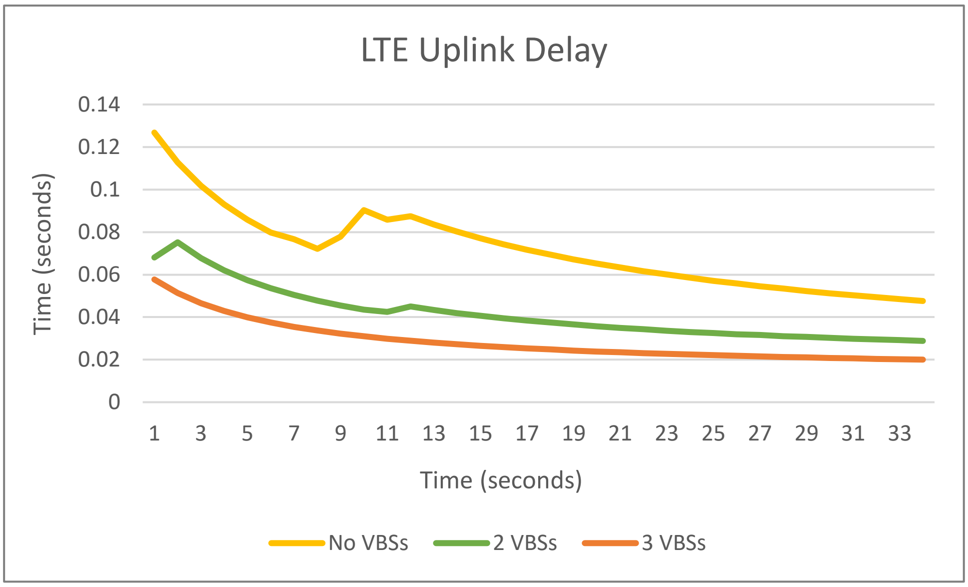


Figure 17.LTE Uplink Delay

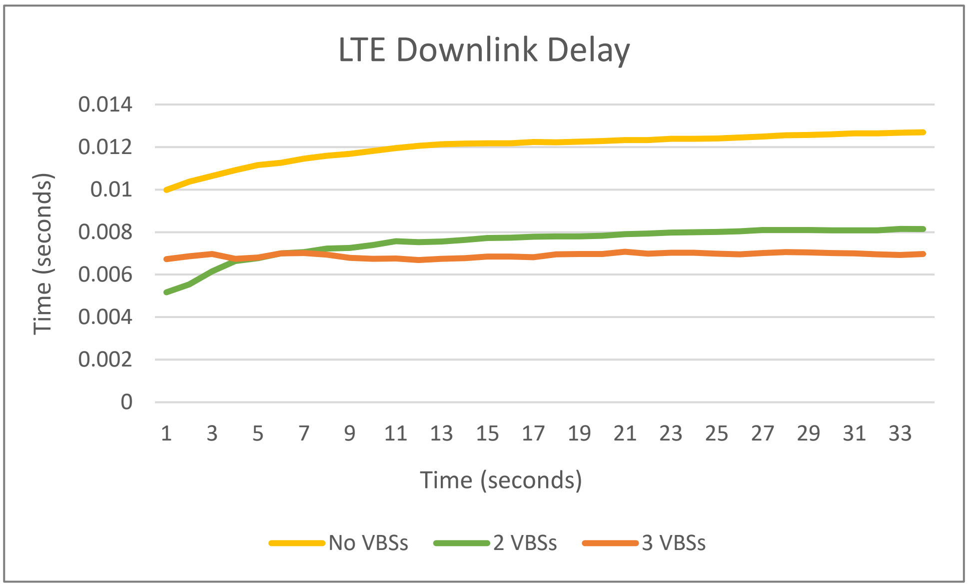


Figure 18.LTE Downlink Delay

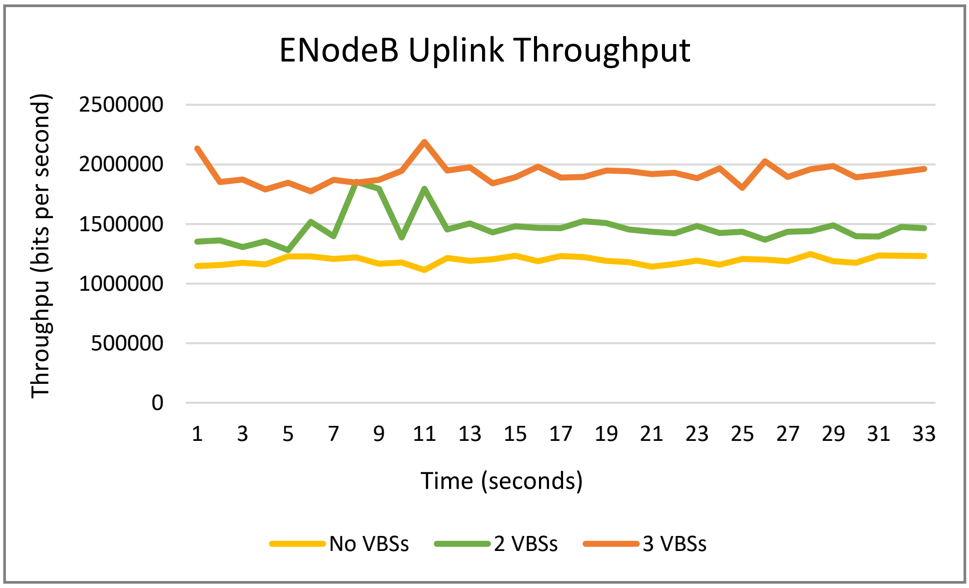


Figure 19.ENodeB Uplink Throughput

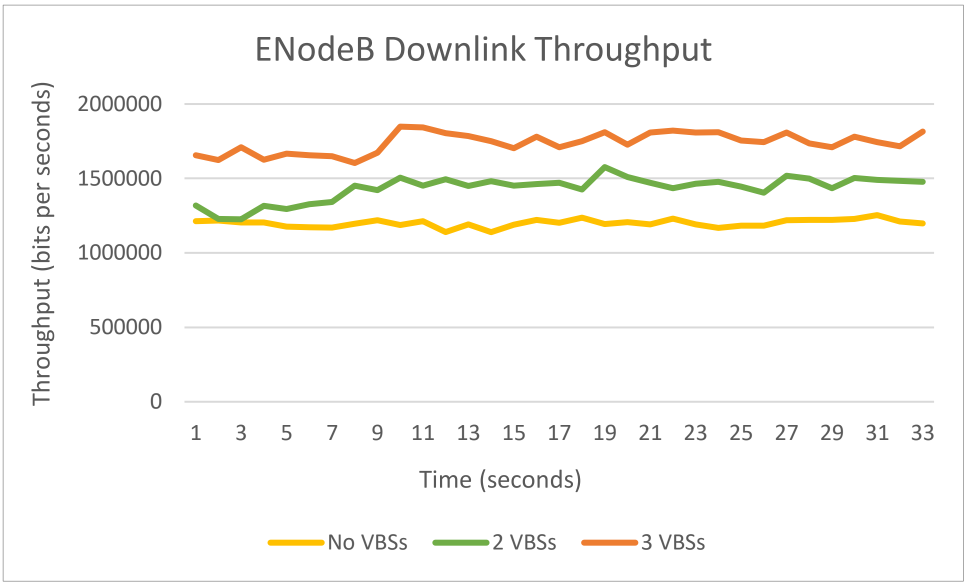


Figure 20.ENodeB Downlink Throughput

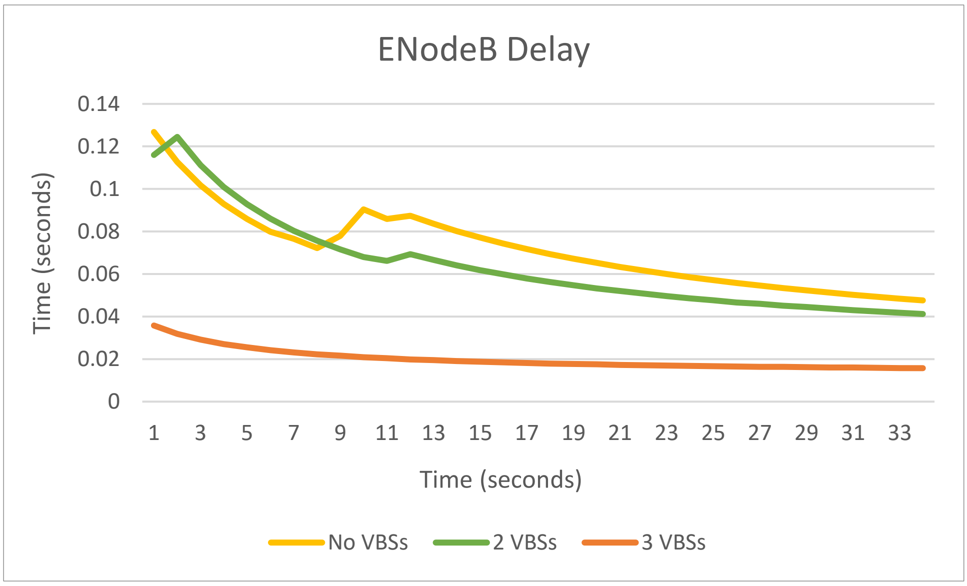


Figure 21.ENodeB Delay

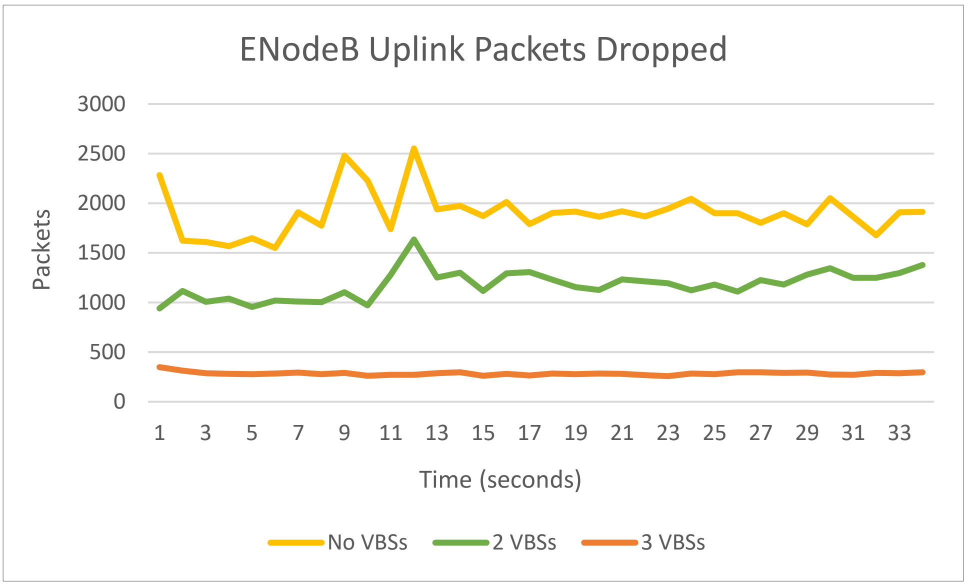


Figure 22.ENodeB Uplink Packets Dropped

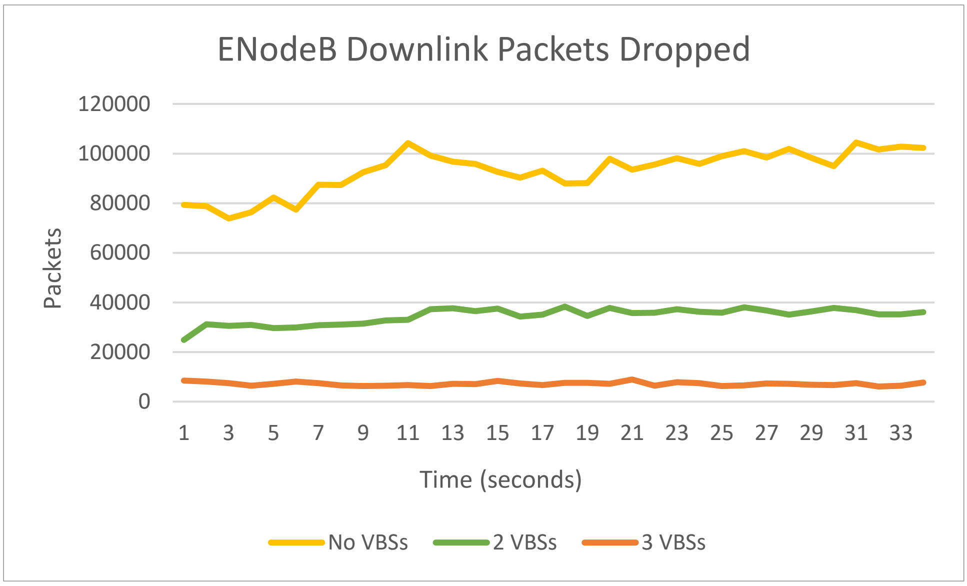


Figure 23.ENodeB Downlink Packets Dropped

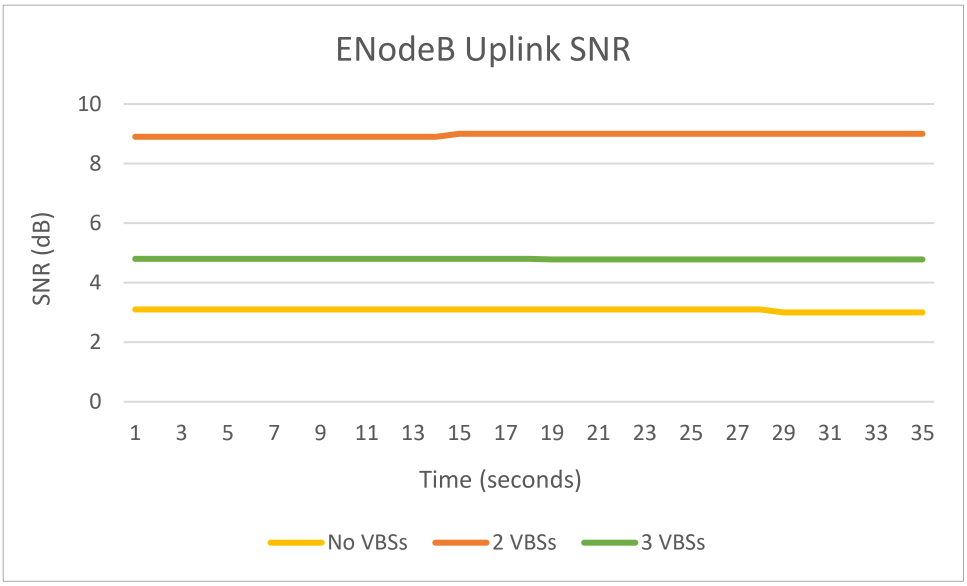


Figure 24.ENodeB Uplink SNR

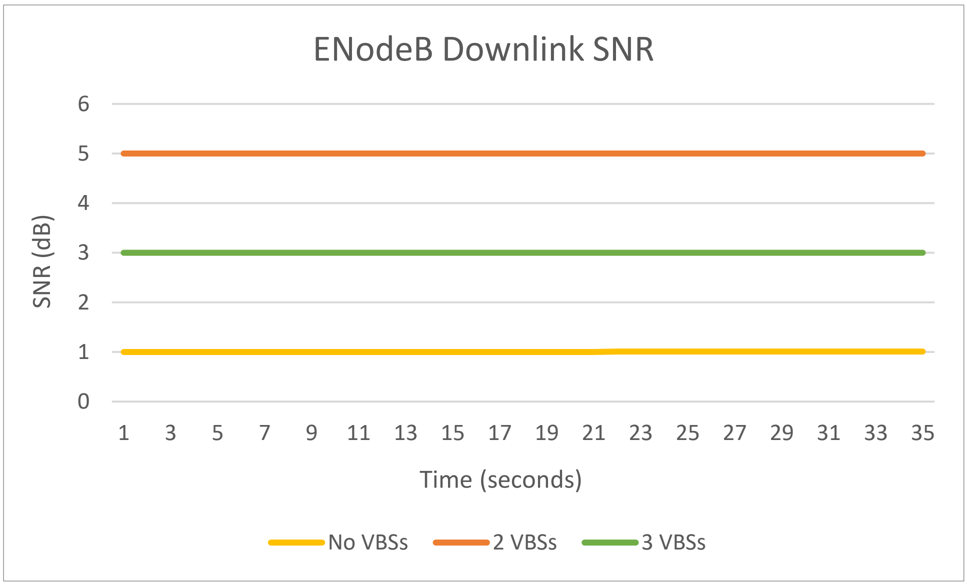


Figure 25.ENodeB Downlink SNR

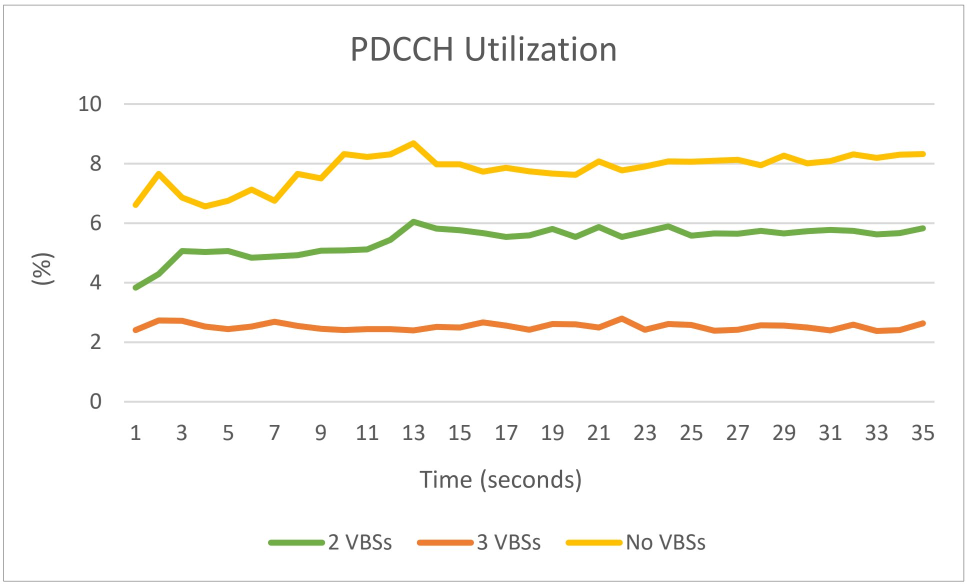


Figure 26.PDCCH Utilization

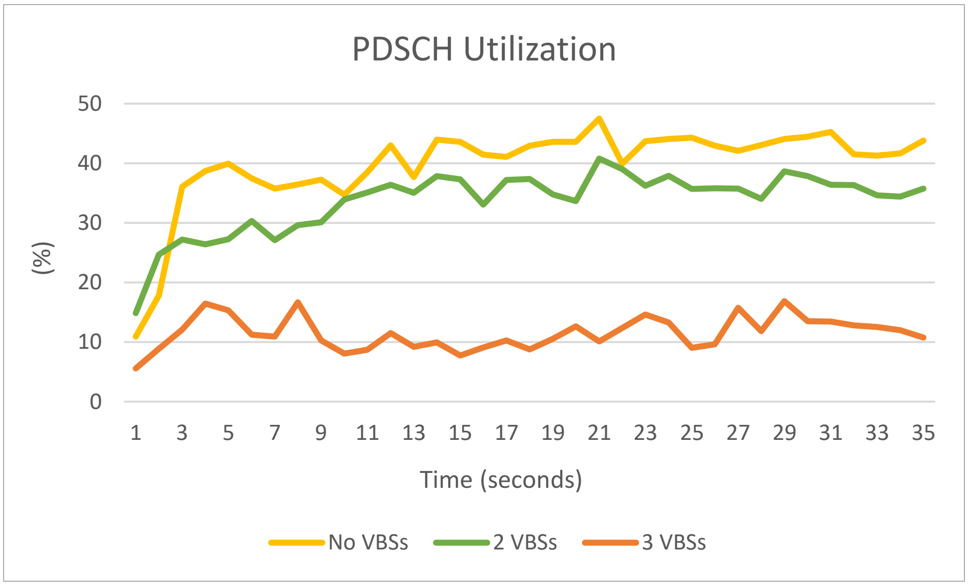


Figure 27.PDSCH Utilization

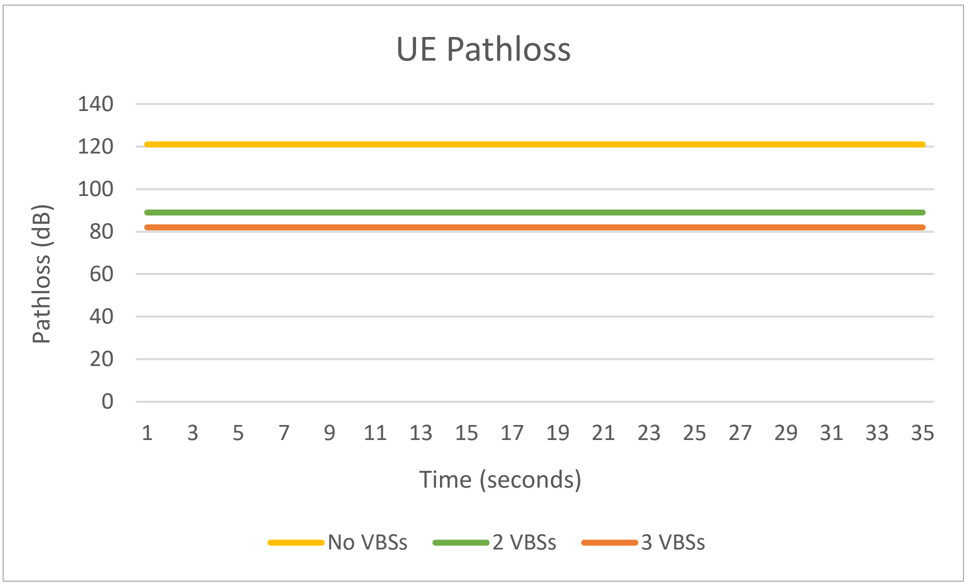


Figure 28.UE 20 Pathloss

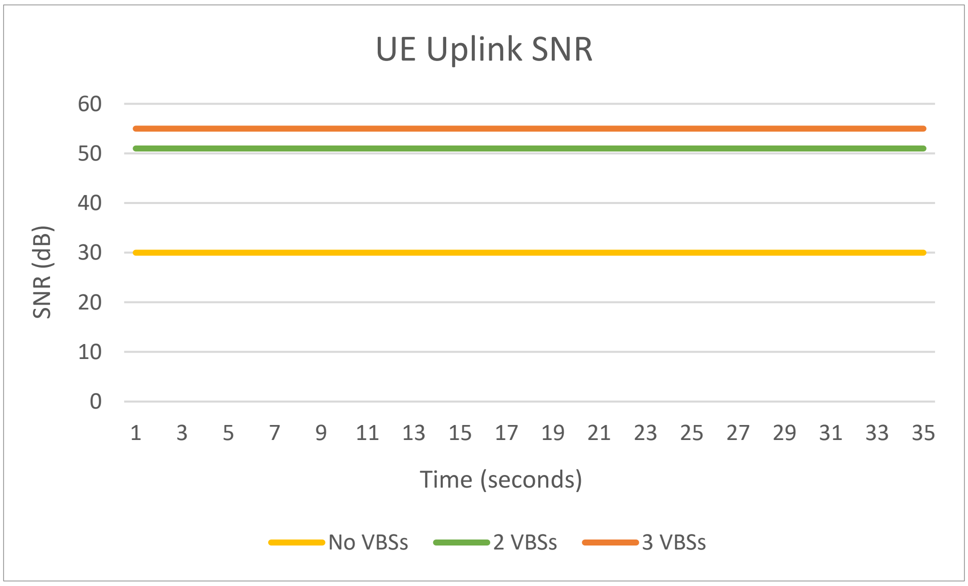


Figure 29.UE 20 Uplink SNR

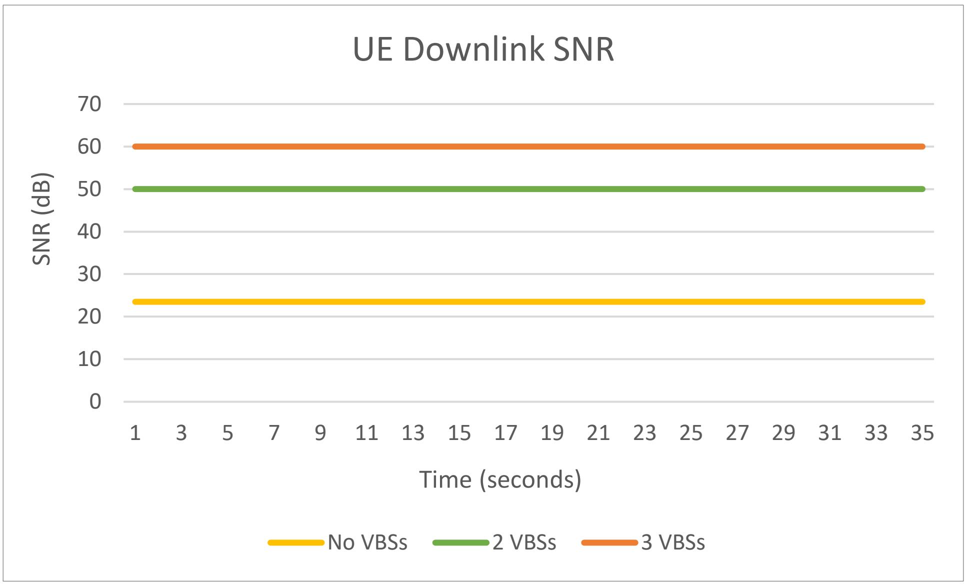


Figure 30.UE 20 Downlink SNR

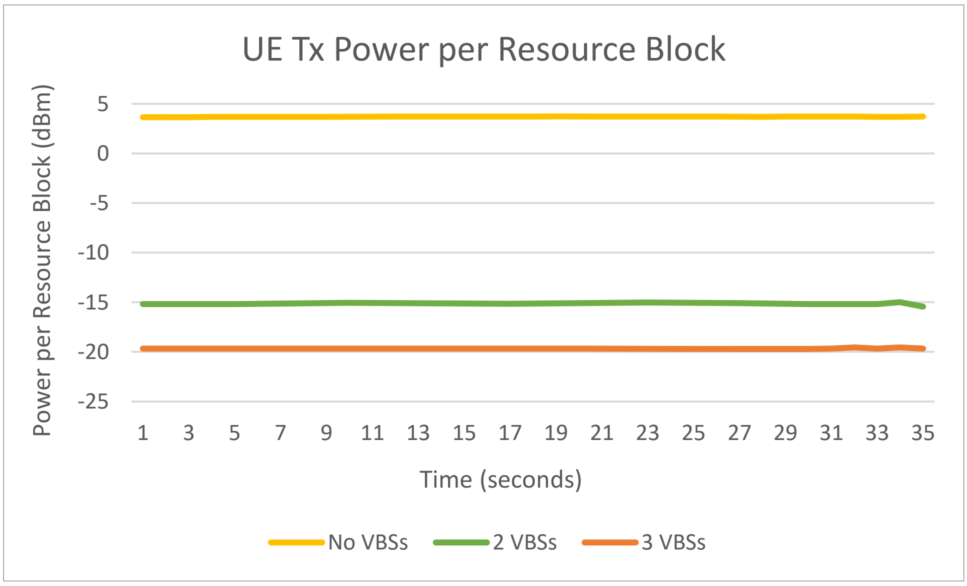


Figure 31. UE 20 Tx Power per Resource Block

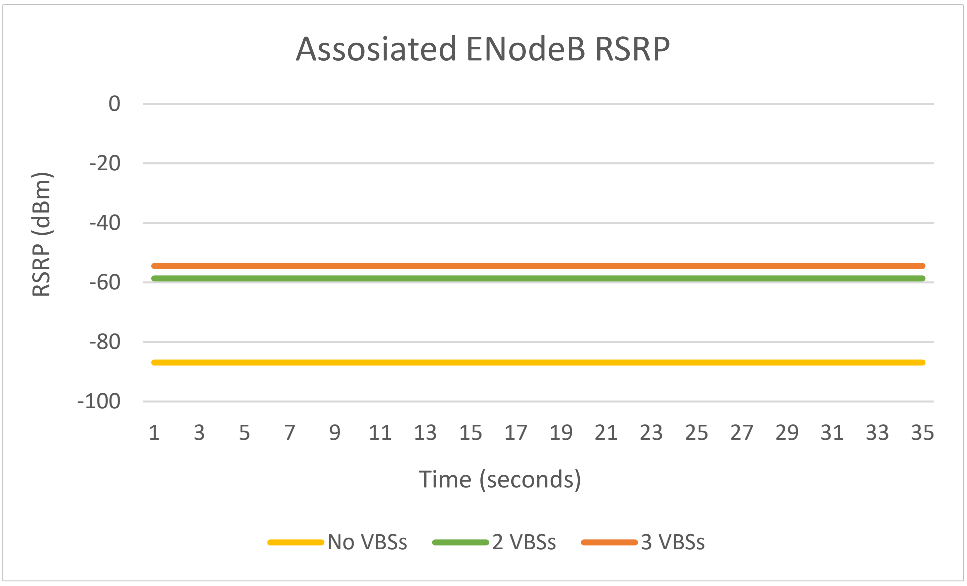


Figure 32. Assosiated ENodeB RSRP

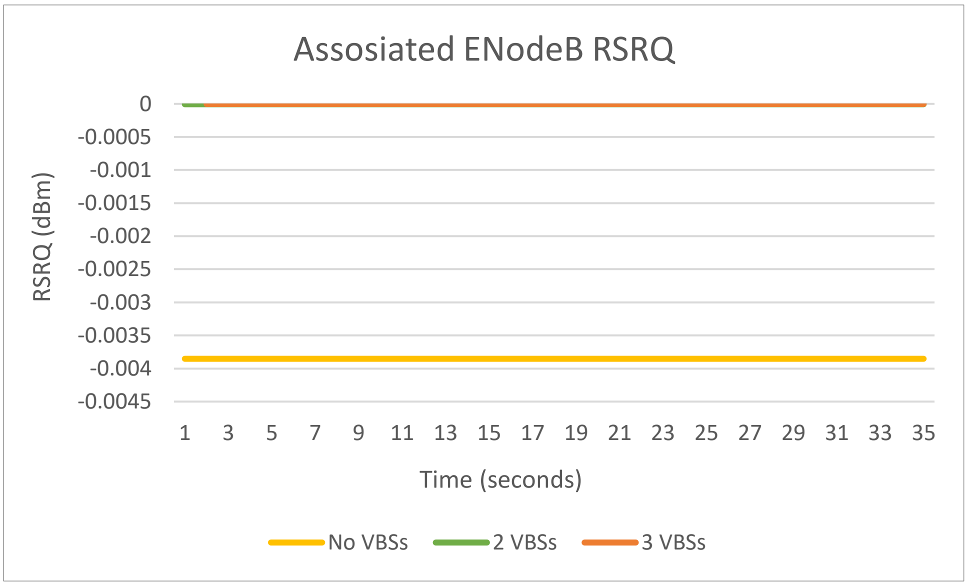


Figure 33. Assiosiated ENodeB RSRQ

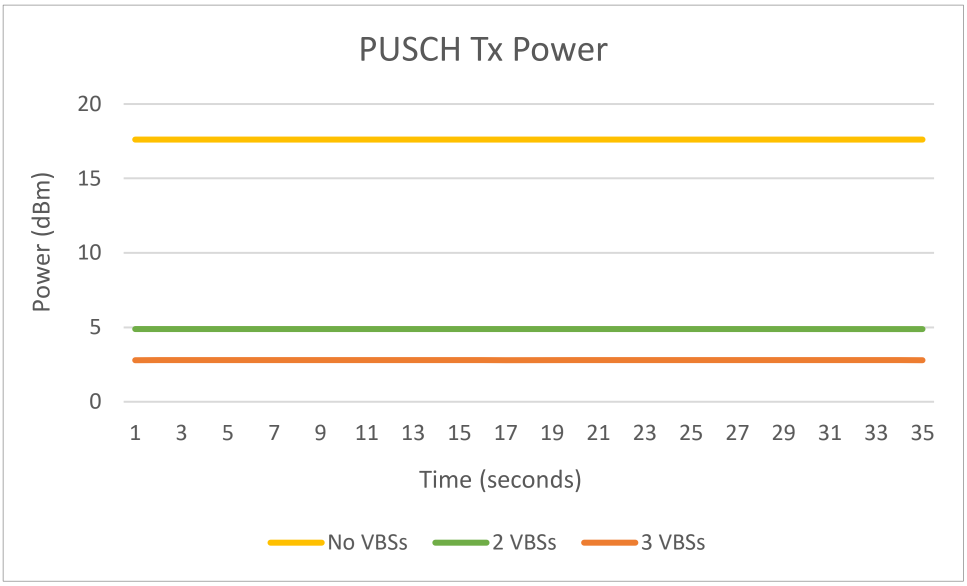


Figure 34.PUSCH Tx Power

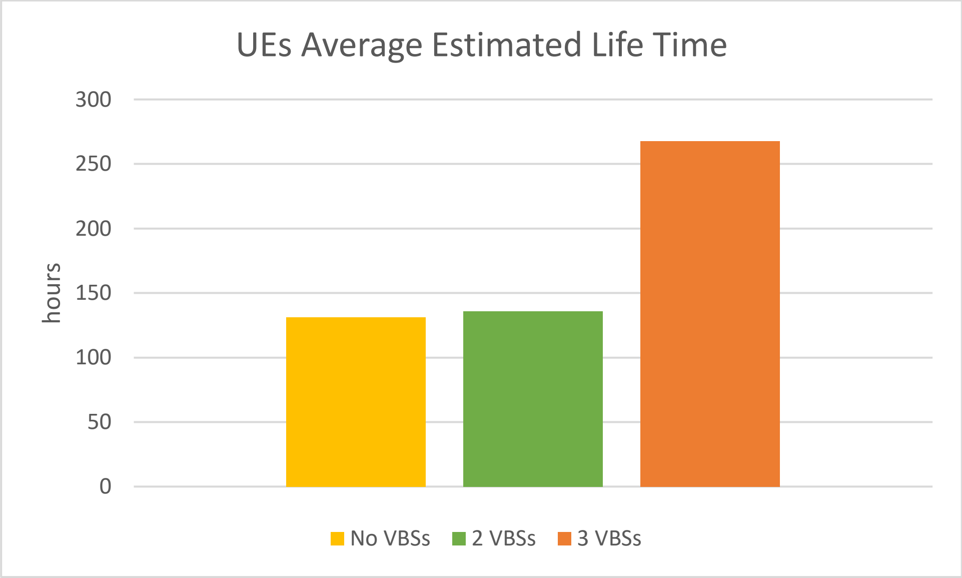


Figure 35.UEs Average Estimated Life Time

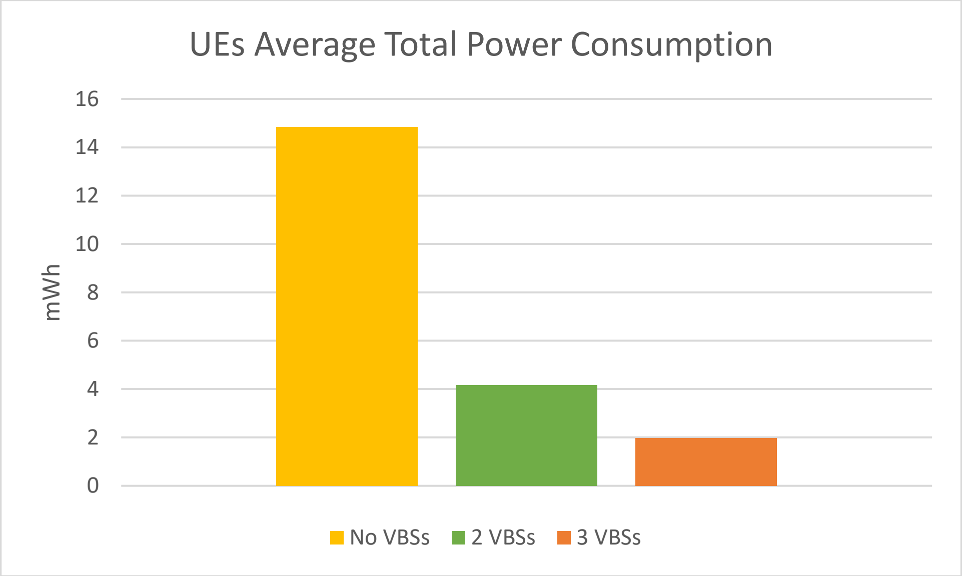


Figure 36.UEs Average Total Power Consumption

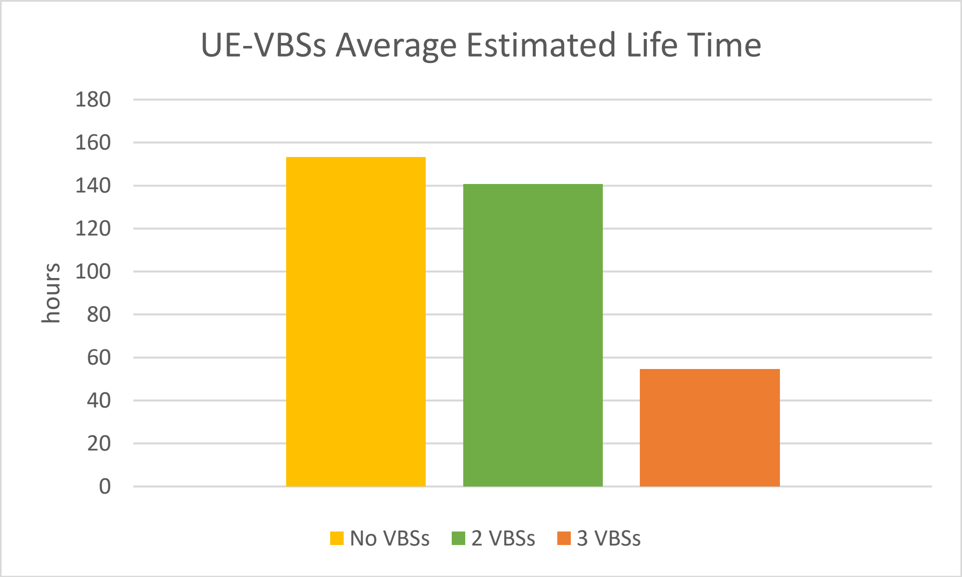


Figure 37.UE-VBSs Average Estimated Life Time

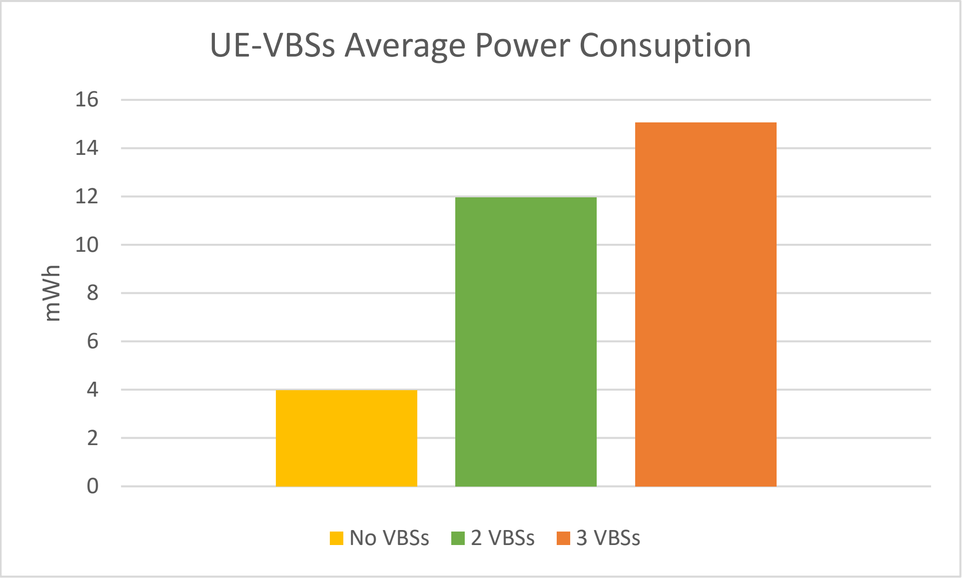


Figure 38.UE-VBSs Average Power Consumption

3.1.5 Conclusions

By examining the results of my simulations and by comparing the three scenarios between them, it is obvious that by enabling the VBSs, the results are better than the scenario of the conventional cellular network with no VBSs enabled. Firstly, the communication links to the ENodeB are less in the scenarios with 2 and 3 active VBSs and so bandwidth is used more