АНАЛИЗ И ПРОГНОЗИРОВАНИЕ СПРОСА НА МОЛОЧНУЮ ПРОДУКЦИЮ В УСЛОВИЯХ ВЫСОКОЙ КОНКУРЕНЦИИ РОЗНИЧНОЙ ТОРГОВЛИ

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Аннотация. В данной статье рассматривается применение аналитики данных для анализа и прогнозирования спроса на молочную продукцию в условиях малого розничного бизнеса. Исследование основано на реальных данных продаж, собранных автором в период работы в розничном магазине на этапе его выхода на конкурентный рынок. Основное внимание уделено анализу спроса, снижению возвратов скоропортящейся продукции, оптимизации товарных запасов и прогнозированию объёмов поставок. В ходе исследования были применены методы анализа временных рядов, агрегирования данных и прогнозирования спроса на основе скользящего среднего. Полученные результаты показали, что использование аналитического подхода позволяет повысить эффективность управления ассортиментом и минимизировать потери, связанные с дефицитом или избыточными запасами продукции.

Ключевые слова: *Аналитика данных, прогнозирование спроса, retail analytics, молочная продукция, анализ продаж, оптимизация запасов, временные ряды, прогнозирование продаж.*

ANALYSIS AND FORECASTING OF DEMAND FOR DAIRY PRODUCTS UNDER CONDITIONS OF HIGH COMPETITION IN RETAIL TRADE

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Abstract. This article examines the application of data analytics for demand analysis and forecasting of dairy products in a small retail business environment. The study is based on real sales data collected by the author during part-time employment in a retail store entering a highly competitive market. The research focuses on demand analysis, reduction of returns for perishable goods, inventory optimization, and forecasting of supply volumes. Time series analysis, data aggregation, and moving average forecasting methods were applied during the study. The results demonstrate that analytical approaches can improve inventory management efficiency and minimize losses associated with product shortages or excessive stock levels.

Keywords: *Data analytics, demand forecasting, retail analytics, dairy products, sales analysis, inventory optimization, time series analysis.*

1. Введение

В современных условиях розничной торговли использование аналитики данных становится одним из ключевых факторов повышения конкурентоспособности бизнеса

autonomous systems, to create value in a wide variety of fields, including management and organizations, has recently been the subject of considerable research (Wodecki, 2020).

In summary, in order to empower individual through the era of AI, we should adopt a balanced approach between opportunities and challenges that this technology presents and create a learning environment that encourages individuals to develop skills of self-learning and to apply latest technologies that support this process in order to effectively prepare them for future workforce that will require constant flexibility and creativity.

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Other barrier relates to inequitable access to tools, technologies, resources and information that support self-learning, irrespective of background. While technology democratizes information or knowledge for some, it can also present number of real barrier to those from marginalized groups and underprivileged communities or developing countries. These include: limited access to stable, affordable, and reliable Internet connectivity, and the necessary devices to access online resources. Many learning materials or resources are not translated or adapted for learners who speak different languages and come from diverse backgrounds. Other barriers to access include cost of online resources, or the lack of inclusive resources that are culturally and contextually relevant. Addressing inequity and creating inclusive environments that support learning in context is essential, and policy and governance have critical roles to play.

Conclusion

Future direction of new learning methods. In summary, self-learning offers a multitude of opportunities for growth of individuals learning to deal with the technological revolution. However, in order to facilitate effective learning and also to develop in learners abilities to deal with changing circumstances, it is necessary to look for solutions to a multitude of challenges encountered in the process of learning. As noted earlier, the learning process is becoming and will continue to be highly complex. In Virk (2022) one can find information about many of the individual and group-based challenges that can be encountered by learners in the process of self-learning, as well as ways and methods to deal with them.

Therefore, in search of future of the education, the necessity for adaptation to change of the learning methods is highlighted. Currently, there are implemented so called traditional learning methods (usually understood as classic), which are confronted with huge challenge in form of new technologies, i.e. rapidly developed and implemented by companies all over the world, as well as rapidly changing business environment and learning requirements in line with changing requirements of job market. As stated before, for the needs of development, adapted learning methods are necessary. The majority of already implemented learning methods (often called traditional) in classic, in the form of lectures, training sessions etc., are not adequate and therefore, are threatened with gradual decay. New learning methods, thanks to AI, enable the individual learning process, so that everyone can learn at their own pace, at any place and at any time, using so called personalized, learning paths. As stated by Bryndin (2024; 2025), AI used in education allows for more in-depth learning, which will be in line with job market requirements, when companies implement new technologies, which are developed and implemented by companies all over the world. Therefore, new future of the education is not only about disseminating knowledge, but also about a possibility of searching and experiments and about self-learning.

