Heterogeneous Networks Handover Strategies with 5G Energy Efficiency

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Abstract

The integration of heterogeneous networks, where several access technologies, including Wi-Fi, cellular, and small cells, coexist to enable seamless connectivity and enhanced data rates, has been made possible by the quick development of 5G technology. However, maintaining energy economy while providing seamless changeover between these heterogeneous networks is still a difficult task. With an emphasis on energy saving, this research provides a thorough analysis of handover methods in 5G heterogeneous networks. Nano cells, including femtocells, picocells, and microcells, have been installed to accommodate hotspots' fast rising data throughput and improve coverage inside buildings. To increase Energy Efficiency and data speeds, femtocells are frequently placed over macrocells in hotspots. The handover issue is more crucial in macro-femto HetNets than in macrocell networks. On the one hand, because femtocells have a limited-service area and are layered, handovers happen more frequently. Hence, several strategies for enhancing network performance, including load balancing, will also result in frequent handover in macro-femto HetNets. As a result, handover significantly affects how well macro-femto HetNets is performed. We investigate different handover decision algorithms, such as signal strength-based, load-based, and mobility-based techniques, and evaluate how well they may reduce energy usage while preserving a high level of user experience. We also investigate how handover performance and Energy Efficiency are affected by network factors, traffic patterns, and mobility scenarios. We offer insights into the trade-offs between Energy Efficiency, handover delay, and user happiness through simulation trials. To achieve Energy Efficient operation in 5G heterogeneous networks, the research's findings provide useful advice for network operators and system designers. Throughout this research, we examined the most recent handover methods designed to maintain active connections or guarantee the level of service received by mobile customers. Next, we discuss handover strategies linked to load balancing. Additionally, a handover technique that uses little energy is described.

1. Introduction

The transmission rate of wireless cellular networks has increased with the innovative evolution of wireless transmission methods, including orthogonal division multiplexing (OFDM) and multiple-input multiple-output (MIMO) techniques, from a few kilobits per second in GSM to 100M/1 Gb/s for high/low mobility. The improvement is noticeable, but the difference between the actual transmission rate and the rising demand is not closing. One explanation is that more mobile users are using mobility supportive applications like Skype, Instagram, and Twitter for a few hours each day, as well as more sophisticated mobile user equipment's (UEs), such iPhones and iPads, to access cellular networks. This is resulting in an exponential rise in mobile traffic, particularly mobile data traffic (Hammed et al., 2021).

Highly using spectrum efficient propagation techniques, including OFDM and MIMO, to boost the bandwidth of wireless networks is one way to deal with the exponential rise in mobile traffic. Deploy the base station (BS) forward to customers by installing small cells, including femtocells, picocells, and microcells, which move LTE regarding heterogeneous networks (HetNets), since this will enhance system capacity and decrease energy usage in cellular networks. The HetNet model has benefits, but it also poses new problems for managing interference, allocating resources, and seamless handover. The conventional goal of handover in cellular wireless networks is to maintain active connections, which is crucial for maintaining the continuity and efficacy of a mobile user's service (Tang et al., 2020).

Handover is used in conventional non-heterogeneous wireless networks to preserve a mobile user's connection. The need for handover in these situations arises from the fact that a single BS transceiver's coverage area does not encompass the entire service area. However, in a heterogeneous cellular network that is layered, handover not only maintains active connections but also improves the network's overall performance and the quality of service (QoS) for the user by moving an active cellular user session from one BS to another. Additionally, because of the disparities in coverage area, broadcast power, and radio propagation, the handover in an overlay heterogeneous mobile network is more complex and intelligent (Jayaraman et al., 2023).

Femtocells are placed in interior settings, such as airports, homes, and businesses, to increase cellular network coverage and QoS, in contrast to microcells and picocells. They have a limited area of coverage, more complex radio transmission settings, various access modalities, and ad hoc deployments. Hence, handover in macro-femto HetNets is more difficult. There are articles that examine this problem as well as some handover architectures and methods that are comparable to those used in other tiny cell HetNets. The current state of handover methods in macro-femto systems is examined in most articles then some that give a handover algorithm that uses less energy consideration (Martikainen et al., 2018).