efficiently. Furthermore, both uplink (UL) and downlink (DL) delay decreases in the scenarios with the active VBSs. In addition, DL throughput increases, while the UL throughput in the scenario with the 3 active VBSs is two times greater than the one with no VBSs enabled. The Physical Downlink Control Channel (PDCCH) and the Physical Downlink Shared Channel (PDSCH) utilization decreased, which means less resources are used, thus the network capacity is increased.

Also, the number of packets dropped is sharply reduced in the scenarios with VBSs, since the difference in the UL is fourfold greater and in the DL eightfold greater in the scenario with 3 VBSs in relation with the scenario with no VBSs.
Moreover, as far as the Signal to Noise Ratio (SNR) is concerned, both in the UL and DL, there is a significant increase for the UEs and the ENodeB. Further, pathloss is notably decreased in the scenarios with the VBSs and above all in the scenario with 3 VBSs and

similarly the transmit power of the UEs is decreased too. RSRQ utilization, that shows the quality of the received reference signal, increases, as well as the RSRP utilization, which shows the quality of the received signals.

Finally, the power consumption of the UEs is less than the scenario without VBSs, hence the estimated battery life time of the UEs is extended. However, VBSs battery consumption is an important disadvantage as it is highly increased.

3.2 Affinity Propagation Clustering Performance Evaluation

I evaluated the performance of Affinity Propagation Clustering using the python programming language and especially sklearn library. I created various datasets with different structures, all with a number of 1500 points, and I used the affinity propagation algorithm to cluster them. For each dataset I calculated the score that affinity propagation achieved on some clustering performance metrics.

