5G (Fifth Generation)

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I. Abstract

5G plays a pivotal force in the mobile accessibility ecosystem. Being introduced in 2019, it is revolutionizing telecommunications and cybernetics for everyone and everything. It is the new ‘generation’ that allows various interactions among machines (e.g. Artificial Intelligence), Objects (virtually and physically), and living species (ourselves). To further emphasize this, it is built off the expectations of its predecessors and offers many advanced benefits such as faster speed, shorter latency, increasing capabilities, and wider bandwidth. However, when discussing 5G “New Radio,” the former definition, as well as its engineering explanation, becomes obsolete and confusing. With that in mind, in this paper, we will be discussing the history of this new technology, the use case that defines its predecessors, how it operates, technologies that circulate the “New Radio”, and most importantly the challenges and solutions that continuously arise.

II. Introduction

It is apparent that the internet has transformed our everyday interactions and our quality of life, making communication convenient and simple in comparison to the previous generation. To illustrate this mutation, consider the communication standard 15 years ago when mobile internet cybernetics only allowed us to view videos posted on well-known platforms-as-a-service and browse company-licensed websites. Today, the norm for mobile internet accessibility has evolved beyond just web surfing to facilitate interactions among machines, primarily Artificial Intelligence, enabling real-time data monitoring, and more. It is apparent, an increasing number of Internet of Things (IoT), Machine Learning (ML), and Artificial Intelligence (AI) devices are becoming readily accessible to the general public. Consequently, the demand for faster and more reliable internet speeds has proportionally grown to accommodate the expanding functionalities of these various devices. Catering to this large demographic, the expectations of the new generation cellular network is becoming a necessity. Which is why the 5th generation New Radio plays a paramount role in the innovative mobile communication market currently and for many years to come. Offering services such as faster, sustainable, and reliable networks, 5G will help shape the new generation in the telecommunication network . However, it is worth mentioning that today, the 5G network is still in its infancy stage, and is expected to stay in this position for many years to come. Let's dive into the history of the term 'Generations' that helped make an impact on the development of 5th generation technology.

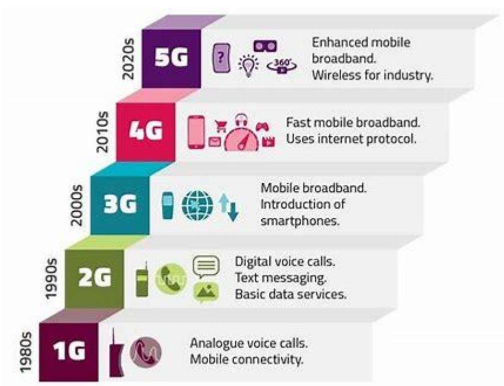
III. “Generation” in Mobile Network

Throughout history, the term “Generation” in technology refers to a significant advancement from its predecessors, manifesting as either physical or software-based upgrades. The 5th Generation New Radio (5G NR) unmistakably builds upon the foundations laid by the preceding four generations of mobile telecommunication. This progression becomes increasingly essential as the demand for intercellular connection rises with IoT, AI, and ML products.

Let’s dig into the previous generations that led up to what we see today. In 1980 first generation (1G) was presented, introducing analog voice transmission at 2.4 Kbps using an 800

MHz frequency. This breakthrough laid the groundwork for subsequent developments in mobile communication, by allowing technological transmission to be flexible given any position. The introduction of second-generation (2G) technology in 1981 brought forth digital voice calls and the early version of Short Messaging Services (SMS); operating at a frequency of 900 MHz and transmitting data at up to 64 Kbps. Setting a new standard in telecommunication, 2G is integrated and advanced upon the primal functions introduced by 1G. The early 2000s witnessed the arrival of the third generation (3G), marking a significant milestone by introducing internet accessibility to mobile devices. Operating in the 2.1 GHz band with a bandwidth of up to 2 Mbps, 3G not only provides higher data transfer rates but also catalyzed the emergence of innovative services (at that time) such as Facetime, voice calls, SMS, and widespread internet accessibility. Like the integration and advancement between 1G and 2G, 3G incorporated and advanced upon the capabilities introduced by its predecessor and became the paramount of its period. This alone sets the standard for what the mobile network can potentially do.

The fourth generation (4G or LTE), introduced in 2009, aimed to establish reliable mobile access for multimedia services. Operating on a 2.6 GHz frequency and providing a bandwidth of up to 100 Mbps; 4G facilitated the growth of IoT products, supporting services such as High Definition (HD) streaming, virtual reality, and online gaming. In comparison to 3G, 4G offered faster internet capabilities, wider bandwidth, and served as a long-term solution for expedited data transfer; setting the stage for the expectations surrounding 5G technology. In essence, this historical overview contextualizes the evolution of mobile technology, embellishing the trajectory that led to the development of 5G and its role in shaping the future of telecommunications**.**



Notice in this image, that the cybernetic industry tends to become more advanced than its predecessors. With the benefits being a foundation to every “generation”’s advancement, it will continue to serve as an innovative monetization step to ensure that there is an elevation in the technology.

3G set the standard of what is a flexible network and became the industry standard for making a faster, more reliable and convenient system.

This section is to present the historical navigation to the expectation of 5G. We will discuss more about the potential security threats and limitations of the 5G networks later in this documentation.

IV. How does 5G operate

To understand the operation of 5th-generation technology, the comprehension of modern-day resources must be employed. One of the crucial resources that allows mobile accessibility on our IoT device is the spectrum band. A spectrum band is the invisible radio frequency through which wireless fidelity travels. Much like how a radio functions, these waves are transmitted by macro towers providing internet access to mobile clients.

Spectrums are typically classified into three categories: Low Frequency, Mid Frequency, and High-Frequency cells; each of them with distinct benefits of its own. Low Frequency transmits wavelengths up to 700MHz (approximately 428.57 meters), offering internet accessibility over a greater wide-area coverage and catering to a larger user scale. This is particularly beneficial for larger venues such as sports arenas or self-autonomous vehicles that heavily depend on wider area coverage. However, the disadvantages of the Low Spectrum Band include the bottom-most data transmission rates and susceptibility to signal interference from solid objects. As we all know, objects such as trees, walls, and buildings integers with the overall transmission of fidelity for Low Spectrum Bands. With that said the Mid Spectrum Band offers coverage up to 6GHz, often seen as a valid balance between wide area coverage and optimal speed; providing accessibility for environmental monitoring and having the potential to power smart cities. In comparison to Low Band Frequency, it does not have a wider area coverage, and the area coverage is much smaller. This is seens as the most highly optimal band in the market today. High Spectrum Bands offer coverage up to 40 GHz, providing higher speeds but with a smaller coverage radius. They bring benefits in empowering smart cities, advancing smart energy systems, improving residential connections, and more advancements. With all 3 bands and their distinctive category, most of these bands are 4G specifically licensed.

