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A comparison analysis of 5G key performance indicators based on entropy

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Abstract

This study presents a comparative analysis of 5G Key Performance Indicators (KPIs) using an entropy-based weighting method to prioritize critical metrics for 5G deployment on existing 4G LTE networks in Mongolia. The proposed methodology quantifies uncertainty and randomness in system performance, assigning objective weights to each KPI based on their contribution to overall information entropy. Among the eight KPIs analyzed in the study, spectrum efficiency emerged as the most critical, with a weight of 0.209. This was closely followed by area traffic capacity at 0.204 and peak data rate at 0.185. By identifying the most significant KPIs, the study suggests that improvements in these areas will positively influence other performance indicators. These results underscore the importance of optimizing these metrics to enhance network performance and user experience. The findings demonstrate that prioritizing specific KPIs can have varied impacts on 5G deployment outcomes, highlighting the significance of a data-driven approach to decision-making in network development. This research provides a practical framework for evaluating and enhancing 5G KPIs, with implications for future 5G deployments from 4G LTE networks in developing countries.

Keywords: 5G key performances indicators, correlation coefficient weight, entropy weight, integrated weight

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1. INTRODUCTION

KPIs are crucial metrics used to assess the performance and effectiveness of 5G networks [1]. These indicators include aspects such as speed, latency, connectivity, and coverage, which are crucial for assessing the overall quality and efficiency of 5G technology [2, 3]. These parameters are essential for understanding and evaluating the performance and capabilities of 5G networks: User experienced data rate provides insight into real-world user performance, peak data rate indicates the maximum potential speeds, mobility ensures reliable service for moving users, latency measures the responsiveness of the network, connection density addresses the capacity to handle numerous devices, energy efficiency focuses on sustainable network operations, spectrum efficiency optimizes the use of available frequencies and area traffic capacity evaluates the network's ability to handle data traffic in a given area [4]. Together, these parameters define the effectiveness and suitability of 5G networks for various applications and use cases, ensuring that they meet the diverse needs of modern connectivity [5, 6]. A comparison analysis of 5G [7] key performances based on entropy [8] offers a valuable perspective on network performance by quantifying variability and consistency in KPIs. This approach provides a deeper insight into the performance of different networks, helping to inform decisions on optimization and enhancements.

By leveraging entropy, stakeholders can enhance the reliability and efficiency of 5G networks, ultimately leading to better user experiences and more effective network management. This study conducts a comparative analysis of key 5G performance metrics through entropy [9, 10]. Entropy, a measure of uncertainty or disorder in a system, is employed to evaluate and compare the performance characteristics of 5G networks. By applying entropy-based methods, the analysis aims to quantify and understand the variability and reliability of 5G performance across different networks and regions. The use of entropy in this context provides a unique perspective on how effectively 5G networks are performing, allowing for a nuanced comparison of various performance indicators [11]. Furthermore, the International Telecommunication Union's International Mobile Telecommunication (IMT)-2020 initiative underlines the evolution of mobile communications, building on previous standards like IMT-2000 (3G) and IMT-Advanced (4G). IMT-2020 introduces new requirements to address the growing demands of modern applications and services [2, 4]. As part of this ongoing standardization effort, the entropy-based weighting method can evaluate performance parameters and indicators effectively. This approach not only facilitates a detailed analysis of current 5G networks but also lays a foundation for assessing future technologies, such as 6G and the internet of things.

2. METHODOLOGY ANALYSIS FOR 5G KEY PERFORMANCES BASED ON ENTROPY

Within in this section, we will introduce the formulation of the analysis for 5G key performances based on entropy. The subsequent subsection will furnish an outline of several fundamental theories, followed by an in-depth explanation of the method based on entropy. The methodology for analyzing 5G key performances using the entropy weighting method [11] involves several steps to objectively evaluate and rank the performance indicators. This approach leverages entropy to assess the variability and significance of each performance metric, leading to a more reliable and unbiased evaluation. In the context of 5G networks, entropy is applied to various aspects to enhance network efficiency, security, and performance. This section aims to deliver a detailed description of the proposed integration algorithm, outlining how entropy can effectively inform performance evaluations and facilitate the continuous advancement of 5G technologies.