For the input parameters of AP, I adjusted the values in each dataset to get a better clustering result. According to the creators of AP the only parameter that needs careful tuning is the damping factor, that is used to avoid numerical oscillations while the messages are exchanged between data points. The creators of the AP algorithm recommend setting the damping factor to 0.9. In my experiments, I adjusted the values between 0.75 and 0.9, trying to achieve the best possible result in each case.

In the following clustering examples, the data points with the same color represent a cluster and the X mark represents the exemplar (cluster head) given by the AP algorithm.

Also, for the evaluation of the algorithm with the datasets I calculated the following Clustering performance evaluation measures:

Homogeneity: is a measure that shows if a cluster contains only data points which are members of a single class. The values range is between 0.0 and 1.0. If 0.0 occurs then the result is bad and if 1.0 occurs then the result is optimal and satisfies.

Completeness: is a measure that shows if all members of a given class are assigned to the same cluster. The values range is between 0.0 and 1.0. If 0.0 occurs then the result is bad and if 1.0 occurs then the result is optimal and satisfies.

V-measure: is a measure of association between homogeneity score and completeness score. The values range is between 0.0 and 1.0. If 0.0 occurs then the result is bad and if 1.0 occurs then the result is optimal and satisfies.

Adjusted Rand Index: is a measure of the similarity between two data clusters. A form of the Rand index may be defined that is adjusted for the chance grouping of elements, this is the adjusted Rand index. The values range is between -1 and 1. If a negative value occurs then the clusters are dissimilar, if it is a positive value then it means that the clusters are similar and if that value is equal to 1.0 then the two clusters have perfect similarity.

Adjusted Mutual Information: is a measure that corrects the effect of agreement solely due to chance between clustering. AMI returns the value 1.0 when the two clusters matched perfectly and the value 0.0 or a negative value, when two clusters are Random.