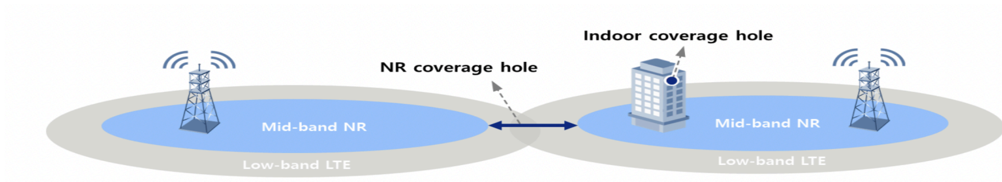
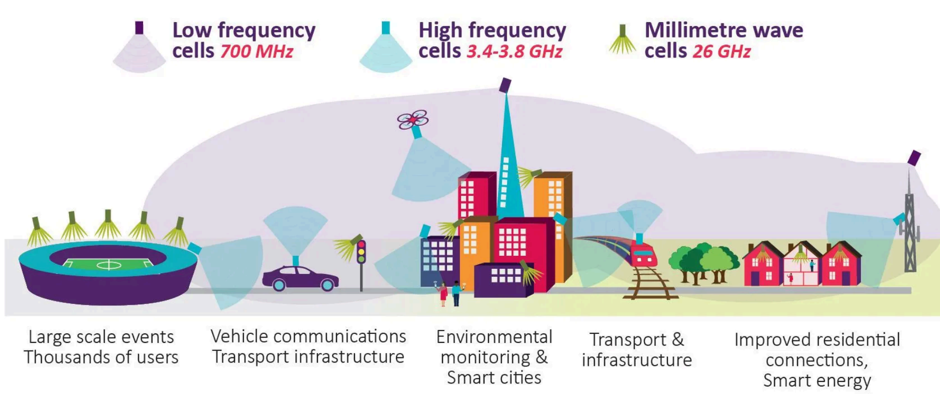


Figure 3. Coverage hole of mid-band NR



So the question we must ask is, why can't the internet provider service industry invest in licensed spectrum bands to provide its users with a uniform experience? The reason why the industry does invest in this is because licensed spectrum bands are very costly; and the majority of Internet of Things users are still utilizing devices compatible only with the 4G LTE licensed spectrum. To put this into perspective, it is estimated that 62% of users are still using a 4G device while 30% of users are using a 5G-operated device. As we may know, why would a company invest in new spectrum band technology when there are not too many 5G users? 4G services are still dominating the communication market, and are expected to dominate for the next several years. Another solution is constructing macro towers with spectrum specifically tailored for 5G users is very costly to manufacture but will be a viable paramount solution. Let's discuss the industry standard trend that helps us solve this dilemma.

V. Industry Solution for the limited Spectrum Band

A common industry-level solution is Static Spectrum Sharing (SSS), where the licensed spectrum is strictly divided to accommodate a small number of 5G users. For example, a 20 MHz spectrum band can be divided into 10 MHz for 4G users and 10 MHz for 5G users. Although this is a viable solution, strictly allocating a licensed 4G spectrum to serve a small number of 5G users may not be optimal at the moment. This approach can lead to bandwidth wastage and create additional challenges for existing 4G users. It is expected to become a more effective solution over time as more 4G users transition to 5G devices, resulting in a shift in the ratio of 4G and 5G users. However, it is not optimal at this period.

VI. Dynamic Spectrum Sharing

Another industry solution trend is Dynamic Spectrum Sharing (DSS). DSS is a technology that enables both 4G and 5G to operate within the same frequency band; while dynamically allocating the spectrum between the two technologies based on their respective demands. For instance, at one point, a 20 MHz spectrum may be divided into an 18 MHz allocation for 4G users and a 2 MHz allocation for 5G users. The reason behind this is because there are more 4G users present at that particular moment and not as many 5G users. At another point, the same spectrum may be split into 17 MHz to cater to 5G users and 3 MHz for 4G users. This allocation varies due to the higher demand for 5G spectrum compared to 4G users during that time frame. Being able to accommodate both users is significant because it will save time, money, and staff as 5G exits from its infant stage.

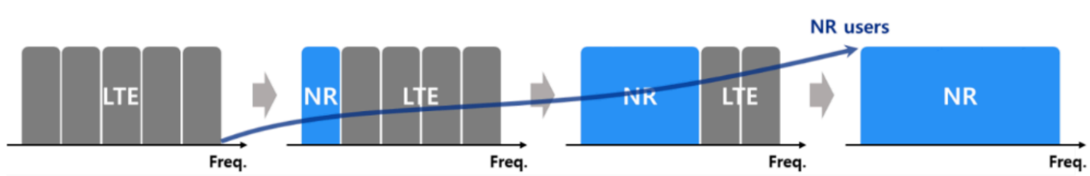
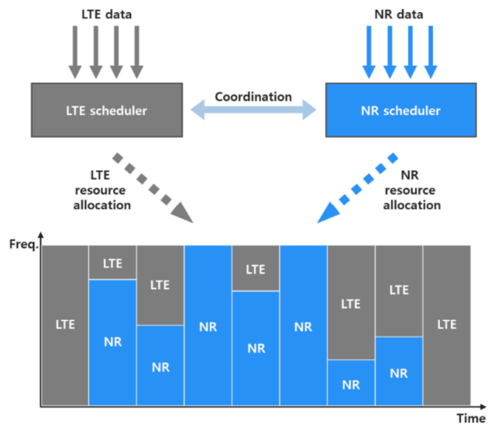
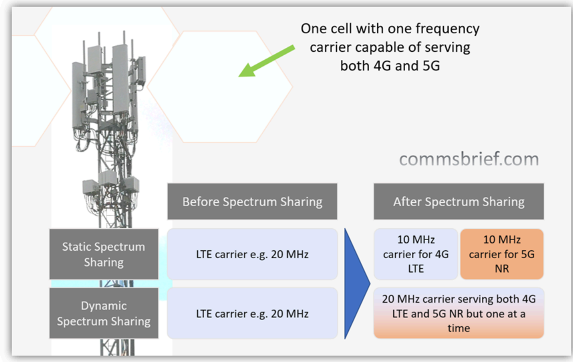


Figure 1. Spectrum re-framing as NR growth





Although Dynamic Spectrum Band is an innovative technology that allows accommodations between 4G and 5G supported devices, it is valuable to face many obstacles and major challenges. Being a software-based antenna technology, several factors can produce major problems that can, hypothetically, impact the 5G network. For instance, when applying spectrum sensing, some of the major challenges that arise are potential hidden primary users, sensing time and energy trade-offs, noises, and hardware limitations. Some significant challenges that may arise include potential software bugs during the updates, limitations in handling increased traffic, and the risk of outdated infrastructure. Many companies face the need for thorough audits to ensure the seamless utilization of this powerful technology. Some of the potential attacks encompass:

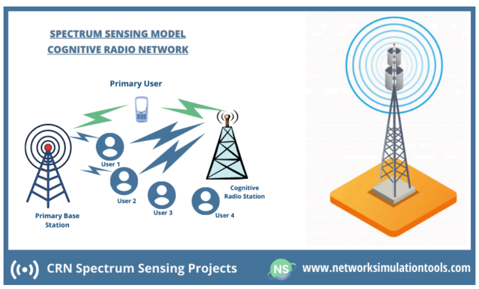
- **Case Problem #1: Surface Sensing Attacks:**
  - **What:** Once an attacker gets access to the spectrum band, they can control the entire mechanism and send false information about the available spectrum. This could lead to unauthorized management of the actual spectrum or a form of denial-of-service attacks.
- **Case Problem #2: Unauthorized Access:**
  - **What:** Once a malicious attacker gets access to the dynamic shared spectrum, they can lead to disruption of communication attacks. This can potentially lead to traffic jams and other forms of attacks on legitimate DSS users.
- **Case Problem #3: The Eavesdropper:**
  - **What**: Since 5G has accommodated a significant amount of users within a larger demographic, once an attacker has control over the 5G mechanism, they can potentially have access to the user's private information. Which is a huge breach in security factors.

All of these case problems are just scratching the surface of the potential security factors of DSS. Since there are different services 5G to perform massive machine type communication (mMTC), having a trusted encrypted network is the norm. Once attackers get in control of the band itself, many of these options are open for them to disrupt the network itself.

VII. Cognitive Radios Networks

A. CRN and its functions

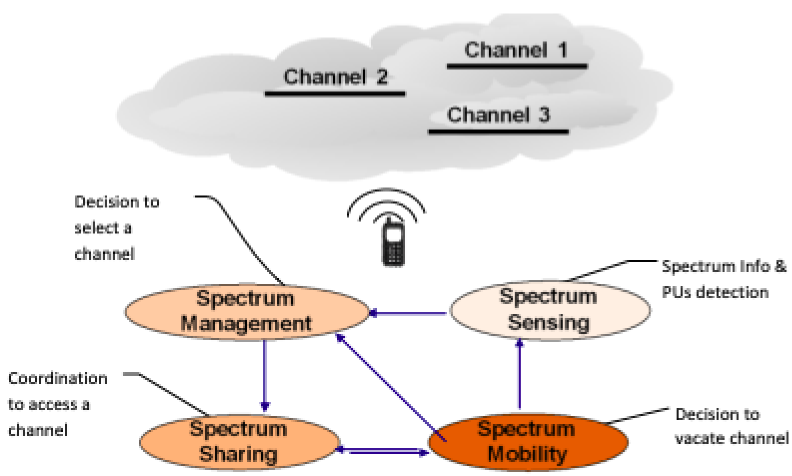
While the wireless spectrum is a powerful tool that facilitates mobile internet accessibility, it also has limitations that make it suboptimal. Some spectrum bands over cluttered, as seen in GSM cellular networks, while others remain relatively underutilized, such as those used by the military. Cognitive Radio(CR) is a technology that can optimize the utilization of the RF spectrum. They are transceivers that intelligently detect and switch to available channels, making it an optimal solution for spectrum coverage. Cognitive Radio networks (CRNs) perform four key functions. These embedded functions are closely interrelated, and a failure at any stage can significantly impact the entire network. This makes CR an advanced tool with the potential to revolutionize 5th-generation technology and allow spectrum management to be fully utilized.



It does not come as a surprise that DSS has it's mechanism security factor placed. Cognitive Security has to synchronously make sure Spectrum Sensing is optimized and secured.

There are four main functions in which the cognitive radio network (CRN) device must perform:

1) **Spectrum Sensing** identifies the parts of the accessible spectrum and senses the presence of the primary user (PU) operating in the licensed band.
2) **Spectrum Management** determines the best channel to establish communication.
3) **Spectrum Sharing** sets up coordination access among users on the selected channel.
4) **Spectrum Mobility** vacates the channel in case the primary user (PU) is detected.

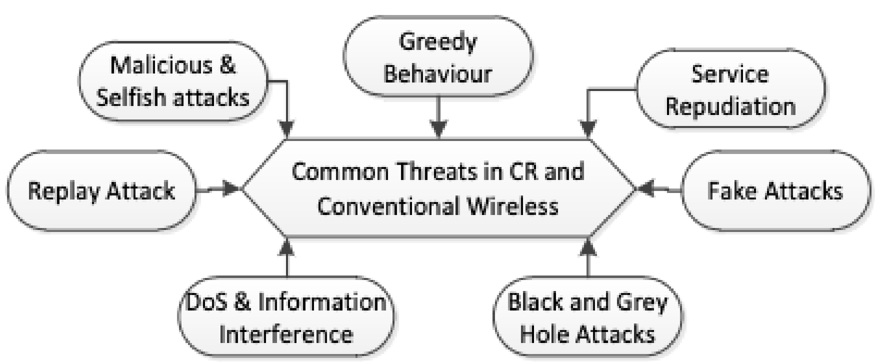


These embedded functions have a strong relationship between themselves and one failure in any step can easily affect the entire network.

B. Common Security Threats in CRN

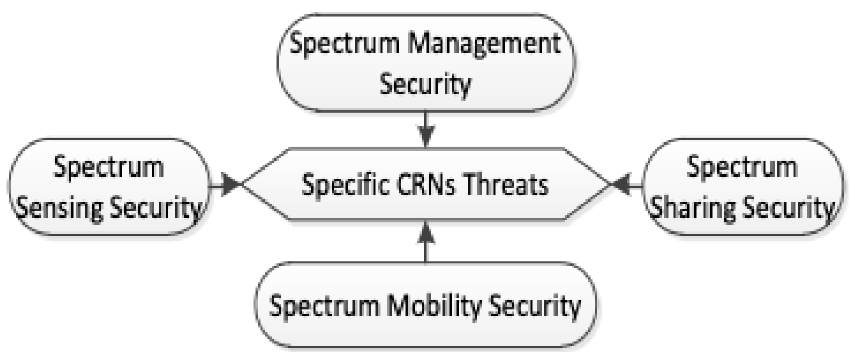
The CR network shares common threats with the conventional wireless network, such as:

- **Fake Attacks:** Happen when a malicious user steals login information and uses it to access the network, obtain the network service, or launch an attack against the network. One of the potential solutions for this issue is having encryption used to protect the user's private information.
- **Information Tampering:** When the information is changed or deleted before reaching the destination, resulting in misleading the receiver, who can then make the wrong decision.
- **Service Repudiation:** When two users agree on a connection, such as purchasing a content, and then one user refuses to pay.
- **Replay Attack:** Where the attacker intercepts and retransmits the same signed information over time to build trust with the receiver, granting them access to new useful information such as user passwords.
- **Denial of Service and Information Interference:** Where the attackers use transmitter power to block ordinary transmission to create interference and noise in wireless communications.
- **Greedy Behavior Attack:** Where the attacker reports false information regarding available channels, causing the receiver to over utilize the neighboring nodes, and maximize the attacker's throughput.
- **Malicious and Selfish Behavior Attacks:** Where the attacker disturbs the network performance, causing the other cognitive users to make handoff from the current channel, which then would maximize the attacker's throughput.
- **Black and Grey Hole Attacks:** Where the attacker pretends to be the destination node, thus obtaining all of the data (in black hole attacks), or part of the data (in grey hole attack)



C. Specific Security Threat in CRN

- **Unauthorized Spectrum Access:** If a device can move across different spectrum bands, there's a risk of unauthorized access to restricted or licensed bands. Malicious users might attempt to exploit spectrum mobility capabilities to gain access to spectrum they are not allowed to use, leading to interference and potential legal issues.
- **Spectrum Hijacking:** Unauthorized users could attempt to hijack the spectrum resources of legitimate users, disrupting their communications. This can be done through various means, such as signal jamming or transmitting on frequencies reserved for critical applications.
- **Spectrum Misuse:** Even if a device has legitimate access to multiple spectrum bands, it may misuse them, causing interference with other users. This could be accidental or intentional, and it can lead to disruptions and security breaches.
- **Security of Spectrum Databases:** In some spectrum mobility scenarios, devices rely on central databases to discover available spectrum bands. These databases must be secure to prevent unauthorized manipulation or access.



VIII. 5G Use Cases

The definition of 5G is complicated. To emphasize this, as mentioned in the “Generation” category, when a new technology follows its designing process to upgrade our current 5G carrier; specific classes and abstractions need to be defined to make proper accommodations for development. To solve this issue, engineers has classified 3 use case categories that defines the overall expectations of the 5G network:

These three(3) use case categories are:

1) **Enhanced Mobile Broadband (eMBB):** 5G has to have sufficient bandwidth, speed, capacity, and mobility to enable new mobile applications such as High-Definition (HD) and augmented Reality (AR).
   a) **Use Case #1:** As a 5G user, I want to be able to use the 5G network, so I can view my stocks in real-time.

    b) **Use Case #2:** As a 5G user, I want to be able to watch my content creator's stream with little disturbance anywhere in the world.
2) **Ultra-Reliable Low Latency Communications (uRLLC):** As its name suggests, focuses on communication reliability up to 99.99% with low latency.
    a) **Use Case #1:** As a 5G user, I should be able to send a WhatsApp message to my relative instantly with little delay.
    b) **Use Case #2:** As a 5G user, I should be able to watch a full video on a Platform as a service with very little low latency.
3) **Massive Machine-Type Communication (mMTC):** 5G has to be scalable to accommodate a large number of variety devices and allows massive interactions (hence the name).
    a) **Use Case #1:** As a 5G user, I should be able to have access to my in-home smart appliance using my mobile IoT device.
    b) **Use Case #2:** As a 5G user, I should be able to monitor my livestocks, soil health, and vertical shipment simultaneously using my mobile IoT device.

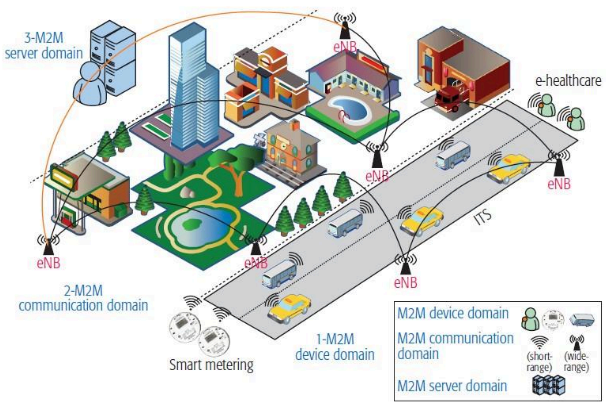


Figure above discusses the overall interactions of mMTC, uRLLC, and eMBB. Unlike the other 2 use cases, mMTC is what really make's 5G the innovative technologies. Allowing interactions between various devices is what makes 5G the pivotal point in the cybernetic community.

As described above, each of these use cases are categorized and solidified concerning its own benefits. If an engineer would like to issue an update (security, advancement, or upgrades), they can use these categories to know the surface areas to issue it. Together, they all overlap and make up the expectation of the 5G network. To specify what we mean, unlike the 4G era, 5G accommodates both machine and living species; making uRLLC an important abstraction and polymorphic. With mMTC, it plays a crucial role in allowing connectivity of "things", not just individual devices. These interactions can be "Machine to Machine", "Machine to Mobile", "Machine to Mobile to Machine to Machine", and so on. However, it does come with specified limitations and security threats. Let's dig deeper into mMTC from a technical perspective.

IX. mMTC

A. What is mMTC?

mMTC is developed by 3rd Generation Partnership Project (3GPP), the organization responsible for standardizing 5G networks and providing new 5G services for the telecommunications industry. MMTC provides a wide area network architecture to deliver high-speed, low latency, and cost-effective communications for a huge number of devices utilizing the internet.

B. Benefits of mMTC

Increased Network Performance:

A key advantage offered by mMTC lies in its ability to boost network performance through the adept use of state-of-the-art technologies like software-defined networks (SDN) and network slicing. Through dynamic resource optimization and bandwidth allocation, mMTC ensures seamless operation for an increased number of devices, even in network congestion scenarios. This optimization not only amplifies overall network capacity but also lays a robust foundation for applications leveraging the 5G infrastructure. The outcome is a substantial enhancement in user experience, with applications harnessing the optimized network for superior performance.

Reduced Latency:

Harnessing the capabilities of 5G technology and deploying low-latency protocols, mMTC aims to establish ultra-low latency connections among IoT devices. This reduction in latency is a game-changer, especially for applications reliant on real-time responsiveness. Whether it's mission-critical tasks or immersive augmented reality experiences, mMTC's role in minimizing communication delays ensures applications can respond with unprecedented speed and reliability. This attribute is pivotal in unlocking the full potential of IoT applications relying on instantaneous data exchange.