Self-learning and adaptive methods therefore bring many benefits, however there are many challenges that need to be addressed, for example, information that learners can access for personal development can sometimes be overwhelming for learners, and be of poor quality. Educational leaders and policymakers need to ensure that technology is used to enable all learners to have access to resources, that enable self-learning and adaptability.

AI-supported systems, on the other hand, can be used to support self-learning. The key role of a teacher is therefore that of a facilitator. He or she guides the student in order to assist them in processing and making use of information, and in achieving their learning objectives. The task of the teacher is thus significantly increased in the case of self-learning, because the teacher not only has to select appropriate information, but also to ensure that the student is able to make use of it effectively. It is therefore important for teachers to possess the necessary skills in order to support students who are working with digital information and using autonomous systems to support their learning. The potential of self-learning, combined with the use of

from any location. Thus, by using online platforms for learning, which are supported by AI, the vast resources of knowledge can be discovered by learners as they are recommended to them on the basis of their behavior and preferences. Thus, in the context of AI-supported self-learning, all individuals, regardless of their background, can acquire knowledge and skills and enrich themselves in the same way as those who complete traditional education and are thus able to enhance their employability and also to engage in lifelong learning, which is becoming increasingly important in today's economy and requires continuous acquisition of new skills and knowledge.

However, skill development is also necessary in order to prepare employees for changes in industries. Thus, self-learning, thanks to AI, will help individuals to constantly update their skills and obtain new knowledge and experience in order to find best jobs and to be able to perform them efficiently. At the same time, AI-based platforms for self-learning, with the help of their analytics, will show learners skill gaps in the labor market and help them to obtain necessary skills and knowledge in order to be more competitive on the labor market. Thus, the culture of adaptability will be created, and individuals will be able to not only work efficiently in their current jobs, but also to look for new jobs, to find best jobs for them, and to grow professionally.

As already noted, self-learning using AI provides great opportunities for personal growth and development, however, in addition to these opportunities, there are also number of challenges and possible limitations, which will be discussed below in order to find ways to improve the self-learning experience and thereby to facilitate individual's growth and learning.

Many educators today are worried that there is an increasing danger of information overload. One of the biggest problems with learning today is that there is so much information coming at learners from so many different sources. And, above all, so much of that information is, in fact, irrelevant and of little or no use. In order to learn effectively, a learner has to be able to focus on the information that is really relevant to his or her learning goals. Yet, in many cases, the volume of information that a learner is exposed to can create what is known as 'cognitive overload' – in which the amount of information that a learner is expected to process exceeds his or her capacity to do so. In some cases, this can lead to learners becoming disheartened and demotivated as they are unable to make sense of the vast amounts of information with which they are presented. In other cases, the simplest solution is to ignore some of the information. Yet, this can create a major problem, as there is no guarantee that the information that a learner chooses to ignore is not, in fact, the information that is most relevant to his or her learning goals. As Virk (2022) noted above, algorithms that support self-learning can, no doubt, help to find the relevant information, but there is, as yet, no program that can initiate a learning program, or support a learner through it, on the learner's behalf.

A number of challenges have been identified that obstruct the process of self-learning through the use of technology in today's fast-changing world. The greatest single challenge is that of information over load, where it is argued that there is such a vast amount of information available that it is impossible for individuals to sort through the material and identify that which is of greatest relevance and importance. The reliance upon technology for information in an environment where there is a constant change can place individuals in a state of catch-up. Those that engage in self-learning must learn new skills at the same time as they have to unlearn outdated ways of working. For individuals without prior experience of technology, or those without adequate formal education, there is every likelihood that they will harbor feelings of failure and inadequacy as they attempt to adapt to changing technologies and the ways in which they are able to be used. The swift adaptability of a number of individuals to new technologies will create considerable variation in terms of the degree of competency that they will possess and thus pose further problems in terms of identifying the most appropriate method of learning that will assist individuals in dealing with the vast array of skills that are currently required.

also fitted to the individual talents and requirements of learners. This also prepares learners better for their future challenges.