Silhouette Coefficient: is a measure that shows how similar a data points to its own cluster, compared to other clusters. If the value is equal to 1.0, then the data point is more similar to its own cluster than anyone else and if the value is equal to -1, then the data was assigned to the wrong cluster.

3.2.1 Affinity Algorithm Evaluation Results

Clustering of dataset Noisy Circles:

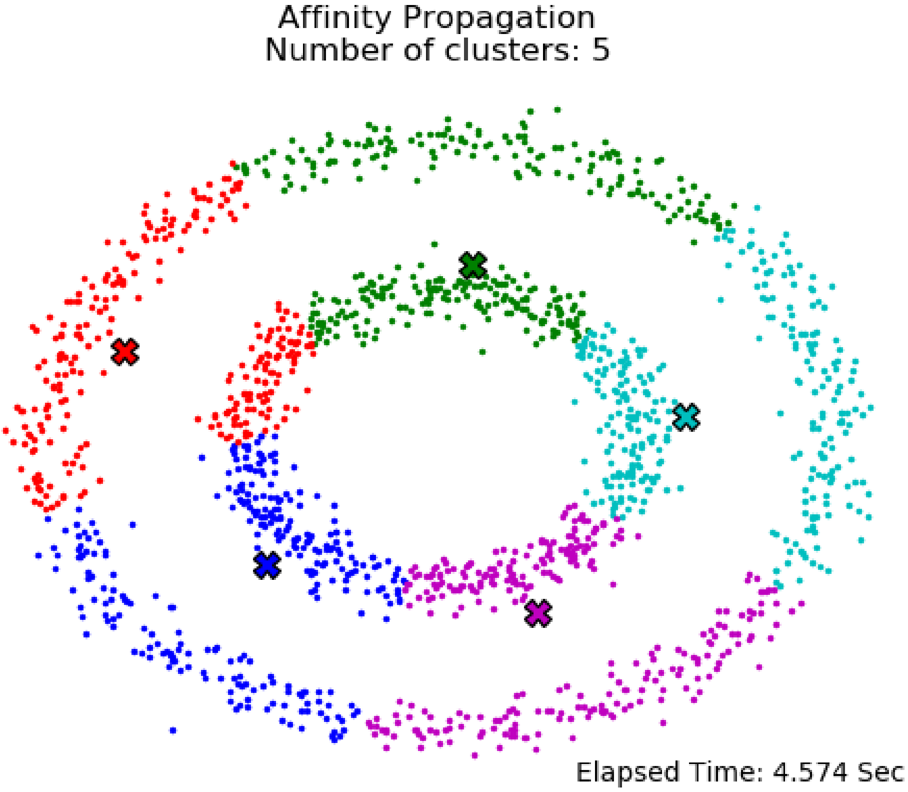


Figure 39. Affinity Propagation clustering result for dataset Noisy Circles.

Clustering Performance Metrics	
Homogeneity	0.010
Completeness	0.004
V-measure	0.006
Adjusted Rand Index	0.004
Adjusted Mutual Information	0.003
Silhouette Coefficient	0.516

Table 2. Clustering performance metrics for dataset Noisy Circles.

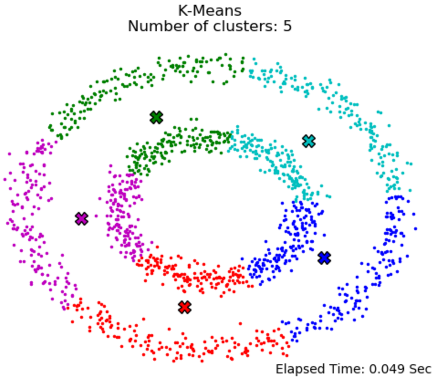


Figure 40.K-means clustering result for dataset Circles.

In this dataset, AP failed to achieve a good clustering. The points in the outer circle should belong in a different cluster than the points in the inner circle. Especially in the case that I am studying, where a cluster represents a virtual small cell, this clustering would cause many problems, as many UEs would be too far from each other. In addition, there are some points that are clearly outliers but since AP does not support noise detection, the outliers end up belonging in a cluster.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that AP requires more time than the K-means algorithm (almost one hundred more time).

To create this dataset I used the code:

noisy_circles = datasets.make_circles(n_samples=n_samples, factor=.5, noise=.05).

Finally, for the Affinity Propagation parameters I used: *damping= .77, preference= -240.*

Clustering of dataset Noisy Moons:

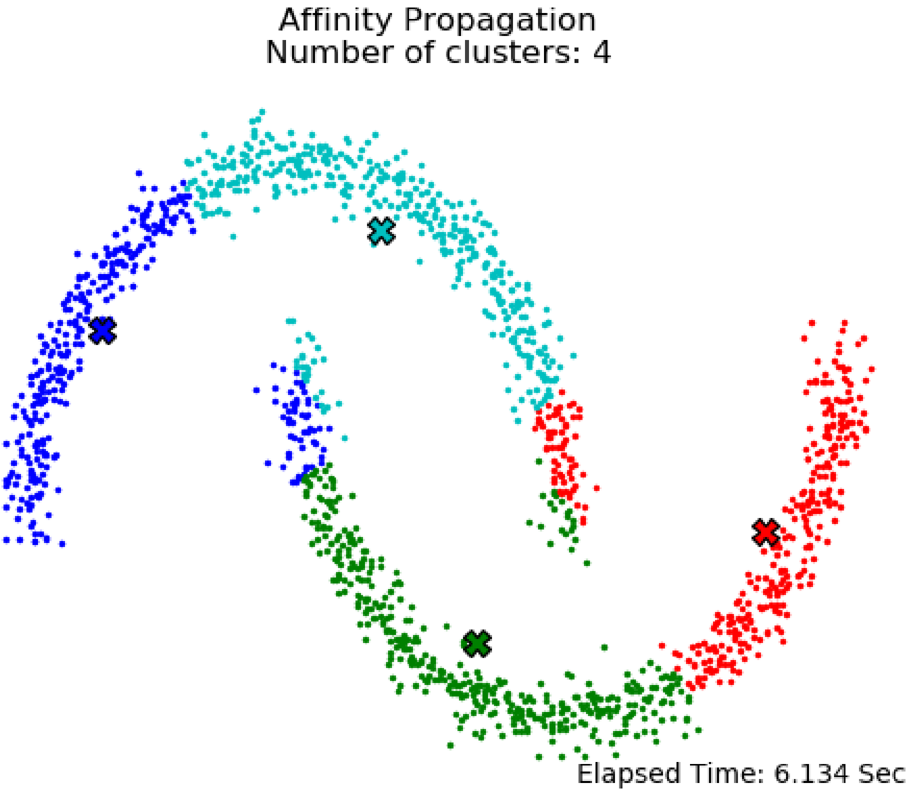


Figure 41. Affinity Propagation clustering result for dataset Noisy Moons.

Clustering Performance Metrics

Homogeneity	0.518
Completeness	0.260
V-measure	0.347
Adjusted Rand Index	0.320
Adjusted Mutual Information	0.260

Table 3. Clustering performance metrics for dataset Noisy Moons.

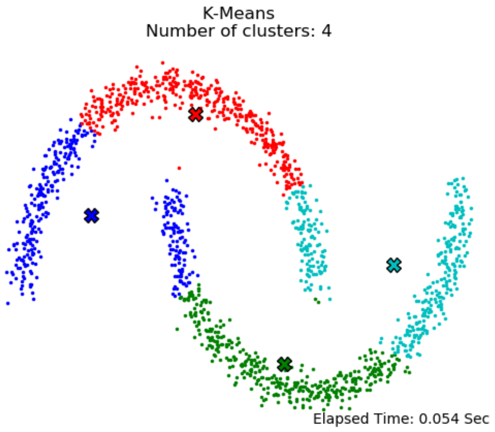


Figure 42.K-means clustering result for dataset Noisy Moons.

