

INNOVATION SCIENCE AND TECHNOLOGY



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ISSUE 11



Acceptance of papers **November, 2025**



**Acceptance of
papers**

Published monthly



Topics

economics,
technology, social
sciences



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THE SCIENTIFIC-POPULAR ELECTRONIC
JOURNAL **"INNOVATION SCIENCE AND
TECHNOLOGY"** HAS BEEN REGISTERED
UNDER THE NUMBER **C-5669633** BY THE
AGENCY FOR INFORMATION AND MASS
COMMUNICATIONS (AOKA) OF THE
REPUBLIC OF UZBEKISTAN, EFFECTIVE
FROM OCTOBER 9, 2024.

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The scientific electronic journal "Innovation Science and Technology" has been included in the list of scientific publications recommended for the publication of main scientific results of dissertations for the award of PhD and DSc degrees in economics and technical sciences, in accordance with the Resolution No. 370 of the Presidium of the Higher Attestation Commission of the Republic of Uzbekistan, dated May 8, 2025.

Electronic publication, Issue 11. 109 pages.
Approved for publication on November, 2025.

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BASE STATION MONITORING TECHNOLOGIES IN MOBILE NETWORKS

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Abstract: The article examines contemporary approaches to monitoring LTE and 5G mobile network base stations, with a focus on the technological, climatic, and operational conditions of the Republic of Uzbekistan. The study emphasizes that reliable monitoring systems are essential for maintaining network stability and service quality, particularly in regions with challenging environmental conditions. A comparative analysis is conducted between low-cost monitoring solutions based on microcontrollers and environmental sensors, energy management systems, and algorithmic methods for regulating the load on transmitter modules. In addition, the role of distributed and edge-level monitoring platforms is considered, highlighting their capacity to process performance data locally and reduce dependence on centralized control centers.

Particular attention is paid to the climatic factors of Uzbekistan, where high summer temperatures, low humidity, and frequent dust and sandstorms place additional stress on base station equipment. These conditions accelerate hardware wear, increase cooling requirements, and heighten the risk of overheating and equipment failure. The article evaluates international practices to identify approaches that can be effectively adapted to the national telecommunications context.

Based on the findings, the study proposes recommendations for improving the efficiency of the monitoring infrastructure. These include implementing standardized monitoring modules, applying adaptive and energy-efficient climate control strategies, and introducing predictive maintenance tools. Together, these measures are expected to improve energy efficiency, reduce operational costs, and enhance the resilience of mobile communication networks in Uzbekistan.

Key words: base stations, network monitoring, LTE, 5G, basic predictive analytics; edge computing; FEU; telecommunications infrastructure; Uzbekistan.

Annotatsiya: Maqolada O'zbekiston Respublikasining texnologik, iqlim va operatsion sharoitlariga e'tibor qaratgan holda, LTE va 5G mobil tarmoq bazaviy stansiyalarini monitoring qilishning zamonaviy yondashuvlari ko'rib chiqiladi. Tadqiqotda tarmoq barqarorligi va xizmat ko'rsatish sifatini, ayniqsa, qiyin ekologik sharoitlarga ega mintaqalarda saqlash uchun ishonchli monitoring tizimlari muhim ahamiyatga ega ekanligi ta'kidlangan. Mikrokontrollerlar va atrof-muhit sensorlariga asoslangan arzon monitoring yechimlari, energiya boshqaruv tizimlari va uzatuvchi modullarga yukni tartibga solishning algoritmik usullari o'rtasida qiyosiy tahlil o'tkazildi. Bundan tashqari, taqsimlangan va chekka darajadagi monitoring platformalarining roli ko'rib chiqiladi, ularning mahalliy darajada ishlash ma'lumotlarini qayta ishlash va markazlashtirilgan boshqaruv markazlariga bog'liqlikni kamaytirish imkoniyatlari ta'kidlanadi. Yozgi yuqori haroratlar, past namlik va tez-tez uchraydigan chang va qum bo'ronlari bazaviy stansiya uskunalariga qo'shimcha yuk keltiradigan O'zbekistonning iqlim omillariga alohida e'tibor qaratiladi. Bu sharoitlar apparatning aşinmasini tezlashtiradi, sovetishtalablarini oshiradi va qizib ketish va uskunalarining ishdan chiqish xavfini oshiradi. Maqolada milliy telekommunikatsiya kontekstiga samarali moslashtirilishi mumkin bo'lgan yondashuvlarni aniqlash uchun xalqaro amaliyotlar baholanadi. Natijalarga asoslanib, tadqiqot monitoring infratuzilmasining samaradorligini oshirish bo'yicha tavsiyalar taklif qiladi. Bularga standartlashtirilgan monitoring modullarini joriy etish, moslashuvchan va energiya tejankor iqlim nazorati strategiyalarini qo'llash va bashoratli texnik xizmat ko'rsatish vositalarini joriy etish kiradi. Ushbu choralar birgalikda O'zbekistonda energiya samaradorligini oshirish, operatsion xarajatlarni kamaytirish va mobil aloqa tarmoqlarining barqarorligini oshirishi kutilmoqda.