2.1 Entropy weighting method

Information entropy quantifies the amount of information derived from a source of random data and was first introduced by Shannon [12, 13, 14]. The entropy weighting method is a technique used to assign weights to various indicators based on the amount of information they provide [15]. This method assesses intent, order, and efficiency by estimating the entropy of information [16, 17]. It leverages the concept of entropy from information theory [18, 19] to objectively determine the significance of each indicator in a multi-criteria analysis [20, 21, 22]. By using entropy to derive weights, this approach improves the objectivity of ranking and evaluation processes [23].

2.2 Correlation coefficient weighting method

To examine the correlation among 5G key performances indicators, the correlation coefficient (CC) formula was applied. Correlation analysis, a quantitative analytical tool, is employed to assess the extent of the relationship between independent and dependent variables [24, 25].

2.3 Integrated weighting method

This subsection aims to provide a detailed description of the proposed integration algorithm.

The following are the specific steps:

1) Given that there are m additional elements to be measured and an algorithm available for evaluating n objects, it is necessary to construct an evaluation matrix for the assessment model.

$$X_{ij} = (x_{ij})_{mxn} \tag{1}$$

where x_{ij} denotes the value of the i^{th} indicator for the j^{th} sample.

2) Normalized using the following procedures:

$$d_{ij} = \frac{x_{ij}}{\max x_{ij}} \tag{2}$$

The normalized matrix is derived as follows:

$$D_{ij} = (d_{ij})_{mxn} \tag{3}$$

3) The corresponding weight of x_{ij} is:

$$\begin{gathered} P_{ij} = (p_{ij})_{mxn} \\ p_{ij} = {d_{ij}}\Big/{\textstyle\sum_{i=1}^{m} d_{ij}} \end{gathered} \tag{4}$$

4) Equation (5) represents Shannon's information entropy for the i^{th} indicator in the matrix, where m denotes the number of indicators and n signifies the number of objects.

$$E_i = -\frac{1}{\ln(n)} \sum_{j=1}^{n} p_{ij} \ln p_{ij} \tag{5}$$

To standardize the value of E_i and ensure that $0 < E_i < 1$.

5) The equation for calculating the entropy weight is provided below:

$$W_{ei} = \frac{1 - E_i}{m - \sum_{i=1}^{m} E_i} \tag{6}$$

6) This yields a symmetric matrix of size mxm, with a generic element represented by r_{ik} in the matrix of R. To determine r_{ik}, follow these steps:

$$r_{ik} = \frac{n\sum x_{ij}y_{ik} - (\sum x_{ij})(\sum y_{ik})}{\sqrt{n\sum x_{ij}^2 - \left(\sum x_{ij}\right)^2} \cdot \sqrt{n\sum y_{ik}^2 - (\sum y_{ik})^2}} \quad (7)$$
$$i, k = 1, 2, \dots, m$$

7) The symmetric matrix should be used to calculate the correlation coefficient.

$$R = (r_{ik})_{mxm} \quad (8)$$
$$i, k = 1, 2, \dots, m$$

We use the sum function to assess the extent of disagreement caused by the index function f_i relative to the other indexes. This means that alternatives with higher discordant scores on criteria f_i and f_k should be assigned a lower r_{ik} rating.

8) The sum vector can be normalized to determine the weight of the CC:

$$W_{cci} = \frac{\sum_{k=1}^{m}(1 - r_{ik})}{\sum_{i=1}^{m}\sum_{k=1}^{m}(1 - r_{ik})} \quad (9)$$
$$i = 1, 2, \dots, m$$

The weight of the CC, denoted as W_{cci} can be determined using Equation (9).

9) To determine the weight W_{eci}, use the outputs from Equations (6) and (9) and apply the calculation specified in Equation (10).

$$W_{eci} = \frac{W_{ei} \cdot W_{cci}}{\sum_{i=1}^{m} W_{ei} \cdot W_{cci}} \quad (10)$$

The proposed weighting method employs the CC weight approach based on the principles of entropy.