In this dataset, the results are better than the first one, but still not tolerable. More precisely, the clusters seem to be formed well, however some points should belong to a different cluster, as they are far away from the rest points of the same cluster and they belong to a different semi-circle. Consequently, there is no similarity and completeness, as it is obvious from the table above too.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that for this dataset too, AP requires more time to run than the K-means algorithm (almost one hundred more time).

To create this dataset I used the code:
noisy_moons = datasets.make_moons(n_samples=n_samples, noise=.05).

Finally, for the Affinity Propagation parameters I used: damping= .75, preference= -220.

Clustering of dataset Blobs:

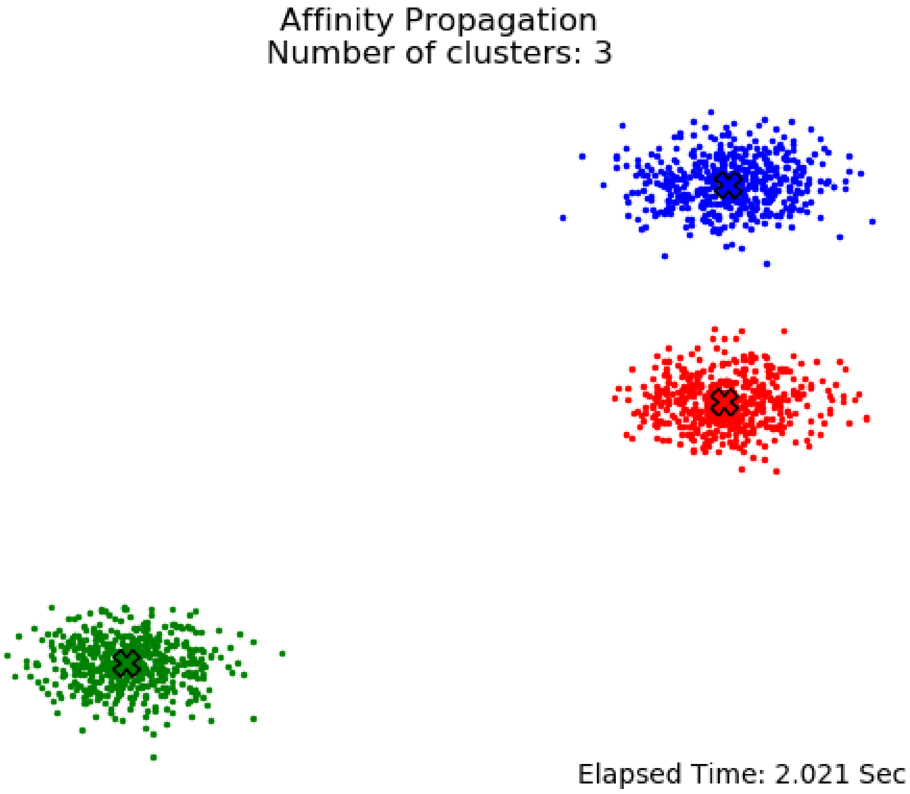


Figure 43. Affinity Propagation clustering result for dataset Blobs.

Clustering Performance Metrics

Homogeneity	1.000
Completeness	1.000
V-measure	1.000
Adjusted Rand Index	1.000
Adjusted Mutual Information	1.000
Silhouette Coefficient	0.949

Table 4. Clustering performance parameters for dataset Blobs.

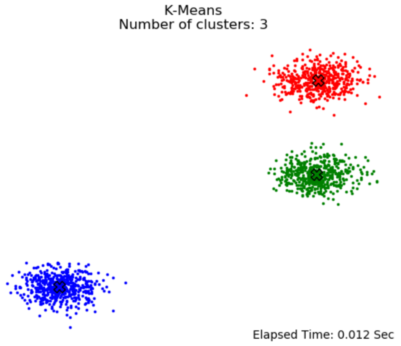


Figure 44.K-means clustering result for dataset Blobs.

In this dataset, AP succeeded to achieve one almost optimal. Since there is a clear structure, we can easily see that each point was added into the best cluster that could has been. Moreover, the clusters have the same density everywhere and the points are all within close distances between them. Hence, this is very positive in the case of VBS, too. On the other hand, the only drawback that exists in this case as well as in first case, is that there are outliers that the AP cannot separate.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe again that AP requires more time than the K-means algorithm (more than one hundred more time).

To create this dataset I used the code:
blobs = datasets.make_blobs(n_samples=n_samples, random_state=8).

Finally, for the Affinity Propagation parameters I used: *damping= .9, preference= -200.*

Clustering of dataset No structure:

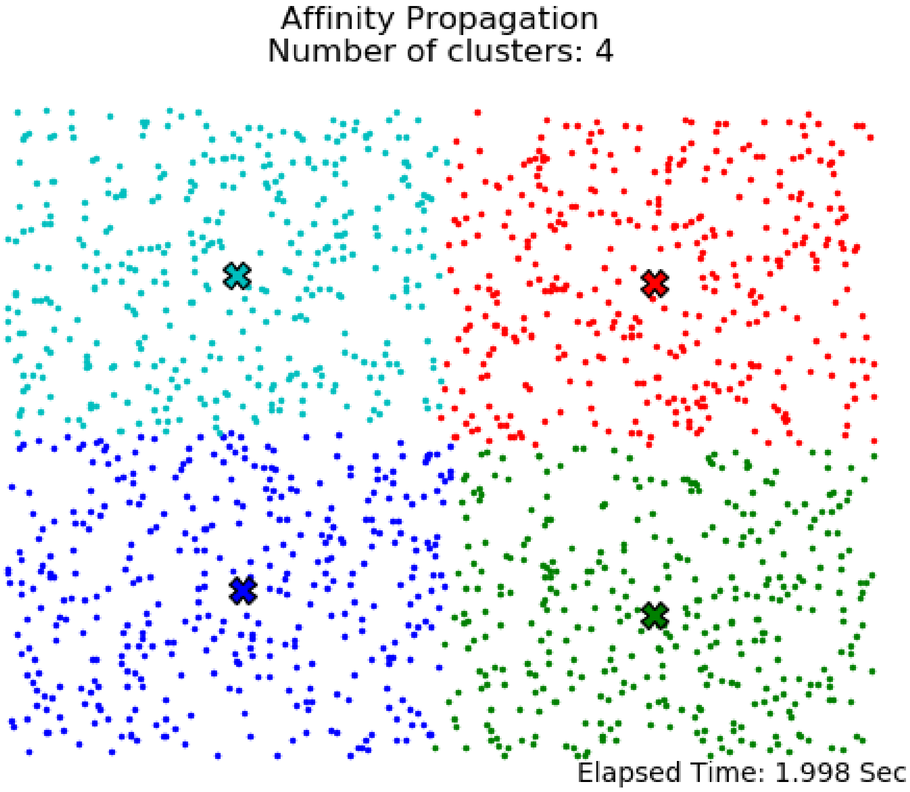


Figure 45. Affinity Propagation clustering result for dataset No structure.

Clustering Performance Metrics	
Silhouette Coefficient	0.588

Table 5. Clustering performance metrics for dataset No structure.

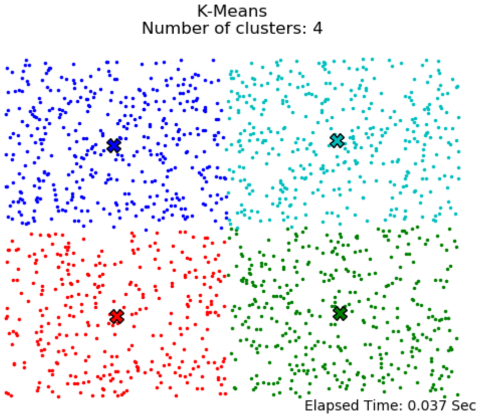


Figure 46.K-means clustering result for dataset No structure.

In this dataset, AP clustered the points in a satisfactory way. The exemplars are in the middle of each cluster, but the results could have been more improved as the data points are in a great distance from the exemplar and the density is not high. Additionally, according to Silhouette Coefficient measure we see that the results are half excelling.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that AP requires more time than the K-means algorithm.

To create this dataset I used the code:
no_structure = np.random.rand(n_samples, 2), None

Finally, for the Affinity Propagation parameters I used: *damping= .9, preference= -200*

Clustering of dataset Aniso:

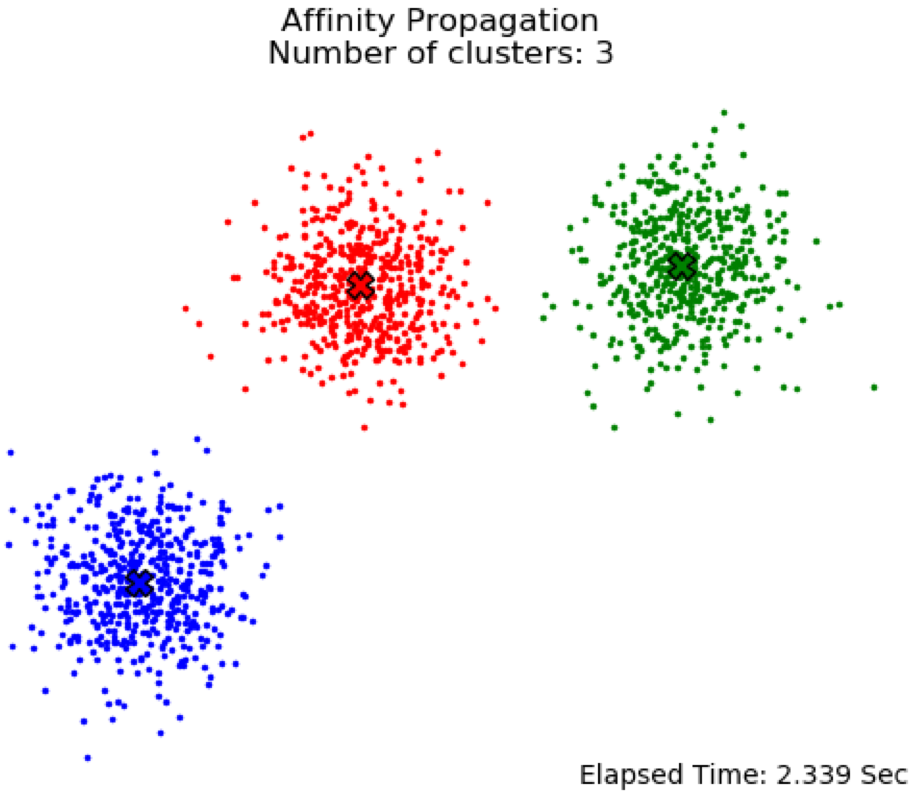


Figure 47. Affinity Propagation clustering result for dataset Aniso.

Clustering Performance Metrics	
Homogeneity	1.000
Completeness	1.000
V-measure	1.000
Adjusted Rand Index	1.000
Adjusted Mutual Information	1.000
Silhouette Coefficient	0.879

Table 6. Clustering performance metrics for dataset Aniso.

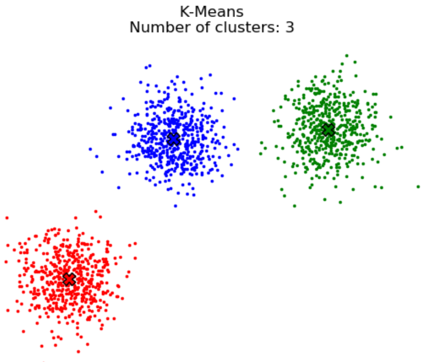


Figure 48.K-means clustering result for dataset 5Aniso.

In this dataset, the algorithm succeeded to achieve one almost excellent clustering. The results are similar to third dataset above, with this one with a slightly better score in the Silhouette Coefficient, which means that the clusters are dense and well separated. Nevertheless, the problem of the outlier points here is more intense as the outlier points are much more than any other dataset we have seen and in a greater distance from the exemplar.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that in this dataset too, as in all the previous ones, AP requires more time than the K-means algorithm (more than one hundred more time).