Kalit so'zlar: baza stansiyalari, tarmoq monitoringi, LTE, 5G, asosiy bashoratli tahlil; chekka hisoblash; FEU; telekommunikatsiya infratuzilmasi; O'zbekiston.

Аннотация: В статье рассматриваются современные подходы к мониторингу базовых станций сетей мобильной связи LTE и 5G с учетом технологических, климатических и эксплуатационных условий Республики Узбекистан. Подчеркивается, что надежные системы мониторинга играют важнейшую роль в поддержании стабильности сети и качества обслуживания, особенно в регионах со сложными климатическими условиями. Проведен сравнительный анализ недорогих решений для мониторинга на основе микроконтроллеров и датчиков окружающей среды, систем управления энергопотреблением и алгоритмических методов регулирования нагрузки на передающие модули. Кроме того, рассматривается роль распределенных и периферийных платформ мониторинга, подчеркивая их способность локально обрабатывать данные о производительности и снижать зависимость от централизованных центров управления. Особое внимание уделено климатическим факторам Узбекистана, где высокие летние температуры, низкая влажность и частые пылевые и песчаные бури создают дополнительную нагрузку на оборудование базовых станций. Эти условия ускоряют износ оборудования, повышают требования к охлаждению и увеличивают риск перегрева и выхода оборудования из строя. В статье анализируется международный опыт для выявления подходов, которые могут быть эффективно адаптированы к национальным условиям телекоммуникаций.

На основе полученных результатов в исследовании предлагаются рекомендации по повышению эффективности инфраструктуры мониторинга. К ним относятся внедрение стандартизированных модулей мониторинга, применение адаптивных и энергоэффективных стратегий управления климатом, а также внедрение инструментов предиктивного обслуживания. Ожидается, что эти меры в совокупности повысят энергоэффективность, снизят эксплуатационные расходы и повысят устойчивость сетей мобильной связи в Узбекистане.

Ключевые слова: базовые станции, мониторинг сетей, LTE, 5G, базовая предиктивная аналитика; периферийные вычисления; ФЭУ; телекоммуникационная инфраструктура; Узбекистан.

INTRODUCTION

According to the Radio Regulations of the International Telecommunication Union (ITU), a base station is defined as a terrestrial station providing communication between user equipment and the wider mobile network [1]. In modern mobile telecommunications, base stations form a core element of the radio access network, supporting wireless connectivity and ensuring the quality and continuity of communication services. Their reliability and operational stability directly affect the performance of communication networks and the user experience.

Object of the study: base stations within contemporary mobile communication systems. Subject of the study: methods and tools for monitoring the operating conditions and performance parameters of base stations.

Purpose of the study is to explore existing monitoring approaches and to identify effective strategies for ensuring stable and efficient operation of base stations.

REVIEW OF LITERATURE AND STANDARDS

There are established approaches and standards in the field of monitoring distributed systems and communication networks. 3GPP (TS 32.401, TS 28.800)[2][3] defines the format and architecture for the exchange of operational information, as well as the principles of interaction between OSS and NMS. ITU and ETSI publish methodologies for assessing service quality and network management. International standards and ITU-R M.1073-1 recommendations[4] were taken as the basic requirements for base stations.