3. PERFORMANCE ANALYSIS

3.1 5G KPIs

KPIs for 5G networks are critical metrics used to evaluate and measure the performance and quality of 5G services. They help in assessing whether the network meets the required standards for speed, reliability, efficiency, and user experience [2]. First, identify the key performance indicators that are relevant for evaluating 5G networks. The IMT-2020 standards outline the key performance requirements for 5G networks.

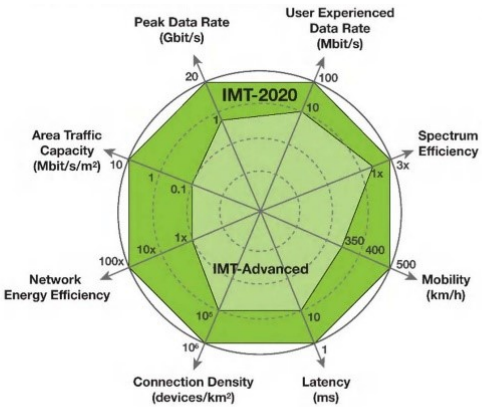

Figure 1. *Enhancement of key capabilities (IMT)-2020 standards* [4]

Table I and Figure 1 show identify a detailed look at the KPIs for 5G [4]. These indicators are vital for evaluating the performance and effectiveness of 5G networks for multiple reasons.

TABLE I

Key performance indicators for 5G

Code	KPI	Definition	Description
X1	User experienced data rate, Mbps	average data rate experienced by users	Indicates the average data rate experienced by users in real-world scenarios. Directly impacts user satisfaction and perceived service quality.
X2	Peak data rate, Gbps	maximum achievable data speeds	Represents the maximum data rate achievable under optimal conditions. Essential for supporting high-speed applications and services.
X3	Mobility, km/h	network's ability to maintain connectivity and performance quality for users and devices in motion	Measures the network's effectiveness in maintaining service quality as users move between cells. Important for ensuring seamless connectivity during mobility.
X4	Latency, ms	time delay in data transmission	Measures the delay in data transmission from the source to the destination. Lower latency is crucial for real-time applications and overall network responsiveness.
X5	Connection density, per km2	number of devices connected per unit area	Assesses the network's capability to support a high number of simultaneous connections per unit area. Important for dense urban environments and events.
X6	Energy efficiency	power consumption relative to performance	Evaluates the network's operational energy consumption relative to its data throughput. Lower energy consumption reduces operational costs and supports sustainability goals.
X7	Spectrum efficiency	utilization of available frequency bands	Measures how efficiently the available spectrum is used. High spectrum efficiency optimizes network capacity and performance.
X8	Area traffic capacity, Mbps/km2	total data traffic capacity per geographic area	Reflects the network's ability to handle high volumes of traffic within a given area. Critical for managing network load and ensuring robust performance in high-demand environments.

When considered together, they offer a complete perspective on 5G network performance, enabling operators to optimize services, enhance user satisfaction, and prepare for future needs [4]. These KPIs provide a comprehensive view of 5G network performance, covering aspects from speed and latency to reliability and energy efficiency [1]. Monitoring and optimizing these indicators are essential for ensuring that 5G networks deliver high-quality service and meet the diverse needs of modern applications and users. These KPIs were selected because they address key aspects of network performance, user experience, and operational efficiency.

They provide a comprehensive view that helps network operators make informed decisions, improve service quality, and optimize resources. Other KPIs might be valuable in specific contexts, but these cover the fundamental areas critical to most cellular network assessments.

3.2 Correlation analysis

Correlation analysis stands as a crucial statistical tool in the development of composite indicators [15, 24]. By elucidating the statistical relationships among the indicators under consideration for inclusion, it offers an initial insight into the robustness of an index and potential issues related to internal consistency. Correlation analysis can also provide insights into the weighting process and the arrangement of indicators [23, 25].

LTE services are now more widespread and will be further improved by the deployment 5G based on existing 4G LTE. The data of 4G KPIs by telecom operators of 21 provinces (aimags) and capital in Mongolia was merged from several Excel files and classified, each according to its category.