Lower Energy Usage:

Reduced energy consumption for Internet of Things (IoT) devices is directly correlated with efficiency in connectivity, and mMTC serves as a driving force toward this goal. IoT devices can run more effectively and use less energy thanks to mMTC's enhanced connectivity mechanisms. As a result, these devices' battery lives are greatly extended, which is an important feature in situations where it is not practical to replace the batteries frequently. IoT devices can operate dependably for longer periods of time thanks to the mutually beneficial relationship between mMTC and energy efficiency, which supports environmentally responsible and sustainable IoT deployments.

C. Challenges of mMTC

The rise of the Internet of Things (IoT) has inaugurated a phase of connectivity, where numerous devices communicate effortlessly to augment effectiveness and convenience. Central to this interlinked environment is mMTC, a technology facilitating communication among an extensive array of devices. Nonetheless, the implementation of mMTC presents a series of complex challenges that require thoughtful examination and inventive resolutions to unlock its complete capabilities.

Security and Privacy:

Safeguarding the security and privacy of data transmitted within a massive IoT ecosystem is a paramount concern. Vulnerabilities in security measures can lead to data breaches and unauthorized access. Robust encryption, authentication, and access control mechanisms are imperative to protect against cyber threats, addressing the critical challenge of security and privacy.

Device Heterogeneity:

Managing diverse devices with varying capabilities and communication requirements poses challenges in ensuring interoperability. Incompatibility issues may arise, hindering seamless integration among different device types. The development of standardized communication protocols and ensuring backward compatibility are crucial to overcoming challenges related to device heterogeneity.

Standardization:

Establishing global standards for mMTC is essential to promote interoperability and consistency. The lack of standardization can lead to fragmentation and hinder the seamless integration of mMTC devices. Collaborative efforts with industry stakeholders and standardization bodies are crucial to developing and adopting global mMTC standards.

D. Common Applications of Massive Machine-Type Communication (mMTC)

Connected Vehicles

Wireless connectivity enables new functionalities and services in the automotive industry. Automotive applications optimize both machine and human communication. The mMTC use case in automobiles enables the exchange of data between machines inside the vehicle or with servers or user devices. mMTC use cases in the automotive industry include traffic efficiency, road safety, remote diagnostics, and control.

Smart Grids

The smart grid is a complex cyber-physical system where energy production is decentralized. There is real-time control and coordination to match the energy supply with demand. The mMTC service provided by 5G wireless technology promotes the establishment of a reliable smart grid. This smart grid, which is a use case of mMTC, is also capable of sending commands and polls.

Factory Automation
By enabling wireless connectivity between various movable machines present in an integrated control system, it is possible to reduce downtime, shut downs, and monetary losses during manufacturing. The application of 5G mMTC over a wired connection helps engineers lower installation costs and eliminate the clutter and weight issues from cables. The most common application of factory automation is the real-time control of sensors and actuators in a closed loop.

Massive machine-type communication (mMTC) services enabled by 5G technology are integral parts of use cases such as factory automation, autonomous vehicle control, smart buildings, smart city systems, smart grids, smart logistics, and geographically spread devices.

E. AI in mMTC

There are several ways in which AI can contribute to the security of mMTC in 5g:

1) Anomaly Detection
2) Behavioral Analysis
3) Threat Intelligence
4) Dynamic Network Monitoring
5) Machine Learning for Authentication
6) Encryption and Privacy
7) Security Analytics
8) Automated Response
9) Predictive Security
10) Collaborative Security

In this report, we will be mainly focusing on how AI helps with Behavioral Analysis.

X. Behavior Analysis in mMTC Security

A. Overview

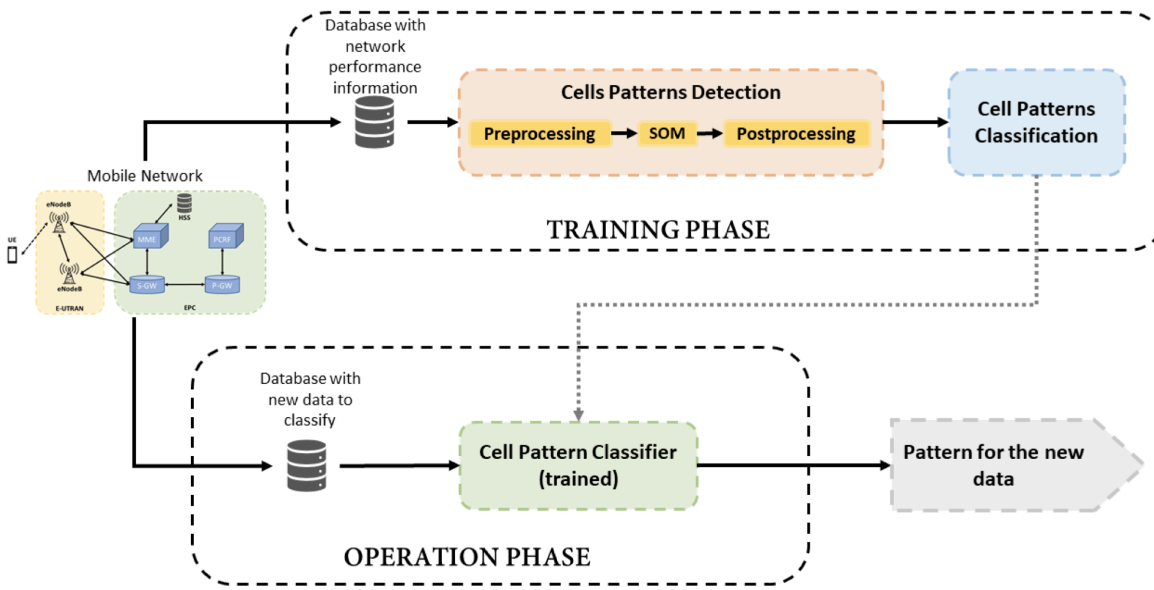
Behavior analysis with respect to mMTC in the 5G network involves studying how many of these devices interact with the network, examining patterns, and understanding their overall impact on the pure network performance. For instance, in an AI model, we can learn typical usage patterns and raise alerts if a device starts behaving in a suspicious manner. This comes no difference from how overall behavior is being analyzed within the pure 5G network. As 5G continues to improve its use cases, the overall integrity and complexity of data exchange will proportionally rise. With that being said, the management of this complicated data will also become more obsolete and needs to be managed to accommodate properly issued updates.

In one of our references, the authors discussed the challenges posed by the increased complexity of the 5G network, which demand efficient management solutions. They talked about the Self-Organizing Network (SON) algorithm for unsupervised learning and the Random Forest algorithm for supervised learning. They have created a framework that will help detect, classify, and monitor cell behavior patterns in real time; and also elaborated challenges throughout the application of the SONs function. Various ML techniques were used, including supervised and unsupervised algorithms such as SOM, Random Forest, and rule-based systems.