The goal of 5G is to decrease energy consumption while increasing telecommunications usage, speed, and services. In the current environment, where the earth must deal with the effects of global warming, energy and material waste, pollution, and many other concerns, this component of Energy Efficiency is very crucial. A typical spectral efficiency serves as a demonstration of effective data transfer in a loaded instance. Low energy expenditure in the absence of data should enable both a high sleep proportion and a lengthy sleep period.

2. Environmental Impacts of 5G

As of the last update in September 2021, there were concerns and debates surrounding the potential environmental issues associated with the deployment of 5G technology (Pápai et al., 2022). However, it is important to note that these concerns were not directly related to the radio frequency (RF) emissions of 5G itself but rather cantered around the increased infrastructure and energy requirements to support the technology (Pisarov & Mester, 2020). Here are some of the potential environmental issues that were discussed at the time:

Increased Energy Consumption: 5G networks require more infrastructure, including additional base stations and small cells, to provide higher data speeds and lower latency. These new installations demand more energy to operate, leading to potential increases in electricity consumption and greenhouse gas emissions if not sourced from renewable energy.

E-waste: The rapid upgrading of technology and devices to be 5G compatible may lead to an increase in electronic waste (e-waste). The disposal and recycling of old 4G devices and infrastructure could pose challenges if not handled responsibly.

Land Use and Habitat Impact: Expanding the infrastructure for 5G networks might require additional land for new base stations and small cells. In some cases, this could lead to the conversion of natural habitats or green spaces, potentially impacting local ecosystems.

Health and Safety Concerns: While not strictly environmental, some discussions have cantered around the potential health and safety implications of increased exposure to electromagnetic radiation from 5G networks. It is important to note that numerous scientific studies have been conducted on this topic, and as of the last update, there was no conclusive evidence of significant harm to human health from RF emissions below the established safety guidelines.

Resource Extraction: The manufacturing of 5G infrastructure and devices relies on specific minerals and metals that may require environmentally damaging extraction practices, such as mining.

It is essential to understand that technological advancements and regulatory changes may have occurred after the last update, research and measures to mitigate potential environmental impacts could have been put in place (O'Connell et al., 2020). Also, keep in mind that 5G technology can also play a positive role in addressing some environmental challenges, such as enabling more efficient and sustainable practices through the Internet of Things (IoT) and smart applications.
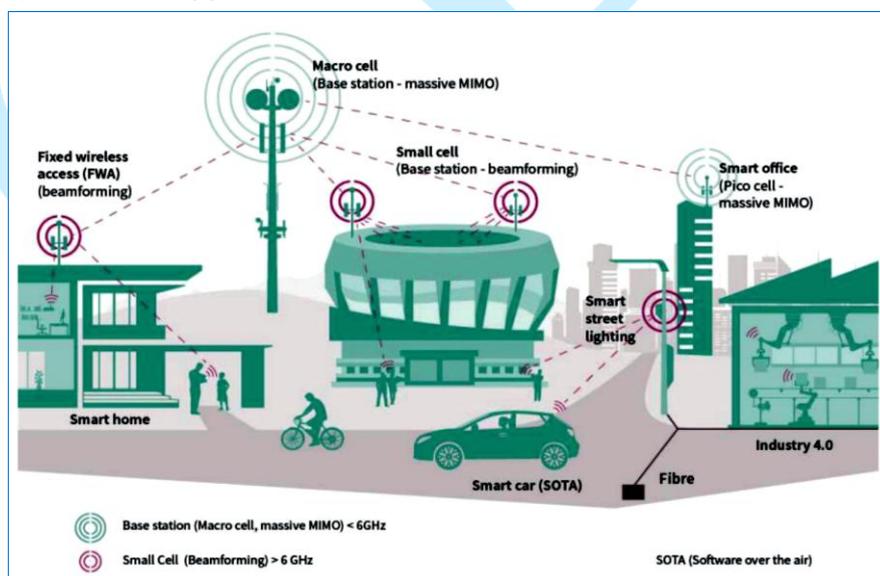