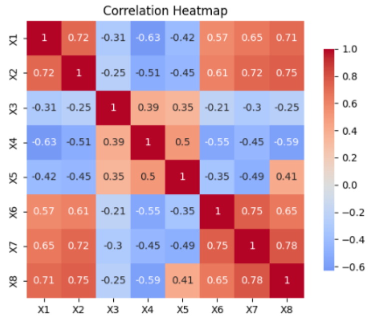

Figure 2. *Pearson correlation coefficient matrix of 5G key performances indicators*

Figure 2 shows the correlation coefficients related to the KPIs for 4G LTE in Mongolia. In general, the correlation coefficients exhibit the anticipated signs within the chosen set of KPIs for 5G.

TABLE II

Correlation of 5G KPIs

	X1	X4	X5	X6	X8
X1	-	Lower latency typically improves the user experience by reducing delays, which is closely linked to higher experienced data rates.			A positive correlation suggests that as the area traffic capacity of the network increases, the user experienced data rate also tends to improve.
X2	Higher peak data rates generally result in better user experience data rates, though the actual experience can be affected by factors like network congestion and signal quality.	Achieving high peak data rates often requires low latency, but in practical scenarios, there might be a trade-off due to the complexity of maintaining both high data rates and low latency.	High connection density can lead to congestion, which may reduce the peak data rate as more users compete for limited bandwidth.	Higher peak data rates may increase energy consumption, impacting energy efficiency negatively.	A positive correlation generally indicates that as the network's ability to handle traffic increases, peak data rates also improve.
X3	This relationship underscores the importance of managing latency to maintain high data rate performance and ensure a positive user experience.	Higher mobility can increase latency due to the need for frequent handovers and adjustments in the network.	A moderate positive relationship, indicating that as connection density increases, there is a moderate tendency for mobility to also increase.	A negative correlation is common, where increased mobility leads to higher energy consumption due to the demands of handovers and signaling.	A negative correlation might suggest that capacity expansions could lead to congestion or interference issues impacting mobility.
X5	The correlation typically reflects how increased device density can impact network performance.	Higher connection density can impact energy efficiency negatively due to increased resource usage.	-		Higher area traffic capacity supports greater connection density without compromising performance, assuming efficient resource management.
X6	A positive correlation indicates that higher data rates are achieved with improved energy efficiency, while a negative correlation suggests that higher data rates lead to increased energy consumption.	Lower latency often requires more energy-intensive infrastructure, though improved energy efficiency practices can mitigate this impact.	Increased connection density might negatively impact energy efficiency, due to higher resource usage and potential congestion.	-	A negative correlation might occur if capacity increases lead to higher energy consumption.

X7	Improved spectrum efficiency typically leads to better utilization of available bandwidth, enhancing the user experienced data rate.	Better spectrum efficiency can reduce latency by optimizing resource use and minimizing delays.	A negative correlation suggests that increased density might reduce spectrum efficiency due to interference and congestion.	Improved spectrum efficiency can enhance energy efficiency by maximizing the use of available resources and reducing wastage.	Improved spectrum efficiency typically results in higher area traffic capacity, as more data can be transmitted over the same spectrum.

Similarly, the moderate correlation observed between the two survey-based measures and the penetration measures derived from administrative data suggests that these two approaches complement each other. Table II presents the correlation of 5G key performance indicators, summarizing the results displayed in Figure 2 and offering a more detailed overview of the relationships between the KPIs. As one KPI increases, the other KPI tends to increase as well. Generally, a strong positive correlation (0.72) is observed between user experienced data rate (X1) and peak data rate (X2), indicating that enhancements in peak rates often lead to improved user experience. Similarly, Area traffic capacity (X8) and connection density (X5) typically show a positive correlation, suggesting that increased capacity supports higher connection densities effectively. As one KPI increases, the other KPI tends to decrease. For instance, user experienced data rate (X1) and latency (X4) have a strong negative correlation (-0.60), suggesting that as latency increases, user-experienced data rate tends to decrease. Mobility (X3) and latency (X4) have a moderate positive relationship, meaning that while mobility does impact latency, the effect is not excessively strong. This suggests that with targeted optimizations, it is possible to further improve network performance and mitigate the impact of mobility on latency. The correlation coefficient between mobility and latency in 5G networks varies depending on numerous factors including network optimization and environmental conditions. The relationship between peak data rate (X2) and energy efficiency (X6) is often moderate, reflecting the trade-offs between higher data rates and increased energy consumption. Additionally, spectrum efficiency (X7) and area traffic capacity (X8) are positively correlated, indicating that more efficient use of spectrum contributes to greater traffic capacity. In addition:

TABLE III

Correlation type and description of 5G key performances indicators

KPI	KPI	Correlation Type	Description
X1	X2	Strong Positive	Higher peak data rates generally lead to improved user experienced data rates.
X1	X4	Moderate Negative	Lower latency typically improves user experience, with reduced latency enhancing perceived data rates.
X2	X4	Moderate Negative	Improvements in peak data rates are often associated with lower latency, though the relationship is not always linear.
X5	X8	Moderate to Strong Positive	Higher area traffic capacity generally supports greater connection density with efficient network management.
X6	X2	Moderate	As peak data rates increase, energy consumption can rise, though advancements may mitigate this effect.
X7	X8	Strong Positive	Improved spectrum efficiency typically results in higher area traffic capacity.
X5	X6	Moderate to Weak	Increased connection density may negatively impact energy efficiency due to higher resource usage and potential congestion.

Table III offers a key overview of the correlations and their impacts derived from the correlation analysis. It outlines various correlation types and their effects on different 5G KPIs, as detailed. Overall, these correlations highlight the complex interplay between different KPIs and underscore the importance of balancing performance metrics to optimize network efficiency. By understanding these relationships, network operators can make informed decisions to enhance overall performance while addressing potential trade-offs. To evaluate and manage deployment issues for a 5G network based on existing 4G LTE infrastructure, it's essential to understand the correlation between various KPIs and their weighted coefficients. Correlation helps determine how strongly each KPI is related to overall deployment success and network performance, while weighted coefficients prioritize the KPIs based on their relative importance.

3.3 Analysis of 5G KPIs

3.3.1 Entropy weight of 5G KPIs

Entropy weight coefficients provide a method to determine the importance or weight of various KPIs based on the amount of variation in their data. The entropy method helps assign weights by analyzing the degree of dispersion or uncertainty in the KPI values. Table IV presents the entropy weight coefficients calculated for various KPIs using formula (6). The entropy weight coefficients indicate the relative importance of each KPI in the context of 5G deployment.

TABLE IV

Entropy weight description of 5G KPIs

KPI	W_e	Description
X2	0.179	This KPI has the highest weight among the listed KPIs. Peak data rate is crucial as it reflects the maximum achievable speed of the network, which is a key selling point for 5G. High peak data rates are essential for supporting high-demand applications and services.
X1	0.161	The second-highest weight. This KPI is vital because it directly affects user satisfaction and service quality. The experienced data rate indicates how well users perceive the network's performance in real-world conditions.
X8	0.149	This KPI measures the network's ability to handle traffic in a given area, which is critical for network planning and ensuring sufficient capacity for users.
X7	0.140	Spectrum efficiency reflects how well the available spectrum is utilized, impacting overall network performance and capacity.
X4	0.124	Latency is crucial for applications requiring real-time data transmission. Lower latency improves the responsiveness and quality of services, which is essential for user experience.
X5	0.106	Connection density measures the network's ability to handle a high number of connections per unit area. This is important for urban areas and events with many connected devices.
X6	0.085	Energy efficiency impacts operational costs and sustainability. While important, it has a lower weight compared to performance-related KPIs.
X3	0.055	Mobility, which measures how well the network handles users moving between cells, has the lowest weight. While still relevant, it is less critical compared to other performance metrics.

By focusing on KPIs with higher weights, such as peak data rate, user experienced data rate, and area traffic capacity, operators can effectively manage deployment issues and optimize network performance. Balancing these priorities with considerations for other KPIs ensures a well-rounded approach to 5G network deployment and management.