To create this dataset I used the code:

random_state = 170

X,labels_true=datasets.make_blobs(n_samples=n_samples,random_state=random_state)

transformation = [[0.6, -0.6], [-0.4, 0.8]]

X_aniso = np.dot(X, transformation)

aniso = (X_aniso, labels_true)

Finally, for the Affinity Propagation parameters I used: *damping= .9, preference= -200.*

Clustering of dataset Varied:

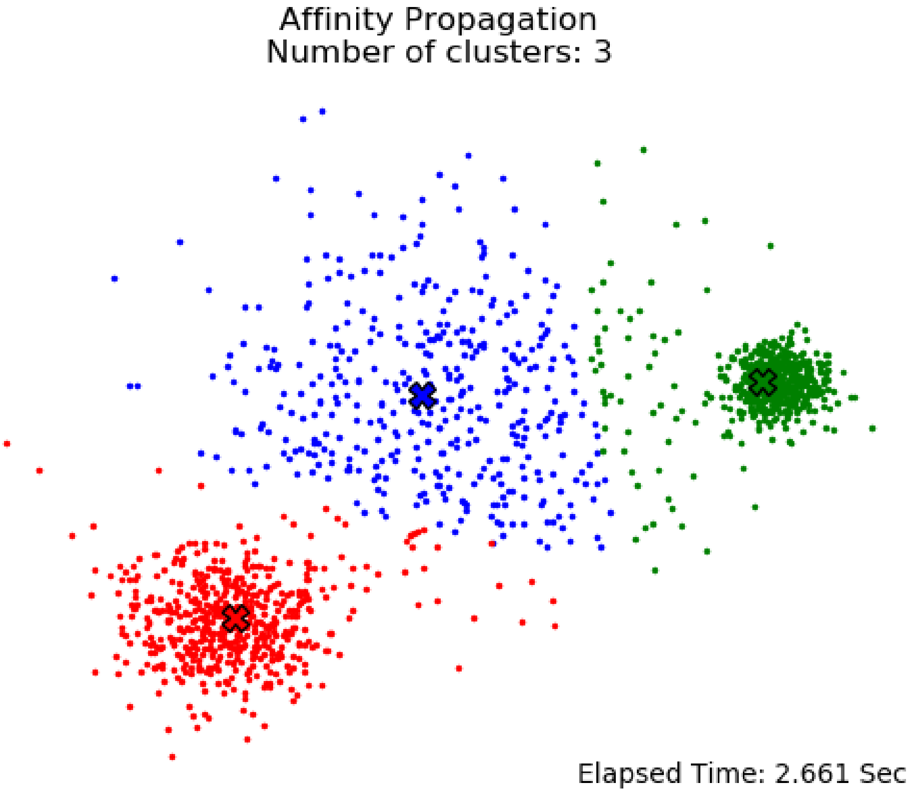


Figure 49. Affinity Propagation clustering result for dataset Varied.

Clustering Performance Metrics	
Homogeneity	0.797
Completeness	0.805
V-measure	0.801
Adjusted Rand Index	0.814
Adjusted Mutual Information	0.797
Silhouette Coefficient	0.766

Table 7. Clustering performance metrics for dataset Varied.

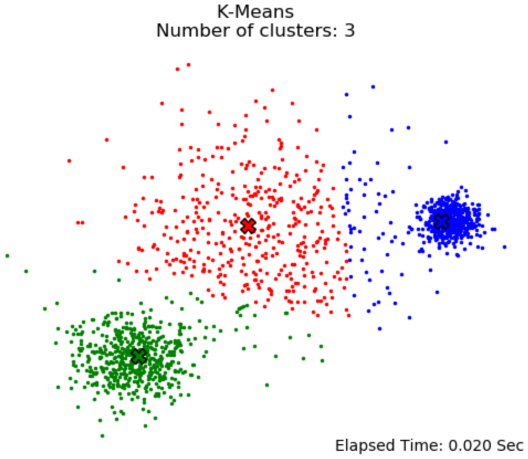


Figure 50.K-means clustering result for dataset Varied.

In this dataset, AP achieved a relatively satisfactory clustering. As seen in the figure above, the blue cluster is the densest of the three clusters and then the green follows, but in the red cluster the points are located a too far from each other. Also, the problem with the outliers remains in this dataset too, but with this separation of the clusters, most of the points end up being outliers.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that AP requires more time than the K-means algorithm (almost one hundred more time).

To create this dataset I used the code:
varied = datasets.make_blobs(n_samples=n_samples, cluster_std=[1.0, 2.5, 0.5], random_state = random_state)

Finally, for the Affinity Propagation parameters I used: *damping= .9*, *preference= -20*

Clustering of dataset Aniso 2:

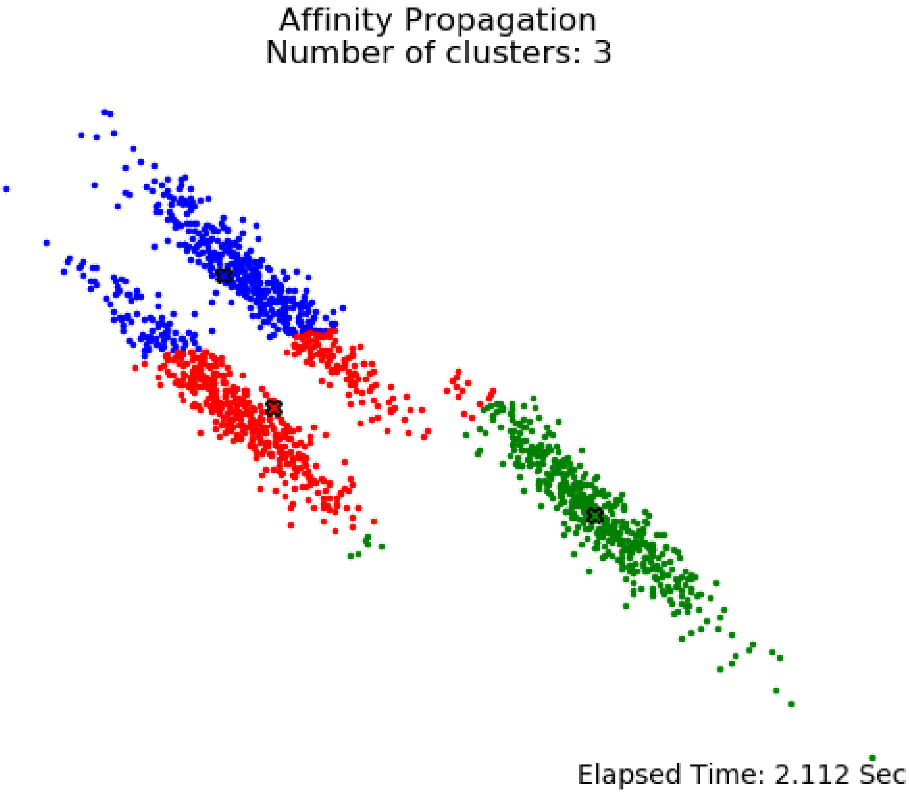


Figure 51. Affinity Propagation clustering result for dataset Aniso 2.

Clustering Performance Metrics	
Homogeneity	0.621
Completeness	0.622
V-measure	0.621
Adjusted Rand Index	0.617
Adjusted Mutual Information	0.621
Silhouette Coefficient	0.683

Table 8. Clustering Performance metrics for dataset Aniso 2.

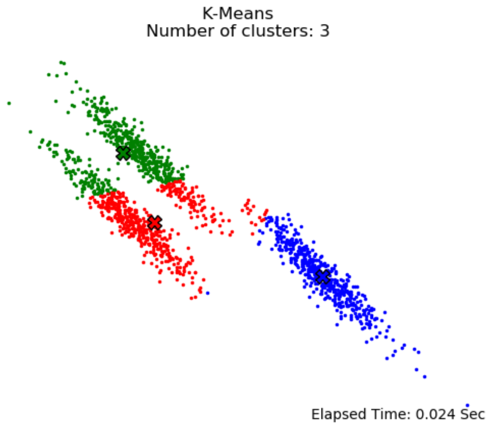


Figure 52.K-means clustering result for dataset Aniso 2.

In this dataset, AP achieved an average result with clustering the data points. Same points are well distributed in the clusters, however some others are not efficiently situated in the right cluster. Furthermore, there are outliers and in this dataset which some of them being to far away from the exemplar. This taking in mind the VBSs concept would be unacceptable.

By comparing the time that the AP algorithm required to run in relation to the time needed from the K-means algorithm (with the same number of clusters), we can observe that AP requires more time than the K-means algorithm (almost one hundred more time).

To create this dataset I used the code:

```
random_state = 170
X,labels_true=datasets.make_blobs(n_samples=n_samples,random_state=random_state)
transformation = [[0.6, -0.6], [-0.4, 0.8]]
X_aniso = np.dot(X, transformation)
aniso = (X_aniso, labels_true)
```

Finally, for the Affinity Propagation parameters I used: *damping= .9, preference= -200*

Clustering of dataset with PCP distribution:

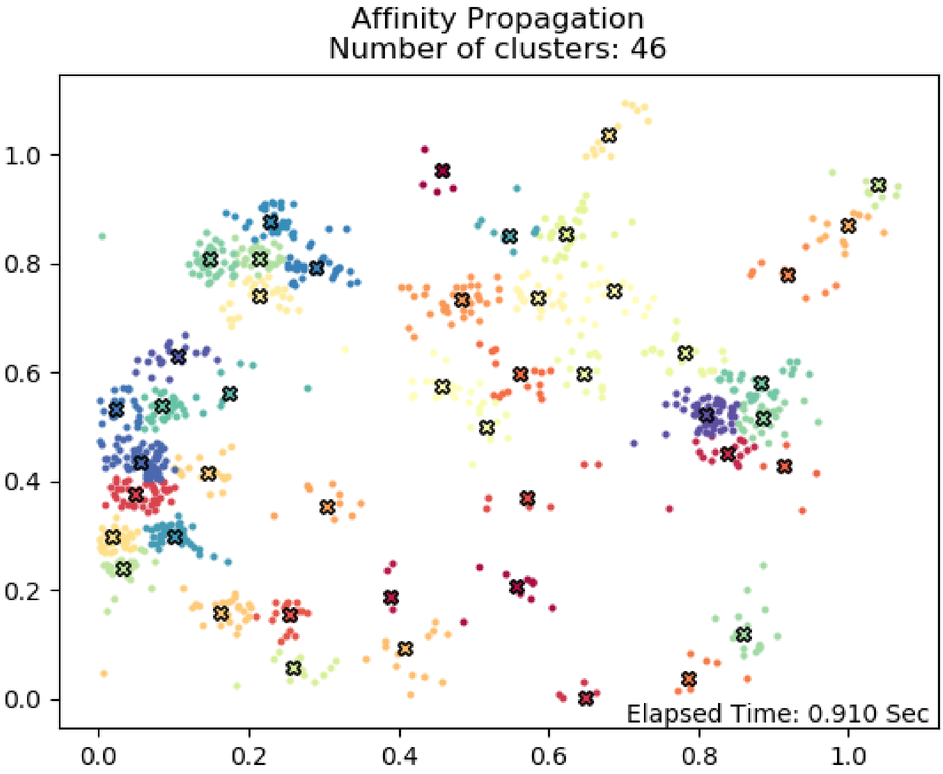


Figure 53. Affinity Propagation clustering result for dataset with PCP distribution.

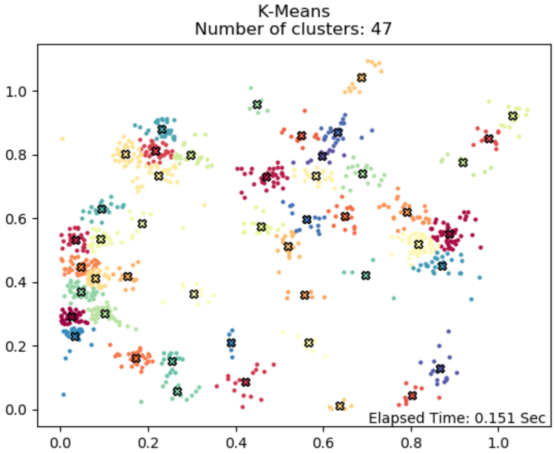


Figure 54.K-means clustering results for dataset with PCP distribution.

Firstly, this dataset uses the PCP (Poisson Cluster Process) [33], which is suitable for user and BS distributions and it is especially used for modelling small cell BSs in hotspots. Moreover, the number of users in this dataset is 1000.

In this dataset, it is obvious that there are a lot of points that are outliers, which is a negative result according to our scenario with the VBSs. However, the rest of the points that are not outliers are clustered in a beneficial way, as the exemplar is in the center of the UEs it will serve and there is a small distance between the points of each cluster.