Fig. 1 Infrastructures of 5G Systems (Source ETSI EE/EE2 power)(Schulz, 2007)

3. How to Enhance the Energy Efficiency of 5G

Improving the Energy Efficiency of 5G networks is crucial to mitigate potential environmental impacts and reduce operational costs for telecommunication companies (Yang et al., 2018). Here are some strategies to enhance 5G Energy Efficiency:

Network Design and Planning: Optimize the network design and planning to reduce the number of base stations and small cells required. Advanced algorithms can help determine the most efficient locations for base stations, minimizing energy consumption while maximizing coverage (Al-Quzweeni et al., 2019).

Energy-Efficient Hardware: Deploy Energy Efficient hardware and components for base stations, antennas, and other network equipment. This includes using low-power transmitters and receivers and implementing power-saving technologies in network components.

Dynamic Spectrum Management: Implement dynamic spectrum management techniques that adjust the allocation of radio spectrum in real-time based on network demand. This helps allocate resources more efficiently and reduce unnecessary energy consumption.

Sleep Mode for Base Stations: Enable sleep mode for base stations during periods of low network activity. By powering down or reducing power consumption during off-peak hours, energy usage can be significantly reduced.

Smart Antennas and Beamforming: Utilize smart antennas and beamforming technologies to focus signal transmission and reception in specific directions. This allows for more efficient use of radio resources and reduces interference, leading to lower energy consumption.

Energy-Aware Networking Protocols: Develop and implement networking protocols that prioritize Energy Efficiency. For example, incorporating energy aware routing algorithms can reduce the energy consumption of data transmission between base stations and devices.

Green Energy Integration: Invest in renewable energy sources to power 5G infrastructure, such as solar or wind power. Integrating green energy into the network can reduce the carbon footprint and long-term operational costs.

Energy Monitoring and Optimization: Implement energy monitoring systems to track the energy consumption of different network components. Analysing this data can help identify areas for optimization and energy saving opportunities.

Edge Computing: Utilize edge computing to process data closer to end-users, reducing the need for data transmission over long distances. Edge computing can lead to lower energy consumption and improved latency.

Software-Defined Networking (SDN) and Network Function Virtualization (NFV): Implement SDN and NFV technologies to enable dynamic resource allocation and network scaling. These technologies can improve network efficiency and allow for more flexible management of resources.

Collaboration with Device Manufacturers: Work with device manufacturers to optimize the energy consumption of 5G-enabled devices. Efficient devices will have a positive impact on the overall Energy Efficiency of the network (Mao et al., 2021).

By adopting these strategies, telecommunication companies can make significant progress in improving the Energy Efficiency of 5G networks, contributing to a more sustainable and environmentally friendly deployment of this advanced technology.
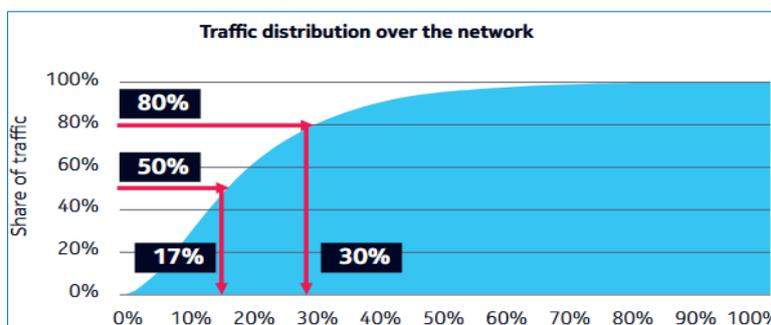