B. Proposed Framework

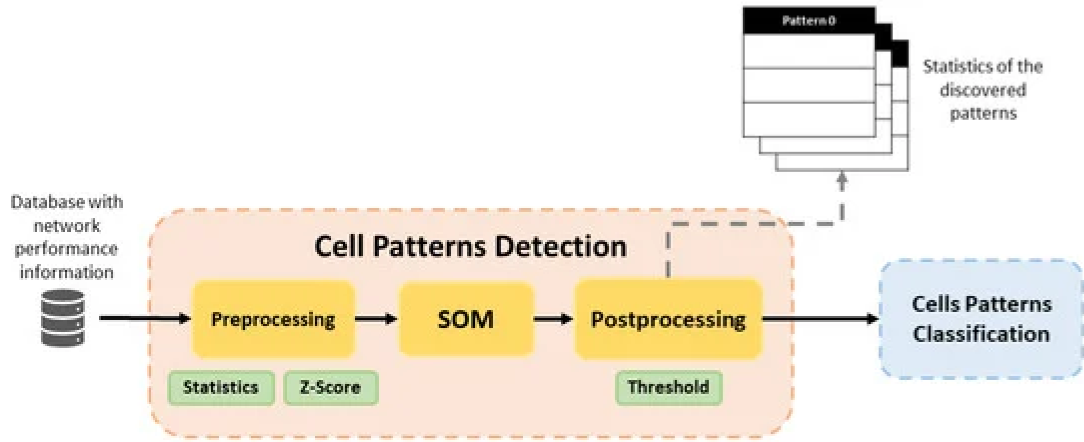
1. Overview

This section describes the proposed framework for classifying and analyzing pattern behaviors in mMTC. The framework consists of two main parts: a block for analyzing and identifying cell behaviors based on collected information over a specific time period, and another block for monitoring the network and detecting changes in cell behavior over time. The framework is divided into Training and Operation phases.



1. Training Phase
   1.1. Overview

The Training Phase prepares the framework for monitoring the cell behavior. It comprises of two functional blocks: Cell Patterns Detection, which uses the Self-Organizing Map (SOM) algorithm to identify behavior patterns in an unlabeled dataset, and the Cell Patterns Classification trains a Random Forest algorithm with the labeled dataset to create a classifier.



1.2. Cell Patterns Detection Block

Cell Pattern Detection block executes pre-processing to prepare data for the SOM. Then, the SOM detects behavior patterns and Post-Processing assigns a label to those cells with similar behavior patterns.

The SOM method is the main element of this block and it is executed as an unsupervised learning algorithm.

Self-Organizing Map

The Self-Organizing Map (SOM) is a three or two-dimensional neural network grid. A weight vector with the same dimensions as the input data is connected to every neuron. High-dimensional input data is used to train the SOM, and at first, neuron weights are either randomly assigned or derived from the training set. A random input vector is selected during training, and the "winning" neuron is the one that has the greatest similarity to the weight vector. Iteratively, the weights of the winning neuron and its neighbors are changed to better match the input vector. Preserving the topological structure of the input space on the lower-dimensional map, where neighboring neurons react to similar input patterns, is a fundamental feature of SOM.

In SOM there are two main phases: competition and cooperation. During competition,Neurons compete to be the best match for the input vector whereas during the cooperation phase the weights of neighboring neurons are adjusted to be more similar to the winning neuron.The influence of neighboring neurons during the weight update is controlled by a neighborhood function. Training doesn't stop until the map stabilizes and the topological relationships in the input space are maintained, at which point the weights converge.

Applications:

Self-Organizing Maps (SOMs) are used for a number of tasks, such as clustering, visualization, and dimensionality reduction. Their usefulness is especially evident in exploratory data analysis, where they provide light on the underlying structures of complex datasets, facilitating comprehension.

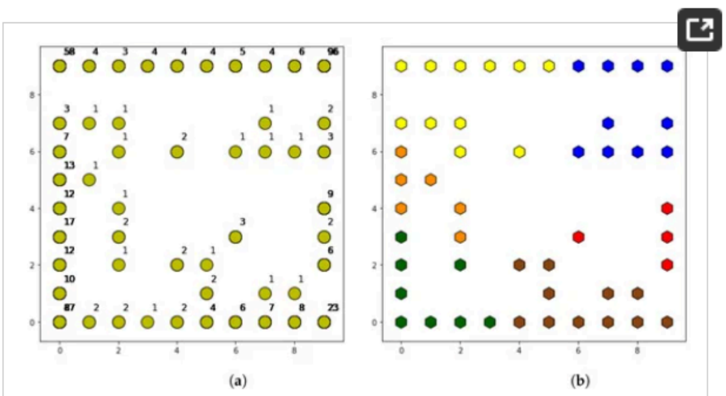
Our team generated a SOM code to scan every possible value in the grid and identify behavior patterns. The code is shown below:

```
SOM_Grid := some grid with random weights for each neuron
learning_rate:= the neighborhood radius
num  := number of behavior for training

Foreach tests in num:
        foreach attributes in the dataset:
                Find the best Matching unit by calculating the neuron with the closest
                weight

                Reduce the learning rate and neighborhood radius over time for the SOM

        endfor
Endfor
```



igure 5. (a) Map of neurons at SOM output. (b) Map of neurons at post-processing output.

In this coding example, it is crucial to include a post-processing phase capable of finding similar behavior in neighboring neurons. The goal is to assess the performance proposed by the framework and optimize the overall cellular network within the 5G network. Unlike real-world SOM, where every input data is selected randomly; in this code, we are going polynomial traversal to indicate where the neuron will be placed and what attributes will be categorized. Every neuron is connected, so determining its neighboring categories is crucial, because it can determine the overall behavior of the system. As shown in the image above, how every neuron sections off the attributes, based on its KPIs. The SOM algorithm detects behavior patterns and labels the data set in the Post-Processing phase at the end of the Cell Pattern Detection block.