Article [5] discusses an inexpensive solution for monitoring the microclimate at base stations using a Raspberry Pi and a DHT11 sensor. The system measures temperature and humidity, displays the data on a local display, and transmits it to the control center (NOC)

via wireless communication, which allows remote monitoring of equipment status and prompt response to overheating. The software is implemented in Python with remote access via SSH. Testing at three real base stations showed the effectiveness of monitoring and the difference in climatic conditions at different points, confirming the need for constant monitoring of the environment to prevent equipment failures.

The work [6] focuses on monitoring the energy consumption of base stations and assessing the potential for energy savings. The study covers six base stations of different types (shelter, room, outdoor) and analyzes the dependence of energy consumption on internal and external climatic conditions, traffic, and station architecture. It was found that up to 40–45% of energy is spent on cooling, and 55–60% on transmitter operation. The use of Monte Carlo simulation showed that turning off some transmitters during periods of low load can reduce energy consumption by 15–24% without compromising communication quality. The need for standardized energy efficiency metrics (e.g., energy intensity of traffic service) is emphasized.

Article [7] discusses the implementation of a Front-End Unit (FEU) system for 5G base stations in China. The FEU provides unified management of the climate, energy, and operational parameters of millions of base stations, solving the problem of incompatibility between equipment from different manufacturers. FEU processes data at the station level (edge computing), unifies telemetry formats, supports remote control, and reduces operating costs. The technology has been implemented in more than 300,000 base stations, ensuring standardization of monitoring and improving network stability.

A study [8] proposes an adaptive microclimate control system for base stations that combines temperature and humidity sensors with algorithmic switching between natural ventilation and air conditioning. The system uses a microcontroller and GPRS communication for remote control and logging. Tests at base stations in Hunan Province showed a 35–55% reduction in energy consumption per year, especially during transitional seasons when the difference between day and night temperatures allows for increased use of ventilation instead of air conditioning.

A study of international standards for the operation and monitoring of base stations indicates the need to control a number of parameters. For example, the International Telecommunication Union (ITU) in its recommendation ITU-T Q.3913 [9] discussed the tasks of monitoring communication infrastructure devices and networks. European base station equipment standards, such as ETSI EN 301 908-1 [10], also set requirements for the control and monitoring functions of base station equipment.

Therefore, parameters such as temperature, humidity, power consumption, and signal strength can be grouped under the heading “climate-energy-technical operating parameters,” which reflects their interrelationship in ensuring the efficient and reliable operation of a base station.

RESEARCH METHODOLOGY

The research methodology is based on a systematic and comparative approach to the analysis of existing LTE/5G base station monitoring technologies. The work includes a review of international standards (3GPP, ITU, ETSI) and a comparative analysis of software and hardware solutions for monitoring microclimate, power consumption, and equipment status.

Structural and functional analysis methods were used to evaluate monitoring architectures and their scalability, as well as induction and deduction to draw conclusions about their adaptability to the telecommunications infrastructure of the Republic of Uzbekistan. Based on the generalization of experimental data and operational practice, recommendations were formulated for the implementation of the most effective monitoring models.

ANALYSIS AND RESULTS

Research by Nabiryo & Itodo [5] shows that even simple and inexpensive solutions based on Raspberry Pi and temperature/humidity sensors can provide round-the-clock monitoring of the microclimate at base stations. Such systems are easy to implement, do not require complex integration, and ensure the transmission of parameters to the control center. However, their key limitation is their locality and the lack of a unified standardized platform, which complicates scaling with a large number of stations.

The work of Spagnuolo et al. [6] demonstrates that up to 40–45% of a base station’s energy consumption is accounted for by cooling systems, and 55–60% by radio modules. At the same time, energy consumption does not adapt to traffic volume, which leads to significant losses, especially at night and in the off-season. Monte Carlo simulation showed that turning off some TRXs during periods of low load can reduce consumption by 15–24% without compromising communication quality, which is critically important for Uzbekistan, where electricity costs and climatic loads are high.