Fig. 2 Distribution of traffic on the network (Source: Nokia White Paper) (Zhao et al., 2004)

4. Femtocell Implementation Procedure and System Framework in 5G Systems

Fig. 3 depicts the complete LTE system framework with femtocell deployment. The Third Generation Partnership Project (3GPP) specifies two common interfaces (X2 and S1). The X2 interface defines information

sharing across various evolved NodeBs (eNBs) and mobility functions. The X2 interface among home eNBs (HeNBs) is also described in 3GPP Release 11 (Mukhtar et al., 2022). The S1 interface enables communication between the eNB and the Mobility Management Entity/Security Gateway (MME/SeGW). Additionally, S1 is employed for communication between the MME/SeGW and the fair access policy (FAP). When a FAP operates at the command plane, it might speak via an S1-MME. In the LTE system, the handover (HO) method involves three stages: planning, carrying out, and wrapping up. During the planning stage, the provider eNB or (H)eNB chooses a (H)eNB that the UE must turn over based on measurement reports from UEs. The chosen target (H)eNB receives the HO-request message from the source (H)eNB. The target (H) eNB executes admission control and allots resources for the UE first after receiving this message. The source (H)eNB then receives a HO-request acknowledgment (ACK) message from the destination (H)eNB. During the operation phase, the UE disconnects from the initial (H)eNB and establishes a connection with the target (H)eNB.
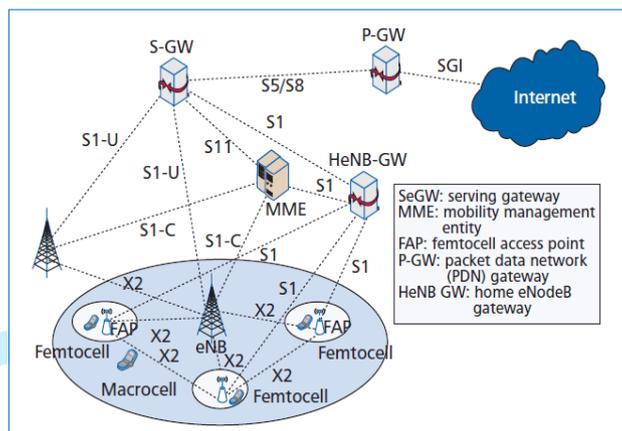

Fig. 3 The architecture of the macro-femto heterogeneous system

The UE transmits the HO-confirmation message to the target (H)eNB after connecting successfully to request that it deliver downlink information towards the UE. During the completion phase, resources allotted to the UE in the original cell are freed while downlink (DL) channel switching is carried out to instruct the core network elements to switch the data pathway from the original eNB to the destination eNB. In Fig. 4, the handover process is depicted.
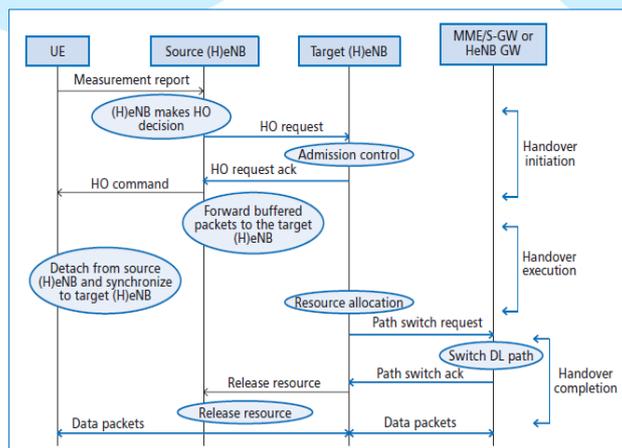

Fig. 4 The handover process for LTE in 5G systems

5. RSS-Based Handover

RSS-Based Handover (Received Signal Strength-Based Handover) is a technique used in cellular networks to facilitate seamless and efficient handover (or handoff) of mobile devices between different base stations or cells. The goal of RSS-Based Handover is to ensure that a mobile device maintains a strong and stable connection to the network as it moves through areas covered by different cells. During the operation of cellular networks (e.g., 2G, 3G, 4G, and 5G), mobile devices are typically connected to the nearest base station or cell. As a user moves, the signal strength of the connection to the serving base station changes (Yew et al.,