3.3.2 Correlation coefficient weight of 5G KPIs

When analyzing KPIs for 5G network deployment, understanding the correlation coefficient weights helps in prioritizing and focusing on the most impactful metrics. The correlation coefficient weight reflects how strongly each KPI is associated with overall network performance or deployment success. The correlation coefficient weights, calculated using formula (9) and summarized in Table V, help interpret the impact of each KPI and guide their effective application. The correlation coefficient weights indicate the relative importance of each KPI in impacting network performance. By focusing on KPIs with higher weights, such as spectrum efficiency, area traffic capacity, and peak data rate, operators can effectively address deployment issues and optimize network performance. Balancing efforts across both high and low-weight KPIs ensures a comprehensive approach to managing and enhancing the 5G network.

TABLE V

Correlation coefficient weight and description of 5G KPIs

KPI	W_{cc}	Description
X7	0.176	This KPI has the highest weight, indicating it has the strongest correlation with overall network performance. Efficient use of spectrum is crucial for maximizing network capacity and performance.
X8	0.162	This KPI is also highly significant, reflecting the network's ability to handle large volumes of traffic in a given area. It is essential for ensuring the network can manage high traffic loads and provide sufficient capacity.
X2	0.147	High correlation with network performance. Peak data rate represents the maximum achievable speed, which is a key performance indicator for user experience and network capability.
X1	0.125	This KPI directly affects user satisfaction by measuring the average data rate experienced by users. It is essential for understanding real-world performance.
X4	0.125	Latency is crucial for applications requiring real-time communication. High correlation indicates its significant impact on the user experience and network performance.
X5	0.097	Measures the network’s ability to handle a high number of connections per unit area. This KPI is important for urban and high-density environments but has a lower weight compared to others.
X3	0.094	Reflects how well the network supports users moving between cells. While important for maintaining a seamless experience, it has a lower correlation coefficient compared to other KPIs.
X6	0.074	Although it has the lowest weight, energy efficiency is still important for managing operational costs and sustainability. It affects the overall operational impact of the network.

3.3.3 Results of Integrated weighting method

Integrated entropy weights and correlation coefficient weights provides a comprehensive approach to prioritizing KPIs for 5G network deployment.

TABLE VI

Integrated weight and description of 5G KPIs

KPI	W_{ec}	Description
X7	0.209	Highest integrated weight, indicating it has both high variability and significant impact on performance. Maximizing spectrum efficiency is crucial for optimizing network capacity and performance.
X8	0.204	Second-highest weight, reflecting its critical role in handling traffic volumes. Effective management of area traffic capacity is essential for ensuring network robustness and user satisfaction.
X2	0.185	High integrated weight due to its importance in delivering high-speed data. Peak data rate is a key performance indicator for user experience and overall network capability.
X1	0.139	Important for user satisfaction as it reflects the real-world data rates experienced by users. Its weight indicates a significant impact on perceived network performance.
X4	0.111	Latency affects real-time communication and user experience. Although not the highest weight, it is still crucial for maintaining a responsive network.
X5	0.072	Reflects the network’s ability to handle numerous connections, particularly in dense environments. While important, it has a lower weight compared to others.
X6	0.044	Represents operational cost and sustainability. Although it has a lower weight, it is important for long-term network management and environmental impact.
X3	0.035	The lowest weight, indicating it is less critical compared to other KPIs but still relevant for seamless user experience during mobility.

The integrated weighting reflects both the importance of each KPI in terms of its variation (entropy) and its impact on overall performance (correlation coefficient). Table VI presents the integrated weights of each KPI calculated using formula (10).

The integrated weighting, combining entropy and correlation coefficient values, provides a balanced approach to prioritizing KPIs for 5G network deployment. By focusing on KPIs with the highest integrated weights such as spectrum efficiency, area traffic capacity, and peak data rate operators can optimize network performance and address deployment issues effectively. Balancing efforts across all KPIs ensures a comprehensive strategy for a successful 5G rollout. Table VII and Figure 3 show the weights and rank of the 5G key performances indicators. Rank KPIs according to their integrated weights. The Figure 3 effectively ranks these KPIs based on their weights, illustrating their relative importance in evaluating 5G performance.