Opportunities to grow and adapt with AI exist in profusion. The use of artificial intelligence in individual self-learning experiences leads to the increased opportunity of access to individualized educational resources for persons all over the world, across disciplines and subject matter within a variety of educational resources. This use also facilitates the ability of learners to cultivate a number of "soft skills," including critical thinking, creative skills, and a host of interpersonal communication skills that are currently in high demand in a growing number of global workplaces. AI-powered educational tools allow for a number of simulations, among other resources, that assist self-learning individuals in cultivating a host of skills that are employed in real-life scenarios in a variety of academic, professional and personal settings. As noted by Kassymova and colleagues (2025) when learning with AI in individual self-learning experiences, a person can acquire and develop a number of unique educational resources in addition to developing needed academic skills and knowledge (Kassymova, 2025, p. 12).

On the other hand, a range of challenges face individuals and/or learners who make use of these technologies. First, the information that is offered up to a learner via AI can lead to information overload. Furthermore, it is possible that a learner may struggle to determine whether the information obtained via AI sources is valid or not. The capacity to become a media literate learner in order to negotiate information and to critically evaluate information sourced from AI has thus become an extremely significant factor for many self-learning individuals and/or learners. In addition, a number of ethical challenges presented by the increasing use of AI have, to date, not been sufficiently addressed. Challenges that pertain to AI use in general and in terms of data privacy, as well as AI-bias. Of greatest concern are the immense disparities that exist with regard to access to technology that is sufficient to facilitate a quality learning experience. Despite an array of technologies designed to democratize access to learning resources, existing socio-economic challenges which affect all aspects of life are heightened when it comes to technology-based opportunities for learning and, consequently, for growth and development in a number of areas.

Results and discussion

The AI era is transforming the world, offering self-learning opportunities that allow individuals to acquire individualized growth and adaptability. This new educational environment uses AI technologies to create a variety of tools that can offer to support learners and their self-learning endeavors, thus enabling them to grow and develop into adaptable individuals equipped to face life's challenges. Self-learning that is supported by AI can create learning opportunities that are particularly individualized to each learner, which enables them to grow and develop as individuals while increasing their understanding and grasp of information and gaining new skills. Opportunities for individualized growth that are enabled by self-learning AI tools and platforms offer new opportunities to reach a wide audience of learners and thus equalize access to the tools and skills they need to adapt and to grow in an information-based world, to acquire the required knowledge and acquire the skills that are relevant in today's world. Opportunities for growth, which are increasingly open to people all over the world thanks to the Internet, can offer support to individualized self-learning programs and support tools, thus supporting each learner in achieving their goals and reaching their full potential, throughout their lives, while developing into versatile, resourceful and adaptable individuals.

The digital transformation of education enables access to a wealth of knowledge stored on online platforms and thus opens up new opportunities for learning. The range of resources available to learners often is affected by geographical and by socio-economic barriers. The AI era, however, is characterized by easy access to knowledge by any individual at any time and

SELF-LEARNING IN AI ERA

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Abstract. The article examines the phenomenon of self-learning in the context of the development of artificial intelligence. It analyzes the potential of AI technologies for personalizing the educational process, increasing access to knowledge, and fostering lifelong learning skills. Special attention is given to the advantages and challenges of self-learning, including issues of information overload, digital inequality, and ethical risks. The study demonstrates that artificial intelligence contributes to the transformation of educational models and requires a rethinking of the teacher's role as a mentor and facilitator. The author concludes that a balanced approach to the implementation of AI in education is necessary for the effective development of future skills.

Keywords:*self-learning, artificial intelligence, digital education, personalized learning, lifelong learning, educational technologies, information overload, digital inequality, adaptive learning, teacher's role.*

Introduction

Self-learning or independent learning, as the term is used in educational studies, more and more frequently characterizes the new paradigm in the development of educational models and practices. With a transition to a new model of education it is acknowledged that traditional models of education are not in a position to arm a contemporary citizen for the ever-changing needs of society and the market. Self-learning today above all relates to an era dominated by technological progress. Artificial intelligence (AI) in the first place changes demands that are put on individuals in a variety of settings. The key to dealing with these changing requirements effectively consists of individual growth, or the development of the learner's cognitive skills and their application. These tasks, in the final analysis, can be addressed effectively through self-learning, or independent learning. For self-learning in a technological environment not only promotes learning that is suited to the individual, it also helps a person to adapt effectively in a constantly changing environment, which is characterized by the obsolescence of learning and skills within a very short space of time. In this sense, self-learning is also seen to foster a learner who engages in lifelong learning.