2020). If the signal strength drops below a certain threshold, the connection quality may deteriorate, leading to issues like dropped calls or reduced data transfer rates. RSS-Based Handover works as follows:

RSS Measurement: The mobile device continuously measures the Received Signal Strength (RSS) from the serving base station and neighbouring base stations. RSS is an indication of the power level of the signal received by the mobile device from a specific base station.

Threshold Check: When the RSS from the serving base station decreases to a predefined threshold level or falls below a certain quality level, the mobile device starts searching for neighbouring base stations that offer a stronger signal.

Handover Decision: The mobile device compares the RSS of the serving base station with the RSS of neighbouring base stations. Based on predefined handover algorithms, it decides whether a handover is necessary or not.

Handover Execution: If the mobile device determines that a handover is needed, it initiates the handover process by sending a handover request to the target base station. The target base station confirms its ability to support the handover.

Data Forwarding: Once the target base station accepts the handover request, it starts forwarding data to the mobile device, and the mobile device starts communicating with the new serving base station.

Connection Release: After a successful handover, the old serving base station releases the connection with the mobile device. RSS-Based Handover aims to provide seamless connectivity for mobile users while they are on the move. By ensuring that mobile devices are always connected to the strongest available signal, the handover process reduces the chances of call drops and maintains a better user experience for voice calls, video streaming, and data transfer (Alnabhan et al., 2020). It is important to note that RSS-Based Handover is just one of several techniques used in cellular networks for handover decision-making. Other methods may consider factors like signal quality, signal-to-noise ratio, signal delay, and load balancing to make optimal handover decisions based on network conditions and user mobility.
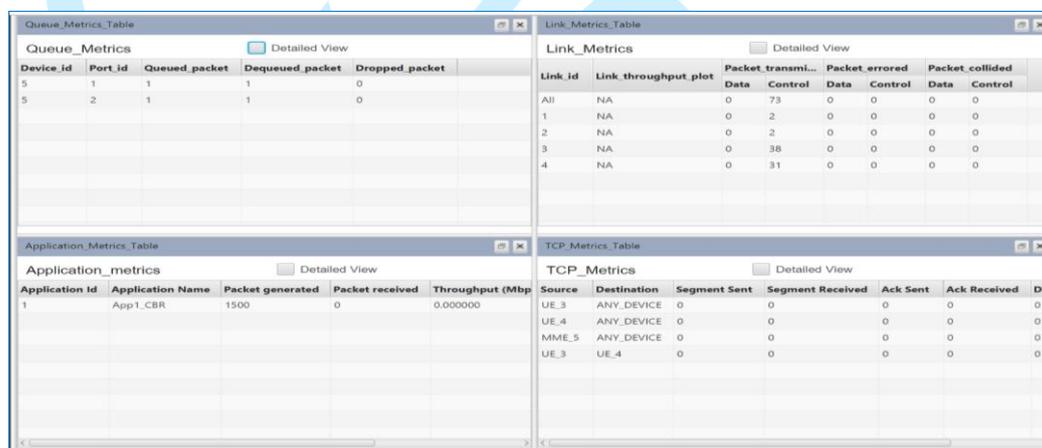

Fig. 5 Matrix Table for Simulation

6. Handover Plans Related to Load Balance

Load balancing in cellular networks is a critical aspect to ensure efficient utilization of network resources and maintain a high-quality user experience. Load balancing-related handover schemes are designed to distribute the traffic load among different base stations or cells to prevent network congestion and improve overall network performance (Kaul et al., 2018). These schemes aim to make intelligent handover decisions based on the load status of neighbouring cells. Here are some load balancing-related handover schemes:

Load Threshold-Based Handover: In this scheme, each base station monitors its traffic load, and when the load exceeds a predefined threshold, it initiates handover procedures for some connected mobile devices to neighbouring base stations with lower loads. This helps distribute the load more evenly across cells and prevents individual cells from becoming overloaded.