Conclusions

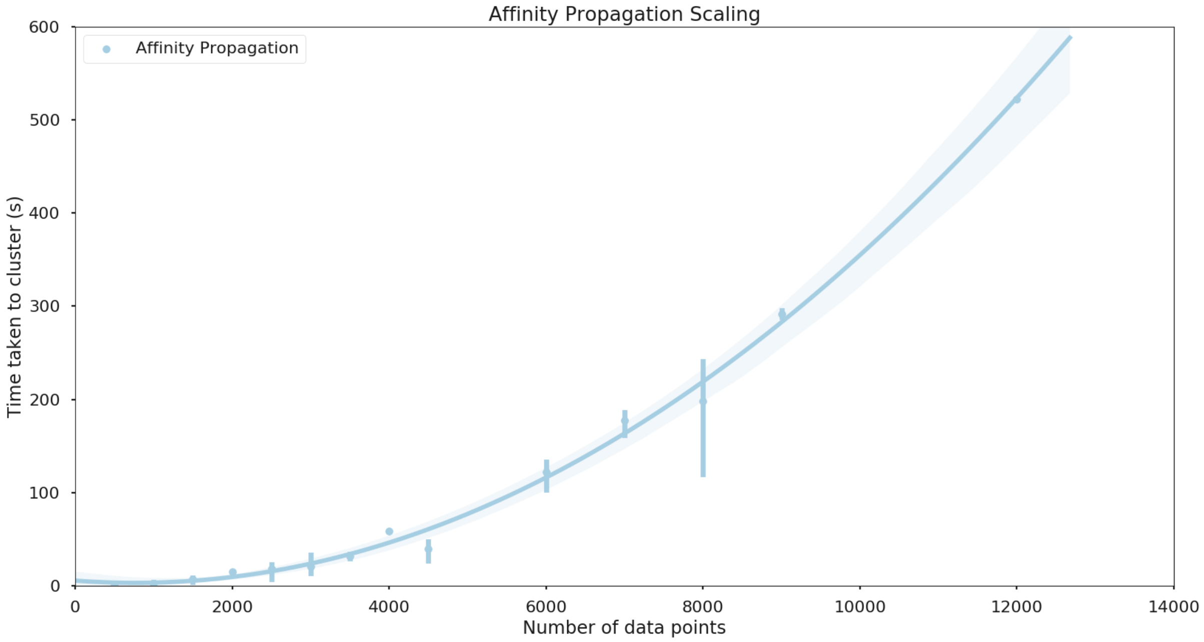


Figure 55. Affinity algorithm total time to run in a dataset of 14000 users.

After running Affinity Propagation algorithm based on the above datasets and examining the results, I came to the conclusion that the AP clustering is satisfactory in some cases, where the density of the points is larger, but it does not satisfy all the requirements for a VBS concept. This happens, due to the fact that in cases where the density is not great, clusters are created in which some user devices are at a large and unacceptable distance from the exemplar, i.e. the user's device that will act as a BS. Additionally, there are many outlier points that AP cannot manage or exclude and these points in the VBS concept should be connected directed to the BS and not being part of a cluster-small cell. Finally, because of the complexity of the algorithm, it takes much more amount of time to run than k-means algorithms (one hundred times more). This is shown in the figures in each one of the datasets above, that contain the running time of k-means with the same number of clusters with AP.

Therefore, I conclude that the AP cluster is a promising algorithm, however cannot meet the needs of the VBS concept. For this reason, in [30] was proposed an idea, which suggests the configuration of the algorithm, in order to take as a parameter the strength of the signal received by a UE from an eligible VBS and also proposes to restrict the passing messages between only the UEs and the eligible VBSs, instead of all the points. Finally, as we can see from the figure above, the algorithm is not profitable in large sets of data, so the [30] also proposes the initial division of the whole dataset into several groups and on which will then run the AP algorithm, to achieve better performance.

Benefits of Affinity Propagation

A big advantage of AP is that it does not need the user to specify the number of clusters as input.

Another advantage is that it supports non-metric dissimilarities, which only a few clustering algorithms support. This is extremely important if the data points are not in a metric space.

Drawbacks of Affinity Propagation

AP cannot detect outlier data points and always adds the noise points in a cluster. Moreover, AP gets extremely slow as the number of data point increases, thus it cannot scale to big datasets.

Furthermore, even if AP eliminates the number of clusters parameter, it has two other input parameters: ‘preference’ and ‘damping’. A lot of times, choosing the right values for these parameters can be hard.

3.2.2 Affinity Propagation Algorithm Evaluation using more clusters

As we have seen above, some of the clusters that are created are not ideal for the scenario with VBSs. Thus, by changing the parameters preference and damping factor of the Affinity Propagation algorithm, I managed to create more clusters in each dataset, so that each cluster contains about 10 users and a VBS, closer to the idea of the scenario with the VBSs. By having approximately 10 users within a cluster and in a smaller distance from the VBS, it reduces the interference and thus the UEs consume less power. Moreover, in this way, we could use millimeter wave to achieve larger frequencies at short distances, without weakening the signal. Below the results are presented.

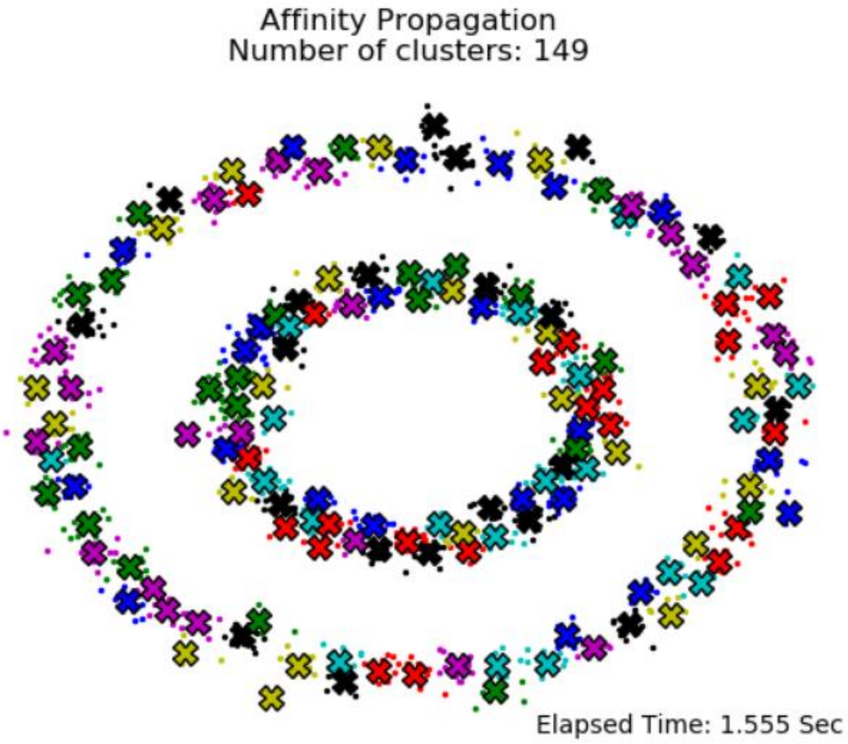


Figure 56. Affinity Propagation clustering result with more clusters (Noisy circles dataset).

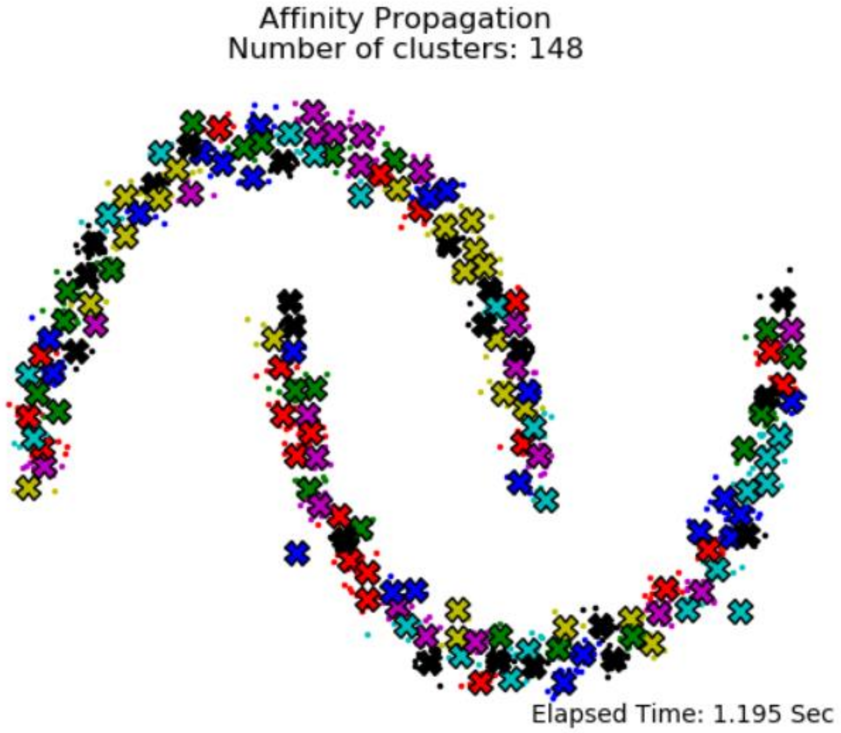


Figure 57. Affinity Propagation clustering result with more clusters (Noisy moons).

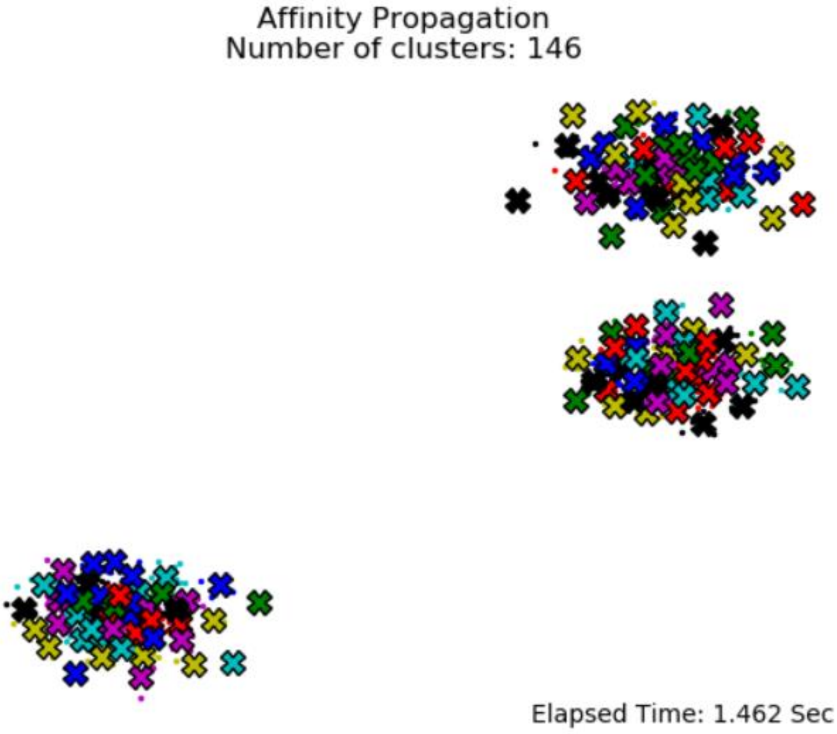


Figure 58. Affinity Propagation clustering result with more clusters (Blobs dataset).

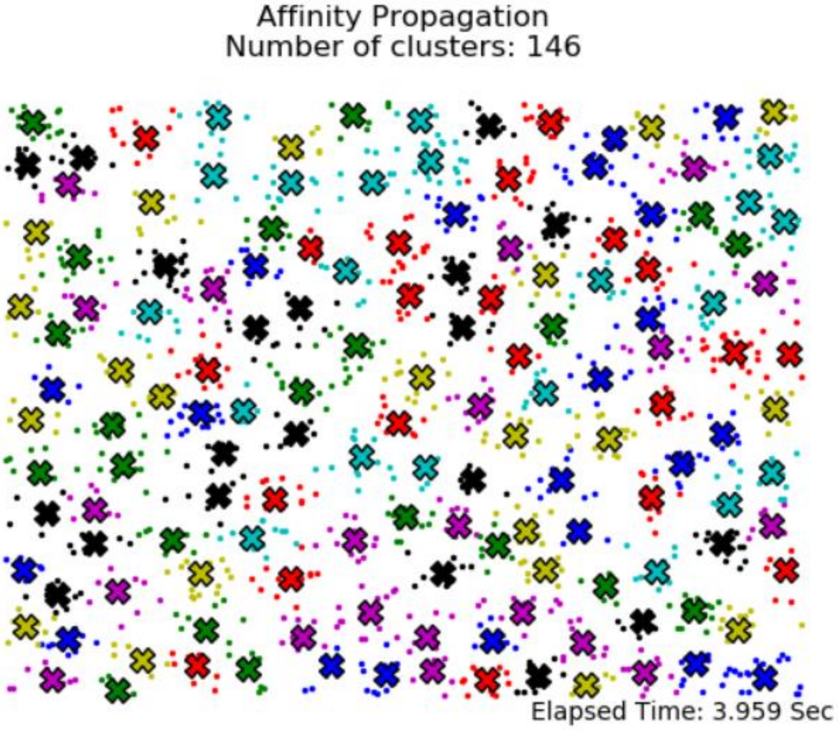


Figure 59. Affinity Propagation clustering results with more clusters (No structure dataset).