However, there is a number of opportunities that self-learning brings. The various AI technologies facilitate the self-learning experience and support the individual in his or her unique learning environment. Algorithmically controlled systems are used to process user data to create learning paths that are adaptable to a learner's current status, skills and knowledge. Thus, these learning paths are individualized to support a learner in achieving his or her goals in the best possible way. Furthermore, the learner can go through the study material as fast as he or she wants, and in the order that he or she prefers. If the learner wants to repeat a part of the study material in order to get a better grasp of the subject matter, then he or she can do so. On the other hand, if the learner wants to skip a part of the study material and move on to another part, then he or she can do so as well. This aspect of self-learning is crucial, because it has a positive impact on the learner's motivation to continue learning. As is stated in the research conducted by Ельшина et al. (2025), the opportunities and applications of AI in various learning environments, support learners in their learning processes. Intelligent tutoring systems, virtual learning assistants and online educational platforms that are fueled by AI, provide the learners with learning contents that are suited to their individual skills and previous knowledge and that can be modified on the fly in response to the learner's progress. Hence, by using self-learning and AI technologies, the learning experiences are not only optimized, but

муҳим омиллардан бири ҳисобланади. [6]. Шу нуқтаи назардан, таълим жараёнини инновацион педагогик ёндашувлар асосида ташкил этиш, таълим мазмунини компетенциявий ёндашув талаблари асосида модернизация қилиш ва рақамли таълим технологияларини кенг жорий этиш долзарб вазифалардан бири сифатида намоён бўлмоқда.

Замонавий дидактик ёндашувлар, хусусан, интерфаол таълим технологиялари, муаммоли таълим, кейс-стади, лойиҳа асосида ўқитиш ва коллаборатив таълим усуллари талабаларнинг когнитив фаоллигини оширишга хизмат қилади. Бундай методлар таълим олувчиларни тайёр билимларни механик ўзлаштиришдан кўра, *мустақил изланиш, таҳлил қилиш, далиллар асосида фикр юритиш ва илмий* хулосалар чиқаришга йўналтиради. [7] Айниқса, рақамли таълим муҳитида электрон платформалар, масофавий таълим ресурслари ва сунъий интеллект технологияларидан фойдаланиш мустақил таълимнинг самарадорлигини оширишга, таълимнинг индивидуаллашувини таъминлашга ҳамда билимларнинг узлуксиз янгиланиб боришига имконият яратади. Шу билан бирга, компетенциявий ёндашув асосида ташкил этилган таълим жараёни *талабаларда нафақат назарий билимларни, балки амалий кўникмалар, аналитик тафаккур, ижодий ёндашув* ва рефлексив фикрлаш қобилиятларини ҳам ривожлантиради[8]. Танқидий фикрлаш компетенцияси шахснинг турли ахборот манбаларини танқидий таҳлил қилиш, мантиқий хулоса чиқариш ва илмий асосланган қарор қабул қилиш қобилиятини шакллантирса, мустақил таълим кўникмалари эса таълим олувчининг ўзини ўзи ривожлантириш ва умр давомида таълим олиш эҳтиёжини қондиришга хизмат қилади. Демак, узлуксиз таълим тизимида мазкур кўникмаларни шакллантириш таълим сифатини ошириш, инновацион фикрлайдиган рақобатбардош кадрларни тайёрлаш ҳамда замонавий жамиятнинг интеллектуал тараққиётини таъминлашнинг муҳим педагогик шарти ҳисобланади.

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ўзлаштиришга йўналтирилган бўлиб, талабанинг аналитик фикрлаш қобилиятини чеклаб қўяди. Америкалик файласуф, педагог ва психолог олим Жон Дьюи таъкидлаганидек, *"таълим инсонни фикрлашга ўргатиши лозим"*[3]. Шу боис таълим жараёнида муаммоли вазиятларни яратиш, таҳлилий саволлар бериш ва баҳс-мунозара методларидан фойдаланиш муҳим аҳамиятга эга. Танқидий фикрлашни шакллантиришда қуйидаги дидактик технологиялар самарали ҳисобланади:

- кейс-стади;
- дебат технологияси;
- "ақлий ҳужум" методи;
- кластер ва интеллект-хариталар;
- лойиҳа методи;
- рефлексив таҳлил усуллари.

Мазкур технологиялар талабаларда ахборотни танқидий қабул қилиш, турли нуқтаи назарларни солиштириш ва мустақил хулоса чиқариш кўникмаларини шакллантиради.