Traffic-Aware Handover: This scheme considers the real-time traffic demands in different cells. Base stations exchange information about their current traffic loads, and mobile devices provide information about their service requirements. Based on this data, handover decisions are made to direct users to less congested cells that can better accommodate their needs.

Proactive Load Balancing Handover: In this approach, handover decisions are made proactively before a cell becomes heavily loaded. Load prediction models and algorithms are used to forecast future traffic loads, and handovers are triggered in advance to balance the traffic load across cells pre-emptively.

Resource-Based Handover: This scheme considers the availability of resources (e.g., bandwidth, capacity) in neighbouring cells. When a cell's resources are fully utilized, the handover decision is based on the availability of resources in nearby cells to provide a better user experience.

Cell Range Expansion/Contraction: In this approach, the coverage area of a base station can be dynamically expanded or contracted based on the traffic load in its vicinity. When the load is high, the base station's coverage area can be extended to offload some users from neighbouring cells. Conversely, when the load is low, the coverage area can be reduced to improve capacity utilization.

Fig. 6 Expansion of cell range

Hierarchical Cell Structure: Some load balancing schemes involve dividing the network into hierarchical tiers. Macro cells can offload traffic to smaller micro or pico cells in densely populated areas. This hierarchical structure helps manage the load more efficiently.

Load balancing-related handover schemes are crucial for providing a stable and high-performing cellular network, especially in dense urban areas and during peak usage times. By optimizing the distribution of traffic load among cells, these schemes contribute to a better user experience, reduced congestion, and improved overall network efficiency.

Fig. 7 UE matrix table for the simulation

7. A Handover Scheme that Saves Energy

An energy-saving handover scheme is designed to reduce the energy consumption of mobile devices during handover procedures, while still maintaining a seamless and efficient transition between different base stations or cells (Satapathy & Mahapatro, 2021). The goal is to minimize the impact of handovers on the device's battery life without compromising the quality of service. Here are some key features of an energy-saving handover scheme:

Optimized Handover Triggers: The scheme uses intelligent algorithms to trigger handovers only when necessary. Instead of constantly scanning for neighbouring cells, the handover decision is made based on predefined criteria, such as the received signal strength (RSS) or the signal quality. This minimizes the frequency of unnecessary handovers, reducing the device's energy consumption.

Predictive Handover: By analysing historical mobility patterns and network conditions, the energy-saving scheme can predict when a handover is likely to be required soon. This allows the device to initiate handover preparations proactively, reducing the time and energy needed for the actual handover process.

Fast Handover Execution: When a handover is triggered, the scheme aims to execute the process quickly and efficiently to minimize the device's active scanning time. Fast handover mechanisms, such as Fast BSS Transition (FT) in Wi-Fi networks or Fast Dormancy in cellular networks, can be used to achieve this goal.

Sleep Mode Optimization: During the handover process, the energy-saving scheme can put the device into sleep mode, when possible, to conserve energy. By carefully managing the device's active and sleep periods, unnecessary energy consumption is minimized during handovers.

Neighbour List Optimization: The device maintains an optimized list of neighbouring base stations or cells. This list is updated periodically based on network conditions. By reducing the size of the neighbour list and including only the most relevant neighbouring cells, the device expends less energy in monitoring and scanning for potential handover candidates.

Energy-Aware Network Selection: In multi-network environments (e.g., Wi-Fi and cellular networks), the energy-saving scheme can make intelligent network selection decisions based on Energy Efficiency. For example, the device can prefer Wi-Fi connections when available, as Wi-Fi tends to be more Energy Efficient than cellular connections.

Load-Aware Handover: The scheme considers the load status of neighbouring cells when making handover decisions. It avoids directing the device to heavily loaded cells, as this can lead to increased energy consumption due to lower signal quality and data transfer rates.