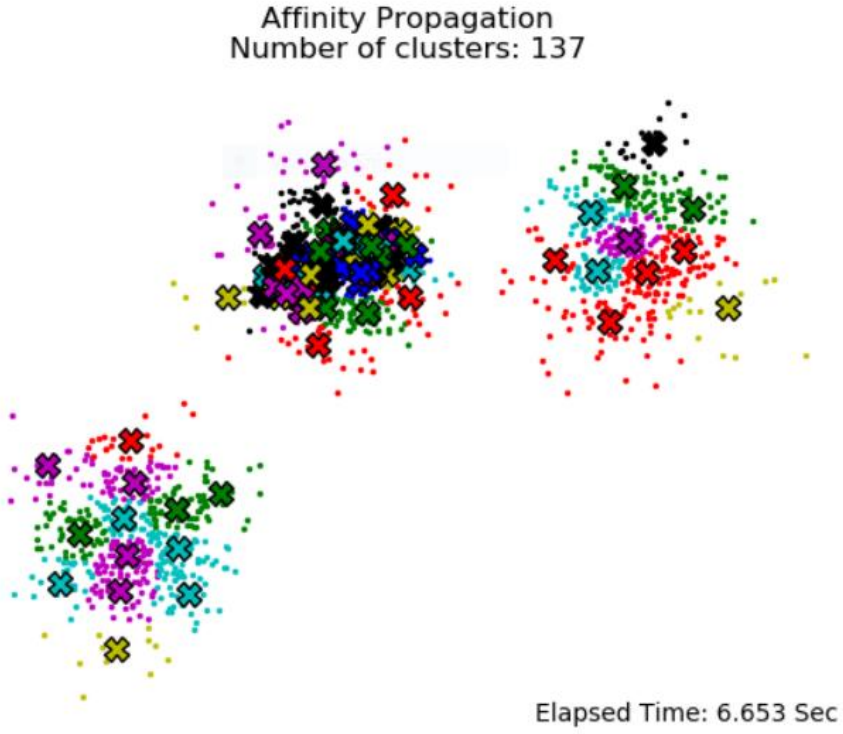


Figure 60. Affinity Propagation clustering result with more clusters (Aniso dataset).

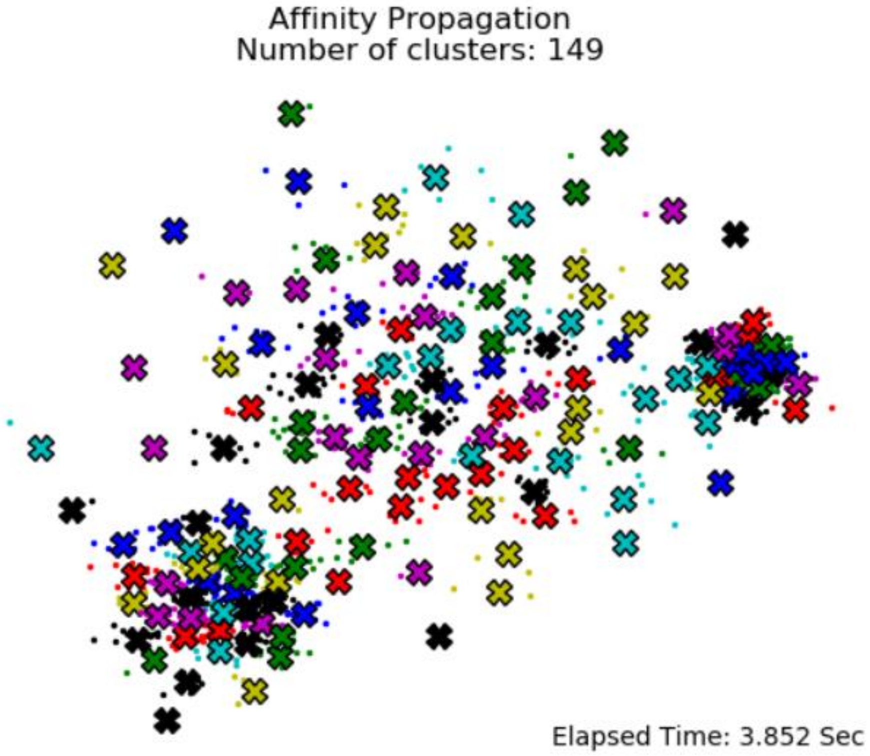


Figure 61. Affinity Propagation clustering result with more clusters (Varied dataset).

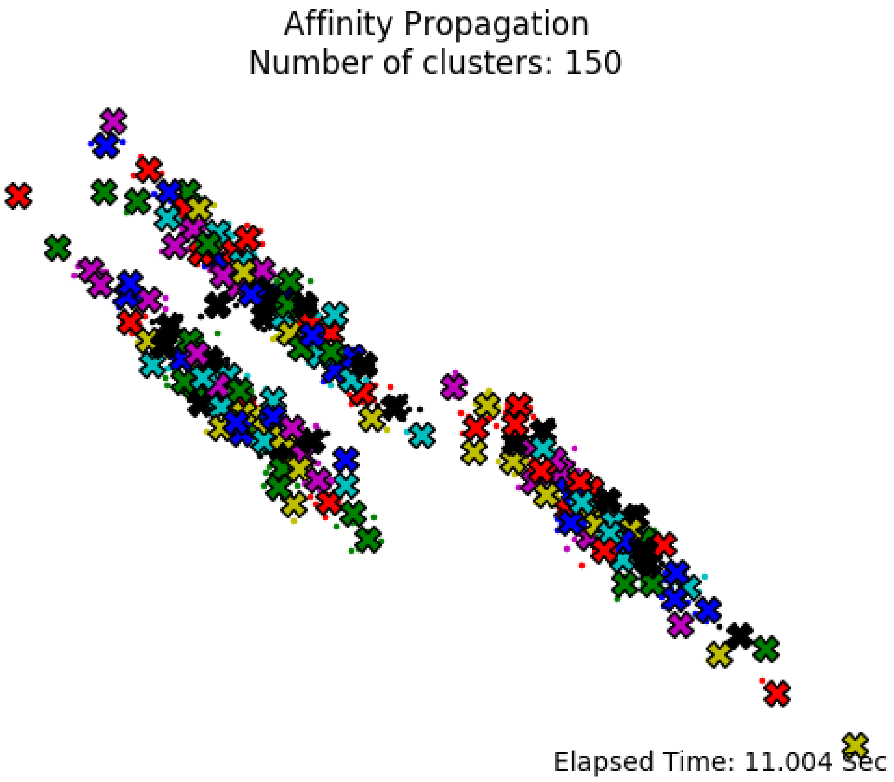


Figure 62. Affinity Propagation clustering result with more clusters (Aniso 2 dataset).

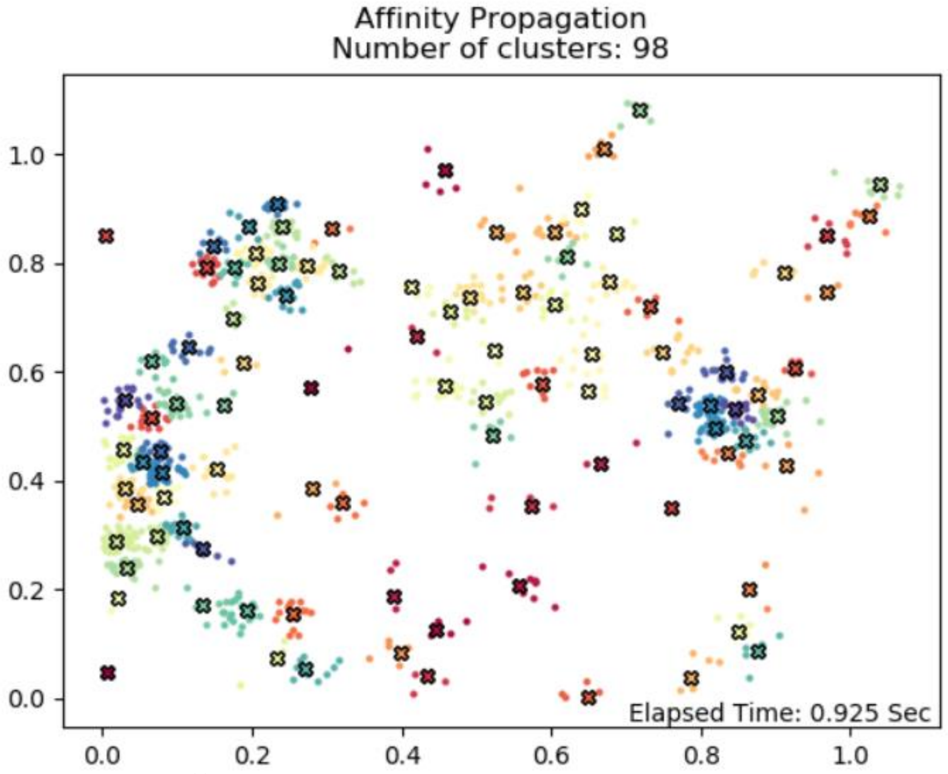


Figure 63. Affinity Propagation clustering result with more clusters (PCP distribution).

Conclusions

Changing the parameters of the algorithm to create more clusters and consequently more exemplars, has produced better results according to the scenario I am studying. By creating approximately 150 clusters in each dataset, the number of users in each cluster is reduced (around 10 users in each cluster), as well as the distance between the UEs within a cluster. Additionally, it is beneficial that the shape of the clusters created is circular, since the cluster center will be the active VBS and the UEs around it will be served by it.

However, by creating more clusters, the time needed for the algorithm to run is much larger compared to the previous evaluation of the less clusters. We also can observe that in the case of more clusters, the algorithm does not ignore the outliers, i.e. the user devices that are distant from the others and should not be categorized into some clusters but directly connected to the macro BS. This is particularly pronounced in some cases where there is only one UE in isolation and the algorithm selects it as an exemplar.

For the reasons I have just mentioned, it is considered necessary to use another algorithm initially, which will separate the users' devices into smaller subsets and then use the AP algorithm to select the appropriate eligible VBS from each cluster. Finally, because the AP algorithm selects the exemplar by passing messages between all the points in a cluster until the desired exemplar is found, it is proposed to configure the algorithm so that the messages are passed only to and from the eligible VBSs using the power received by a UE from the eligible VBSs.

Chapter 4

Conclusion

5.1 Conclusion

Due to the demands and high expectations of 5G, it is essential to use innovative and efficient ways to meet its goals for continued coverage and better connectivity. The idea of using some UEs that will act as BSs in ultra-dense networks is a promising solution, where my thesis focused. Having implemented a variety of scenarios in the Opnet simulator, where I studied the difference between the existing cellular networks and the cellular networks that use VBSs, I came to the conclusion that the use of VBSs is a possible solution for 5G, with many potentials to support the fast growing and changing needs of the future. The advantages are many and they highlight the usefulness of VBSs, as the VBSs will be activated in indoor and outdoor environments, especially in cases where the system will be highly stressed and will offer massive coverage at any time. Also, the simulation results showed an increase in network capacity and data rates and less energy consumption and lower delays.

Next, I focused on how the active VBSs will be selected among the eligible VBSs, which is also an important part that contributes to the effectiveness of this scenario. The algorithm of the Affinity Propagation was proposed for this purpose and so I evaluated the behaviour of this algorithm in several cases with many users. The results obtained were satisfactory but not optimal, since the algorithm cannot exclude the isolated UEs that should be directly connected to the macro BSs and not being a part of a cluster in the case of the VBS scenario. Additionally, it was demonstrated that the algorithm does not work properly in cases with many users, as it requires a significant amount of time to run.

Finally, I propose to use a different algorithm at the beginning to divide users into smaller subsets and also to exclude the outliers, and then use a modified version of the AP, in order to select the most suitable VBS for activation from each subset.

5.2 Future Work

This thesis has demonstrated the effectiveness of the scenario using VBSs and evaluated the algorithm of the AP. However, it is only a small contribution of the research on how to choose each VBS from each cluster. A future work could be the evaluation of the configured AP algorithm that will take as a selection parameter the received power from the UEs to the potential VBSs. Also, the implementation of a scenario in which the users would be initially divided by a suitable algorithm into smaller subsets and then the modified AP will be used. Finally, the Opnet simulations could be made with a more realistic scenario where the VBSs would have mobility.

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Appendix A - Abbreviations

3GPP	Third-Generation Partnership Project
DeNB	Donor Enb
AMPS	Advanced Mobile Phone System
AP	Affinity Propagation
BS	Base Station
CaPex	Capital Expenditure
CelDes	CelEc Devices
CGS	Closed Subscriber Group
C-RAN	Cloud Radio Access Network
D2D	Device to Device
DL	Downlink
EDGE	Enhanced Data Rates for GSM Evolution
eNB	evolved NodeB.
ENodeB	evolved NodeB
FBS	Femtocell BS
FUE	Femtocell UE
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HeNB	Home eNodeB
IoT	Internet of Things
LTE	Long Term Evolution.
MBS	Macrocell Base Station
mmWave	millimeter-Wave,
MUE	Macrocell UE
mW	milliwatt
NFV	Network Function Virtualization
NLOS	Non-Line Of Sight
NMT	Nordic Mobile Telephone
OFDMA	Orthogonal Frequency Division Multiple Access
OpEx	Operation Expenditure

PCP	Poisson Cluster Process
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
QoS	Quality of Service
RAN	Radio Access Network
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SDN	Software Defined Network
TACS	Total Access Communications System
UE	User Equipment
UE-VBS	UE-based Virtual Small Cell Base Station
UL	Uplink
VBS	Virtual Base Station