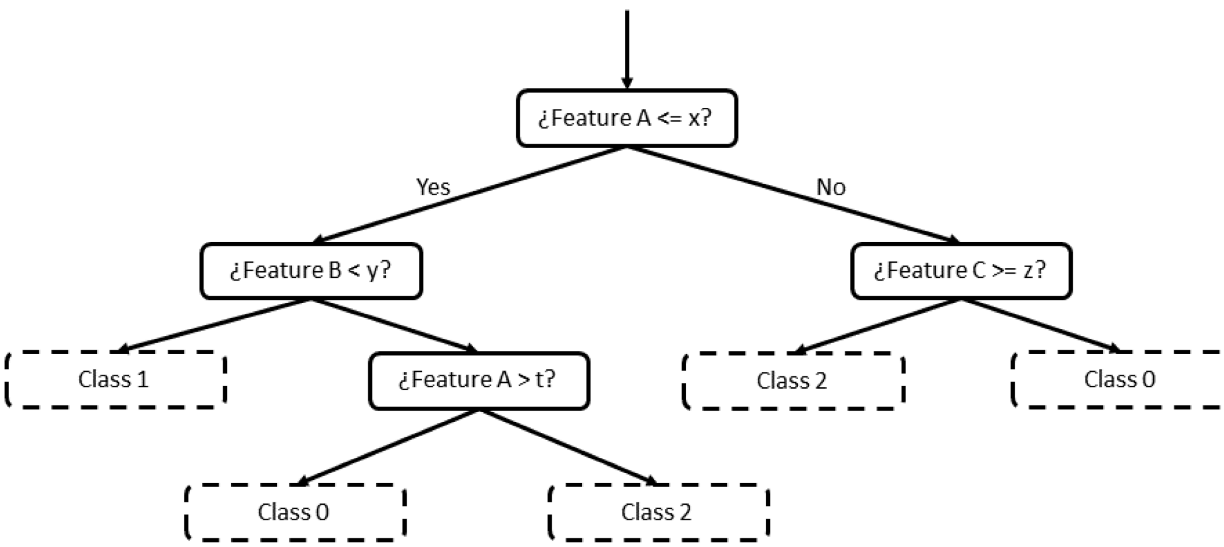
A Real World Example of is:

1) **Select the random input**
2) **Compute winner neuron: the closes neuron to the space**
3) **Update neurons:** All neurons are connected, so there will be some sort of displacement among the bunch of neurons.
4) **Repeat for all input data**
5) **Classify input data**

All of which will still give the same results when executed properly.

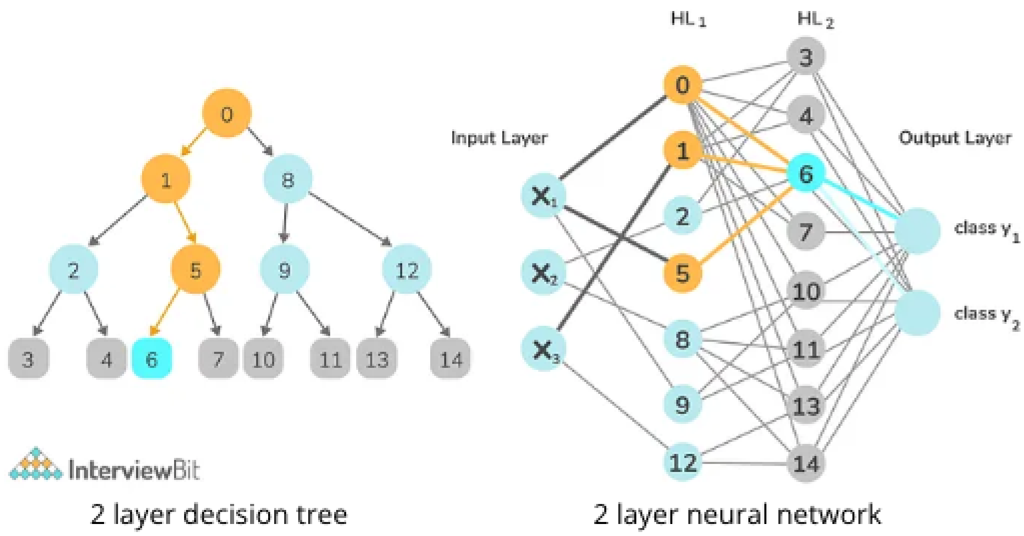
1.3. Cell Patterns Classification Block

This block is responsible for building a classifier based on the Random Forest algorithm using the labeled dataset generated from the Cell Pattern Detection block. Random Forest is a supervised machine learning algorithm built on decision trees. These decision trees consist of hierarchical nodes or leaves, with each node splitting into two others in a downward direction. The criteria for these divisions are based on features of the input data, with the algorithm typically seeking the highest difference between two splits by comparing certain features. An illustrative example of a decision tree is provided in figure below, where each node undergoes successive divisions until a value is reached for classification, with nodes depicted using dashed lines.



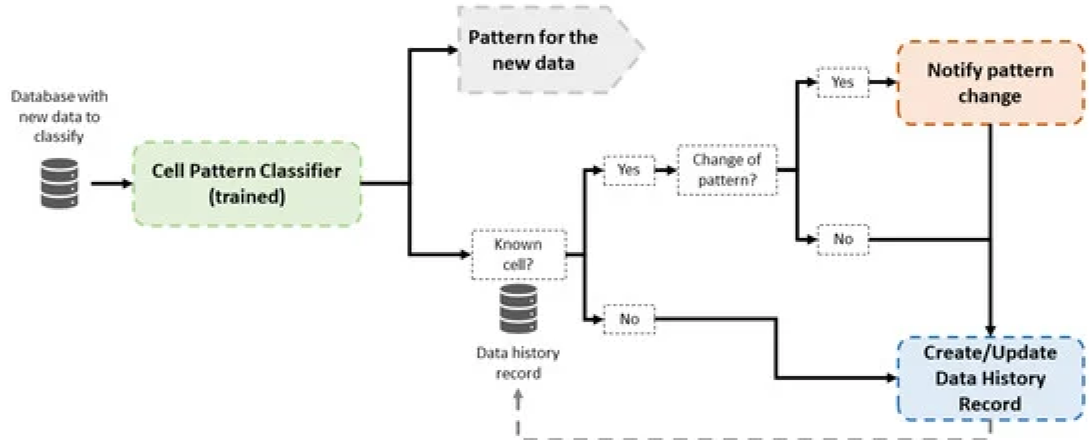
The algorithm operates in two phases: training and evaluation. The input dataset is divided into a larger part for training and a smaller part for evaluation. During training, data with corresponding labels are input into the algorithm, enabling it to learn the relationships between feature values and labels. In the evaluation phase, only feature values are considered, and the classifier outputs a label. The accuracy of the trained classifier is then assessed by comparing the output label with the original label.

The use of Random Forest is justified by its ability to achieve higher accuracy with a short response time compared to other classifiers. However, a 2-layer neural network might be used as a classifier instead of a 2-layer decision tree depending on the types of the dataset. A 2-layer neural network classifier provides higher accuracy on unstructured data, such as images, video, audio, and text, although training time might be longer.



2. Operation Phase

The Operation Phase uses the trained classifier to monitor the network and detect changes based on new data. When new data is available, a classification is carried out in the previous step. Then, historical data is consulted to check if the cell has been previously classified in the system. In the affirmative case, the new classification is compared to historical data of this cell, and a notification is raised to inform a pattern change if classifications are different. In the negative case, data from this new cell are stored with the assigned pattern classification. This allows for the detection of future pattern changes for this specific cell.