Collaboration with Network: The energy-saving scheme can work in conjunction with network-side optimizations. For example, the network can inform the device about upcoming handovers, allowing the device to prepare in advance and minimize energy-intensive tasks during the handover process.

Battery model			☑ Detailed View				
Device Name	Initial energy(mJ)	Consumed energy(mJ)	Remaining Energy(mJ)	Transmitting energy(mJ)	Receiving energy(mJ)	Idle energy(mJ)	Sleep energy(mJ)
WIRELESS_SENSOR_1	6480.000000	272.259601	6222.141273	234.668776	10.338140	27.252684	0.000000
WIRELESS_SENSOR_2	6480.000000	118.838419	6375.562455	0.000000	0.047555	118.790864	0.000000
WIRELESS_SENSOR_3	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_4	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_5	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_6	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_7	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_8	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_9	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_10	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_11	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_12	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_13	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_14	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_15	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000
WIRELESS_SENSOR_16	6480.000000	118.807211	6375.593663	0.000000	0.000000	118.807211	0.000000

Fig. 8 Load aware handover energy saving

An effective energy-saving handover scheme helps prolong the battery life of mobile devices and contributes to a more sustainable and efficient use of wireless networks. By optimizing handover procedures and reducing unnecessary energy consumption during transitions, users can experience longer-lasting devices and better overall network performance.
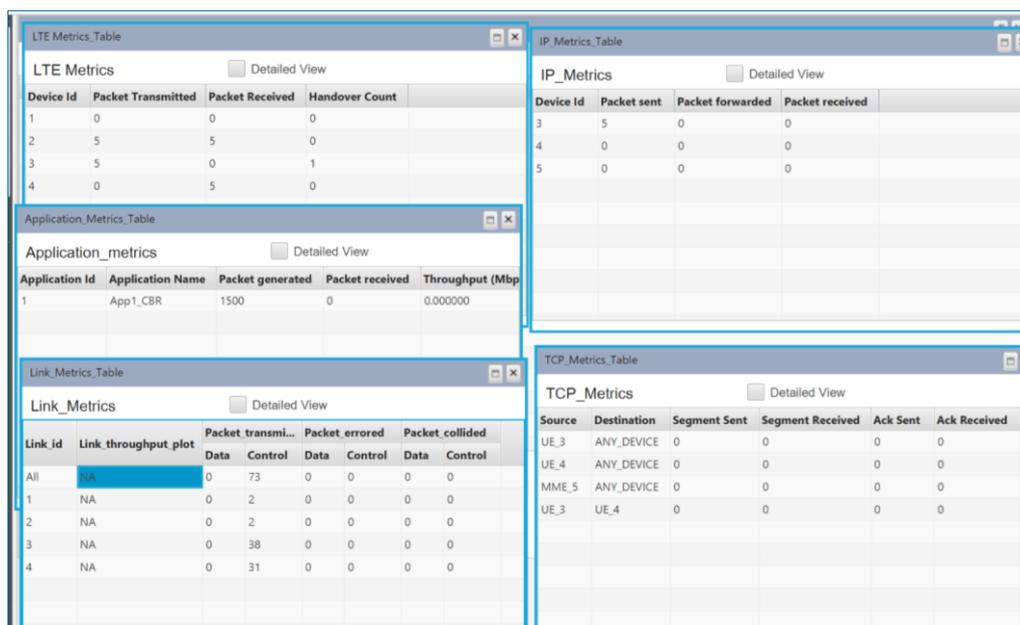