Мустақил таълимнинг педагогик имкониятлари Мустақил таълим узлуксиз таълим тизимининг муҳим таркибий қисми ҳисобланади. Айниқса, рақамли технологияларнинг ривожланиши мустақил таълим имкониятларини кенгайтирмоқда. Электрон платформалар, LMS тизимлари, виртуал кутубхоналар ва онлайн курслар таълим олувчиларга вақт ва макондан мустақил равишда билим олиш имкониятини бермоқда. Бугунги кунда сунъий интеллект технологияларидан таълим жараёнида фойдаланиш ҳам мустақил таълимнинг янги босқичини шакллантирмоқда. Масалан, *адаптив таълим платформалари талабанинг индивидуал қобилияти ва билим даражасига мос контентни* таклиф этиш имкониятига эга [4].

Шу билан бирга, мустақил таълимни ташкил этишда педагогнинг роли ҳам ўзгармоқда. Замонавий ўқитувчи билим манбаи эмас, балки таълим жараёнини бошқарувчи фасилитатор сифатида майдонга чиқмоқда. Бу эса шахсга йўналтирилган таълим концепциясининг ривожланиши билан бевосита боғлиқ.

Компетенциявий ёндашув ва инновацион таълим Ҳозирги таълим тизимида компетенциявий ёндашув муҳим аҳамият касб этмоқда. Ушбу ёндашув таълим олувчининг фақат назарий билимларини эмас, *балки амалий, коммуникатив ва аналитик компетенцияларини ҳам ривожлантиришга* қаратилган [5]. Танқидий фикрлаш ва мустақил таълим кўникмаларини ривожлантиришда STEAM таълими, флиппед классрум (flipped classroom), blended learning ва inquiry-based learning технологиялари муҳим ўрин тутади. Айниқса, флиппед классрум модели талабаларнинг дарсдан ташқари вақтда мустақил билим олишини кучайтиради.

Тадқиқотлар кўрсатишича, танқидий фикрлаш кўникмаси ривожланган талабалар:

- муаммоларни тезроқ ҳал қилади;
- ахборотларни саралай олади;
- инновацион ғоялар ишлаб чиқади;
- касбий фаолиятга тез мослашади;
- ижтимоий фаолликни намоён этади.

Бу эса таълим сифатини ошириш ва рақобатбардош кадрлар тайёрлашда муҳим омил ҳисобланади. Қайд этиш жоизки, глобаллашув ва рақамли трансформация жараёнлари жадал кечаётган ҳозирги шароитда узлуксиз таълим тизимида танқидий фикрлаш ва мустақил таълим кўникмаларини шакллантириш стратегик аҳамият касб этмоқда. Мазкур компетенциялар шахснинг интеллектуал салоҳиятини ривожлантириш, унинг ахборотларни таҳлилий баҳолаш, мустақил қарор қабул қилиш ҳамда ўзгарувчан ижтимоий-касбий муҳитга мослашиш қобилиятини таъминловчи

УЗЛУКСИЗ ТАЪЛИМ ТИЗИМИДА ТАНҚИДИЙ ФИКРЛАШ ВА МУСТАҚИЛ ТАЪЛИМ КЎНИКМАЛАРИНИ ШАКЛЛАНТИРИШНИНГ ДИДАКТИК ИМКОНИЯТЛАРИ

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Аннотация. Мақолада узлуксиз таълим тизимида танқидий фикрлаш ва мустақил таълим кўникмаларини шакллантиришнинг замонавий дидактик имкониятлари таҳлил қилинган. Шунингдек, рақамли таълим муҳити, компетенциявий ёндашув ва интерфаол методларнинг таълим самарадорлигига таъсири ёритилган. Муаллиф томонидан мустақил таълимни ташкил этишнинг инновацион усуллари ва танқидий фикрлашни ривожлантирувчи педагогик механизмлар илмий жиҳатдан асосланган.

Калит сўзлар: *узлуксиз таълим, танқидий фикрлаш, мустақил таълим, дидактик имкониятлар, рақамли таълим, интерфаол методлар, компетенциявий ёндашув, инновацион педагогика.*

DIDACTIC OPPORTUNITIES FOR DEVELOPING CRITICAL THINKING AND INDEPENDENT LEARNING SKILLS IN THE SYSTEM OF CONTINUOUS EDUCATION

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Abstract. The article analyzes modern didactic opportunities for developing critical thinking and independent learning skills within the system of continuous education. It also highlights the impact of the digital educational environment, competency-based approaches, and interactive teaching methods on educational effectiveness. The author scientifically substantiates innovative methods of organizing independent learning and pedagogical mechanisms aimed at developing critical thinking.