The Training Phase requires a sufficiently large dataset for reliable pattern detection and may be executed periodically to find new behavior patterns. On the other hand, the Operation Phase can be executed at regular intervals, such as daily, weekly, or monthly, based on operator preferences.

C. Experiments

An experiment was conducted utilizing the same framework, testing 450 cells with 23 Key Performance Indicators (KPIs) related to aspects such as throughput, traffic, quality, and resource usage. In this experiment, the SOM algorithm was employed with the largest LTE network set. The reason for using a LTE network dataset and not 5G accumulated data is because 5G is still in its infancy.

In the training phase, 90% of the 450 cells, each consisting of 23 KPI, are used to construct the classifier. These 90% of the 450 cells are fed into the decision tree and used to test how efficient the network is.

Category	Key Performance Indicator
Traffic and Throughput	Cell throughput in downlink
	User throughput in downlink
	Volume data traffic in downlink
	Cell throughput in uplink
	User throughput in uplink
	Volume data traffic in uplink
Quality	QPSK usage rate in downlink
	QPSK usage rate in uplink
	Spectral efficiency downlink
	CQI
Users	Average of connected users
	Maximum of connected users
	Restablishments success rate
	Restablishments per connected user
Use of Resources	PRB usage rate in downlink
	PRB usage rate in uplink
	Blocking rate in signaling resources
	Signaling resources usage rate
Others	Latency in downlink
	RSSI in uplink control channel
	RSSI in uplink shared channel
	UE distance
	SINR lower than 2 dB rate

The SOM algorithm identifies 6 patterns (P0-P5) per KPI, the patterns are represented by a different color. A portion of the patterns and statistics per KPI chart is shown below:

Key Performance Indicator	P0	P1	P2	P3	P4	P5
Number of cells	132	20	120	36	57	85
Cell throughput in downlink	↑	↘	↓	↗	↗	→
User throughput in downlink	→	↓	↓	↑	↓	↑
Volume data traffic in downlink	↑	↘	↓	→	↗	↓
Cell throughput in uplink	↑	↓	↓	↗	→	↘
User throughput in uplink	↑	↓	↓	↑	→	↑
Volume data traffic in uplink	↑	↘	↓	↘	↗	↓
QPSK usage rate in downlink	↓	→	↑	↘	↘	↗
QPSK usage rate in uplink	↓	↑	↑	↓	→	↘

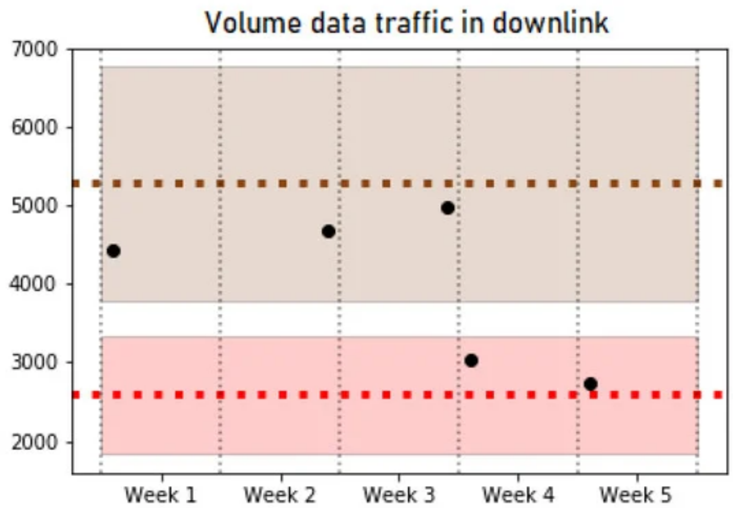
Each color pattern is defined as:

- **Green (PO):** Represents a good behavior pattern, signifying a high volume of connected users, a substantial amount of transmitted data, and exceptionally high connection quality.
- **Red (P1):** Indicates cells with an extensive coverage area, albeit with a lower number of connected users. Blue: Contrary to the positive attributes of Green,
- **Blue (P2):** Indicates cells that may perform less optimally in the network. These cells exhibit lower transmission levels and a reduced number of data transmissions on both links.
- **Orange (P3):** Characterized by high blocking rates, improved latency, and a classification as a high-performing segment of the network.
- **Brown (P4):** Denotes traffic transmission resources dedicated to both signaling and user data.
- **Yellow (P5):** Signifies a scenario where the volume of connected users is relatively low, signaling/data resource utilization is minimal, but the transmission rate is notably high.

The 6 patterns (P0-P5) are used to train the Random Forest algorithm and build a pattern classifier at the end of the training phase. The remaining 10% (45) to test the effectiveness of the algorithm, giving an accuracy per pattern as below: The goal is to find the best configuration for accurate classification. In essence, these tables provide insights into the accuracy of pattern classification for each behavior pattern, highlighting potential challenges in distinguishing similar patterns. Additionally, they shed light on the importance of different KPIs in the classification process, emphasizing variations in their influence on the final classification by the algorithm.

Pattern	Accuracy
P0	0.95
P1	1.00
P2	0.97
P3	1.00
P4	0.95
P5	0.92

In the operation phase, the trained classifier is used to find out the pattern that corresponds to new data collected from the network and to monitor possible changes in the pattern of a certain cell. In the test carried out in the article, a pattern change in one cell was detected. For the particular cell, the pattern for KPI value ‘Volume data traffic in downlink’ changed from P4 (brown) to P1 (red) at week 4, thus a notification was raised.



XI. Conclusion

To properly understand the 5G network translates to exploring its predecessors, the resources it uses to operate, and the challenges it faces. Crucial to this understanding is the recognition of Dynamic Spectrum Sharing (DSS) as an innovative technology, showcasing how 5G maximizes existing Spectrum Band. The three defined Use Cases—Enhanced Mobile Broadband (EMBB), Ultra-Reliable Low Latency Communications (uRLLC), and Massive Machine Type Communications (mMTC)—establish the diverse capabilities of the 5G network and set the overall expectation of 5G. Our proposed framework incorporates a Self-Organizing Map (SOM), an artificial neural network facilitating unsupervised learning through sorting and mapping. By comparing high-dimensional input data to a lower-dimensional grid, SOM reveals patterns within complex datasets, offering a visualization to discern optimal behavior from non-optimal tendencies. The efficiency of our framework in detecting and understanding the network behavior dynamics as it aligns to the demands placed on the 5G infrastructure. In essence, our approach provides a foundation for comprehending and optimizing the expectation of 5G network performance. This will definitely help assist the entire 5G network as it continues to exit its infant stage.

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