Fig. 9 Energy Saving scheme table for the simulation

8. Conclusion

The rollout of 5G, the fifth generation of telecommunications, is about to begin across Europe. Regarding its applicability to the several verticals, this technology is quite promising and will foster the birth of innovations. However, the Energy Efficiency about 5G is a significant worry at a time that has become crucial to reduce energy consumption as much as feasible. The literature has extensively examined techniques and options for making 5G as Energy Efficient as predicted more than 90% more Energy Efficient over LTE. Since base stations use 80% in the energy required for data transmission, putting them in "sleep mode" is one of the primary solutions mentioned in most studies on the problem. Beamforming, spatial multiplexing, longer battery life, reduced energy usage by auxiliary equipment, and greater hardware efficiency are other alternatives. In mobile cellular networks, handover is a well-known and significant problem, and there have been numerous studies on the topic. But as macro-femto diverse cellular networks are implemented, new problems and research directions are presented. The field of view of just one femtocell is limited, and because of this, distinct femtocells as well as macrocells and femtocells overlap one another. Therefore, handovers with macro-femto HetNets occur more frequently than in macro-macro wireless networks. This would result in ping-pong and significant handover signalling overhead, which will ultimately hurt network performance and QoS for mobile users. Secondly, femtocells are different from macrocells in nature, lacking strong mobility support and having different access modes. When choosing the destination femtocells to switch to, we considered how these inherent femtocell characteristics affect the quality of service (QoS) of mobile customers.

A higher RSS value generally indicates a stronger and more reliable signal, leading to better communication performance, higher data rates, and fewer errors from Fig. 10. When the UE moves between cells or access points, the network may trigger a handover to ensure continuous and optimal connectivity. The decision to handover is often based on the RSS levels from neighbouring base stations. RSS can impact the energy efficiency of the UE. When the signal strength is weak (low RSS), the UE may need to increase its

transmission power to maintain communication with the base station. This can result in higher power consumption and reduced battery life for the UE from Fig. 10 below.
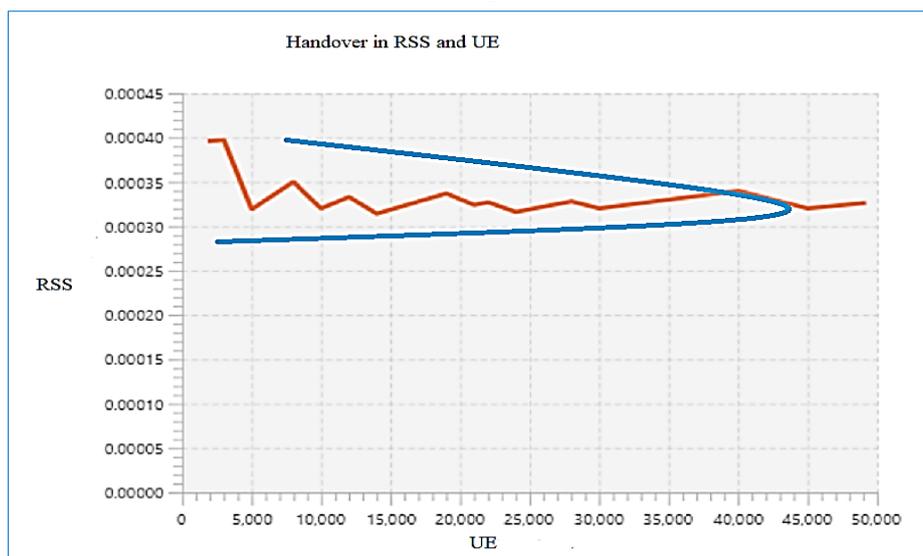

Fig. 10 Heterogenous Energy Efficient transmission

Overall, maintaining an appropriate RSS level is essential for providing reliable and efficient wireless communication services to the UE. It ensures good signal quality, coverage, and seamless handover while also contributing to better energy efficiency for the user devices. Additionally, some energy-saving techniques, such dynamic sleeping and power regulation, will disable a femtocell's radio antenna or reduce its transmission range, which will result in handover and have an impact on cell selections. Finally, interference termination, distributing resources, load balancing, and power regulation will have an impact on the handover choices and processes in a macro-femto HetNet. It is difficult to optimize these problems together.

Declaration of Conflict
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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