Keywords: *continuous education, critical thinking, independent learning, didactic opportunities, digital education, interactive methods, competency-based approach, innovative pedagogy.*

Ҳозирги глобаллашув ва рақамли трансформация шароитида таълим тизими жамият тараққиётининг стратегик омилига айланмоқда. Замонавий меҳнат бозори нафақат муайян билимларга, балки мустақил фикрлай оладиган, таҳлил қилиш қобилиятига эга ва инновацион қарорлар қабул қила оладиган мутахассисларга эҳтиёж сезмоқда. Шу нуқтаи назардан, узлуксиз таълим тизимида танқидий фикрлаш ва мустақил таълим кўникмаларини шакллантириш долзарб педагогик муаммолардан бири ҳисобланади.

Танқидий фикрлаш шахснинг ахборотни таҳлил қилиш, мантиқий баҳолаш ва асосланган қарор қабул қилиш қобилиятини ифодалайди. *Америкалик олим Ричард Пол танқидий фикрлашни "инсоннинг ўз фикрлаш жараёнини назорат қилиши ва такомиллаштириши" сифатида* изоҳлайди [1].Бу жараён таълим олувчининг интеллектуал мустақиллигини таъминлайди. Мустақил таълим эса таълим олувчининг педагогик жараёнда фаол субъект сифатида иштирок этишини англатади. Хусусан, *мустақил таълим инсоннинг ўз билимларини мунтазам равишда янгилаб бориши* ва касбий ривожланишини таъминлашга хизмат қилади [2].

Танқидий фикрлашнинг дидактик аҳамияти Замонавий дидактикада танқидий фикрлашни ривожлантириш таълимнинг асосий вазифаларидан бири сифатида қаралмоқда. Чунки анъанавий репродуктив таълим моделлари кўпроқ тайёр билимларни

деформациями фуллерена, что позволяет интерпретировать временной ряд как отклик системы на изменение локального рельефа потенциальной энергии.

Заключение

В работе показано, что метод компьютерного моделирования позволяют эффективно исследовать миграцию атома никеля на поверхности фуллерена C_{60}. Молекулярно-динамическое моделирование позволило определить особенности движения атома Ni, характерные положения адсорбции и влияние температуры на его подвижность. Полученные результаты могут быть полезны для дальнейшего изучения наносистем и разработки новых функциональных материалов.

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Ni–C_{60}, записанные с интервалом 0,1 пс. Такой подход позволяет идентифицировать моменты перехода никеля между различными положениями адсорбции, поскольку миграционные события сопровождаются характерными скачками или изменениями энергии взаимодействия. Полученные временные зависимости показывают, что при повышенных температурах наблюдаются значительные флуктуации энергии связи, отражающие динамическую реструктуризацию локального окружения и миграцию экзоатома в новые стабильные или метастабильные положения на поверхности C_{60}. На рисунке 2 показана серия снимков конфигураций системы, демонстрирующих характер миграции экзоатома Ni в разные моменты времени и подтверждающих переходы между различными областями поверхности фуллерена.