TABLE VII

The weights and rank of the 5G KPIs

	W_{cc}	rank	W_e	rank	W_{ec}	rank
X1	0.161	2	0.125	5	0.139	4
X2	0.179	1	0.147	3	0.185	3
X3	0.055	8	0.094	7	0.035	8
X4	0.124	5	0.125	4	0.111	5
X5	0.106	6	0.097	6	0.072	6
X6	0.085	7	0.074	8	0.044	7
X7	0.140	4	0.176	1	0.209	1
X8	0.149	3	0.162	2	0.204	2

Spectrum efficiency (X7) and area traffic capacity (X8) are identified as the top priorities, essential for optimizing network resources and user experiences. The inclusion of other indicators provides a holistic view of 5G performance, highlighting areas for potential improvement and development in future deployments.

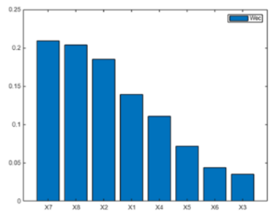

Figure 3. *The W_{ec} weights of 5G key performances indicators*

This prioritization helps focus on the most impactful areas for deployment (Table VIII). Implementing the suggested weighting method results in indicators X7 and X8 emerging with the highest rank among the 5G key performances indicators, signifying their development in ICT in the country. Conversely, indicators X6 and X3 attain the lowest rank.

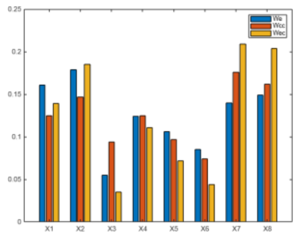

Figure 4. *The weights of 5G key performances indicators*

It appears that weights between indicators calculated by equations (6), (9), and (10) pillar scores in Figure 4, are generally favorable, with values ranging from 0.074-0.176 for the W_e, from 0.055-0.179 for the W_{cc}, and from 0.035-0.209 for the W_{ec}.

TABLE VIII

Interpreting the Integrated Weights

High-Priority KPIs	Moderate-Priority KPIs:	Lower-Priority KPIs:
Spectrum Efficiency (X7) (0.209) Area Traffic Capacity(X8) (0.204) Peak Data Rate(X2) (0.185)	User Experienced Data Rate (X1) (0.139) Latency(X4) (0.111)	Connection Density (X5) (0.072) Energy Efficiency (X6) (0.044) Mobility (X3) (0.035)
These KPIs have the highest integrated weights, making them top priorities for deployment. Focus efforts on enhancing spectrum efficiency, area traffic capacity, and peak data rates to maximize network performance and user experience.	These KPIs are also crucial but have slightly lower integrated weights. Ensure they are adequately managed to maintain a high level of user satisfaction and network responsiveness.	While still important, these KPIs have lower integrated weights. Address these areas as needed, focusing on efficiency improvements and sustainability.

This indicates a successful consolidation of information from indicators into key pillars. Use Table VIII to prioritize focus areas and resource allocation during 5G network deployment. By understanding the integrated weights and their descriptions, operators can develop targeted strategies to address high-priority KPIs effectively, ensuring a successful and efficient deployment based on existing 4G LTE infrastructure. Although the research is based on data from existing 4G LTE networks, the general correlation pattern is valid for 5G NSA when deploying 5G in Mongolia.

4. CONCLUSIONS

This methodology employs the entropy weighting method to analyze KPIs, enhancing evaluation accuracy and reliability. By quantifying KPI variability and assigning objective weights, it facilitates informed decision-making and strategic planning for 5G development.

Additionally, the weighted analysis provides a practical tool for adjusting KPI weights, ensuring smooth transitions and addressing deployment challenges. Understanding the correlations among KPIs and their weighted coefficients is vital, as it reveals their relationships with deployment success and prioritizes them based on significance.

The methodology is adaptable to changes in the number or composition of KPIs, making it crucial for evaluating and managing deployment issues for 5G networks using existing 4G LTE infrastructure. Notably, focusing on enhancing the peak data rate (X2) is essential for improving overall network performance, as it positively impacts user experience (X1), connection stability during mobility (X3), latency (X4), connection density (X5), and energy efficiency (X6).

Importantly, this study represents the first application of entropy-based weighting in 5G performance evaluation in Mongolia. This innovative approach enables a more objective, data-driven assessment, distinguishing our research from previous studies and enhancing the robustness of our findings.

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