The FEU system developed by China Tower [7] solves the problem of equipment incompatibility by providing a unified monitoring protocol, pre-processing data at the station level (edge computing), and remotely controlling climate and energy modules. Scaling this system to 300,000+ stations shows that interface standardization and telemetry unification are key to effective large-scale infrastructure management.

The development by Zhang & Liu [8] demonstrates that adaptive microclimate control — automatic switching between air conditioning and ventilation depending on the difference between indoor and outdoor temperatures — can reduce energy consumption by 35–55% per year, especially in regions with significant daily temperature fluctuations. This climate-control mode is particularly relevant for the climatic conditions of Uzbekistan (high summer temperatures, sharp differences between day and night).

RESULTS FOR CONDITIONS IN UZBEKISTAN

The climatic conditions for the operation of base stations in Uzbekistan are characterized by high summer temperatures, low humidity, and frequent dust and sand storms, especially in the western and southern regions. According to the World Bank's climate profile, the country is experiencing an increase in extremely hot days and intensifying arid conditions, which creates additional risks of overheating and equipment degradation [11]. In addition, regional environmental assessments by the UN highlight the sustained impact of dust storms associated with the post-Aral Sea zone on communications infrastructure and the need for enhanced protection of telecommunications facilities from dust [12].

An analysis of the solutions considered shows that the optimal model for Uzbekistan is a combined monitoring model that includes:

1. A unified standardized module for data collection and processing at the station level (similar to FEU).
2. Continuous monitoring of operating parameters (temperature, humidity, energy consumption, transmitter load).
3. Adaptive climate control with priority given to natural ventilation during nighttime and cool periods.
4. Algorithmic reduction of the number of active TRXs at low load.

Taken together, this allows us to expect:

- a 25–40% reduction in energy consumption,
- increased reliability of base stations,
- a reduction in accidents due to overheating, especially in the summer months,
- a reduction in operating costs for mobile operators.

CONCLUSIONS AND RECOMMENDATIONS

The effective implementation of base station monitoring systems in Uzbekistan requires a comprehensive and consistent approach that combines technical, organizational, and infrastructural measures. An analysis of international practices and the results of implemented solutions shows that a key condition for the reliable operation of LTE/5G infrastructure is the constant monitoring of climatic, energy, and technical parameters: temperature, humidity, energy consumption, and the load on transmitting units. In the hot and arid climate of Uzbekistan, as well as in conditions of increased air dustiness, a violation of these parameters leads to increased energy costs, accelerated equipment wear and tear, and the risk of overheating of base stations.

It is important to standardize monitoring processes, ensure a uniform telemetry format, and use edge agents similar to FEU for local data processing and reducing the load on central control systems. This approach not only improves diagnostic accuracy, but also ensures scalability for managing hundreds and thousands of heterogeneous stations, which is particularly relevant for networks with equipment from different manufacturers.

From an energy efficiency perspective, the most promising are adaptive climate control systems that use natural ventilation at low outdoor temperatures and air conditioning only when climate thresholds are exceeded. Combined with algorithmic switching of some transmitters to low-activity mode at low load, this allows reducing the energy consumption of base stations by 25–40%, which is confirmed by research results and experimental implementations.

Thus, for the conditions of Uzbekistan, it is recommended to:

1. Implement a unified monitoring module at the station level (analogous to FEU) to standardize data exchange and remote equipment control.
2. Switch to continuous monitoring of operating parameters with deviation forecasting and automatic notification of critical conditions.
3. Use adaptive cooling schemes with priority ventilation at night and during the off-season to reduce energy costs.
4. Apply dynamic transmission path control (TRX Sleep Mode) during periods of low traffic to improve energy efficiency.
5. Conduct scheduled climate risk analysis by region and develop different maintenance strategies for areas with high dust levels and extreme temperatures.

The comprehensive implementation of these measures creates the basis for a sustainable, reliable, and cost-effective telecommunications infrastructure capable of ensuring continuity of communication and quality of service in the face of intense load growth and climatic challenges in the Republic of Uzbekistan.

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Proofreader: Zokir ALIBEKOV

Layout and Designer: Oloviddin Sobir ugli

2025. № 11

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