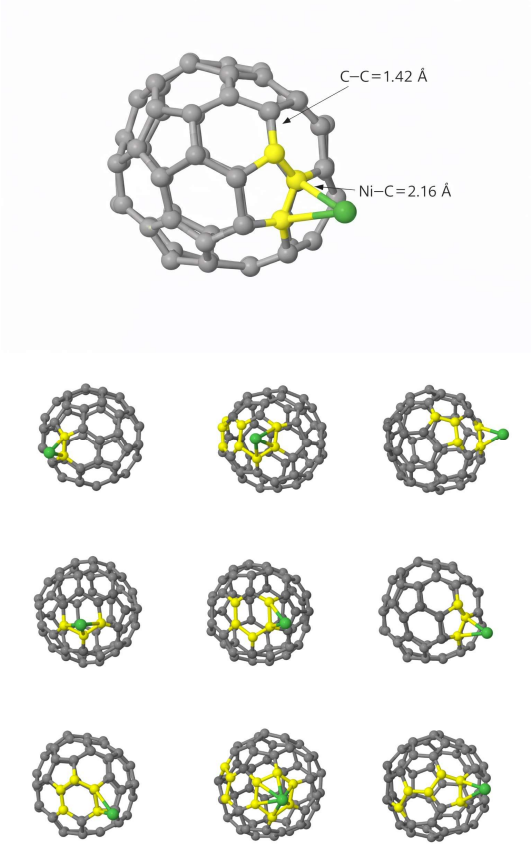

Рис. 2. Равновесные длины связей C–C в фуллерене C_{60} — 1,42 Å и Ni–C — 2,16 Å, а также траектория миграции экзоатома Ni на поверхности C_{60} по данным молекулярно-динамического моделирования в течение 1000 пс. Показаны характерные адсорбционные положения и переходы между ними, отражающие температурно-индуцированную подвижность атома никеля.

Временной анализ показывает, что характерные переходные времена между локальными минимумами составляют приблизительно 5–15 пс. Этот диапазон согласуется с типичными временными масштабами тепловых колебаний углеродного каркаса при исследуемой температуре. Это предполагает, что миграция экзоатома в основном обусловлена температурно-индуцированными деформациями структуры фуллерена, которые периодически изменяют высоту барьера на потенциальной поверхности и создают условия для скачкообразного перемещения. Другими словами, миграция термически активирована, что типично для адатомов на наноструктурированных углеродных поверхностях. Таким образом, полученные результаты демонстрируют связь между динамикой экзоатома и колебательными

с молекулами фуллеренов привлекает значительное внимание благодаря потенциальным областям применения в катализе, молекулярной электронике и разработке наноматериалов [1-3]. Особый интерес представляют фуллерены, функционализированные никелем, поскольку присутствие экзоатома никеля может изменять электронные и магнитные свойства углеродного каркаса, влияя на его химическую активность и стабильность [4,5]. Предыдущие исследования методом DFT показали, что экзоэдрические атомы переходных металлов преимущественно адсорбируются в местах C–C-мостиков на поверхности C_{60} с энергиями взаимодействия порядка 1 эВ [6]. Понимание механизмов миграции атомов металла на поверхности фуллерена имеет решающее значение для контроля этих свойств в наномасштабе [7,8].

Методы исследование

Все симуляции в этой работе были выполнены с использованием пакета LAMMPS с открытым исходным кодом, основанного на методах молекулярной динамики (МД) [9]. Координаты молекул фуллерена C_{60} были подготовлены с помощью программы Nanotube Modeler. Атомные координаты фуллерена C_{60} были сгенерированы в LAMMPS и впоследствии релаксированы с использованием классической минимизации энергии с помощью алгоритма сопряженных градиентов. Релаксация проводилась в рамках той же межатомной потенциальной структуры, которая использовалась для последующих симуляций молекулярной динамики. Квантово-химическая (DFT или Gaussian) структурная оптимизация не применялась, поскольку целью данного исследования является изучение динамики миграции, обусловленной температурой, в течение длительного времени моделирования. Длины связей Ni–C были проанализированы и визуализированы с помощью программы JMOL для изучения конфигурации адсорбции Ni@C_{60}. Для поддержания выбранной температуры в ансамбле NVT использовался термостат Нозе–Хувера [10,11].

Первая часть предназначена для описания взаимодействия в плоскости фуллерена C_{60}. Для взаимодействия C-C можно использовать известные потенциалы, например, адаптированный эмпирический потенциал межмолекулярного взаимодействия AIREBO [12]. Он хорошо проверен и активно используется для изучения углеродных структур [13]. Потенциал состоит из трех частей:

$$E = \frac{1}{2}\sum_i \sum_{j\neq i} E_{ij}^{REBO} + E_{ij}^{LJ} + \sum_{k\neq i,j} \sum_{l\neq i,j,k} E_{kijl}^{TORSION}, \qquad (1)$$

где — энергия ковалентного взаимодействия, — энергия Ван дер Ваальса, — энергия вращения плоскости. Межатомные взаимодействия были описаны с использованием гибридной потенциальной схемы, реализованной в LAMMPS.

Взаимодействие Ni–C было описано потенциалом Морзе с расстоянием отсечки 4,0 Å, что позволяет непрерывно ослаблять связь и естественным образом диссоциировать во время миграционных событий. Аналитическая форма потенциала Морзе задается следующим образом:

$$U(r) = D_e \left[\left(1 - e^{-\alpha(r-R_e)}\right)^2 - 1\right], \qquad (2)$$

где r — расстояние между атомами, D_e — энергия разрыва связи, R_e — равновесная длина связи, α — жесткость связи.

Результаты и обсуждение

Для анализа динамики движения экзоатома никеля относительно поверхности фуллерена были рассчитаны и сохранены временные ряды энергии связи

КОМПЬЮТЕРНЫЕ МОДЕЛИРОВАНИЕ МИГРАЦИИ АТОМА НИКЕЛЯ НА ПОВЕРХНОСТИ ФУЛЛЕРЕНА C_{60}

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Аннотация. В данной работе рассматривается применение методов компьютерного моделирования для исследования миграции атома никеля на поверхности фуллерена C_{60}. Основное внимание уделяется молекулярно-динамическому моделированию температурно-зависимого движения атома никеля, анализу его взаимодействия с углеродным каркасом и обработке полученных расчётных данных. Использование специализированных программных средств позволяет оценить особенности поведения наносистемы при различных температурах и выявить условия, при которых наблюдается миграция атома по поверхности фуллерена. Полученные результаты могут быть использованы в области наноматериалов, вычислительной физики и прикладных информационных технологий.

Ключевые слова: *компьютерное моделирование, молекулярная динамика, атом никеля, фуллерен C_{60}, миграция атома, наносистема, температурная зависимость, численное моделирование.*

COMPUTER MODELING OF NICKEL ATOM MIGRATION ON THE SURFACE OF FULLERENE C_{60}

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Abstract. This work considers the application of computer modeling methods to study the migration of a nickel atom on the surface of fullerene C_{60}. The main focus is on molecular dynamics simulation of the temperature-dependent motion of the nickel atom, analysis of its interaction with the carbon framework, and processing of the obtained computational data. The use of specialized software tools makes it possible to evaluate the behavior of the nanosystem at different temperatures and to identify the conditions under which atomic migration occurs on the fullerene surface. The obtained results can be applied in nanomaterials research, computational physics, and applied information technologies.

Keywords: *computer modeling, molecular dynamics, nickel atom, fullerene C_{60}, atomic migration, nanosystem, temperature dependence, numerical simulation.*

Введение

Современные информационные технологии широко применяются в научных исследованиях, особенно при компьютерном моделировании сложных наносистем. Миграция атома никеля на поверхности фуллерена C_{60} представляет интерес для изучения свойств наноматериалов и их возможного применения в электронике, катализе и материаловедении. Использование методов молекулярной динамики позволяет исследовать движение атома при различных температурах и анализировать его взаимодействие с углеродным каркасом. Взаимодействие атомов переходных металлов

While Zigbee 3.0 remains one of the most efficient communication standards for smart buildings, securing it requires continuous adaptation. Combining Zigbee 3.0 standards with AI anomaly detection and decentralized blockchain validation provides a robust defense model. As Uzbekistan expands its smart city programs, embedding advanced data security into urban planning is vital for maintaining economic and social stability.

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Dubai Smart Tower Incident (May 2024): Attackers breached the Building Management System (BMS) of a major 180-company commercial center in Dubai. They forcibly shut down HVAC systems across 15 floors and locked occupants inside elevators while monitoring building feeds via compromised security cameras. The exploit succeeded due to legacy protocol fallbacks and misconfigured IoT gateways.

Omni Hotels & Resorts (April 2024): A major cyberattack targeting hotel infrastructure rendered Zigbee-based smart room locks and reservation databases completely inoperable, halting operations for several days and causing multi-million dollar losses.

Uzbekistan Breach Events (February 2026): On February 12, 2026, the Ministry of Digital Technologies confirmed a breach involving over 60,000 personal data records. While centered on primary authentication systems (OneID), this event serves as a critical warning for smart building deployments: compromising the central coordinator (Trust Center) compromises the entire facility.

6. Proposed Hybrid Security Model: Blockchain and Artificial Intelligence

Traditional static security models are insufficient for next-generation smart buildings. Studies demonstrate that Radial Basis Function (RBF) neural network architectures achieve a 98% detection rate for network traffic anomalies.

Proposed Architecture:

• AI (RBF) Anomaly Monitoring: Continuously monitors packet traffic from IoT sensors. If a sensor generates abnormal burst patterns indicative of a DoS or flooding attack, the system isolates the node dynamically.

• Blockchain Security (BCS): Decentralizes key management functions. New devices must be validated against a distributed blockchain ledger before obtaining network credentials, mitigating single-point-of-failure risks at the Trust Center level.

7. Conclusion

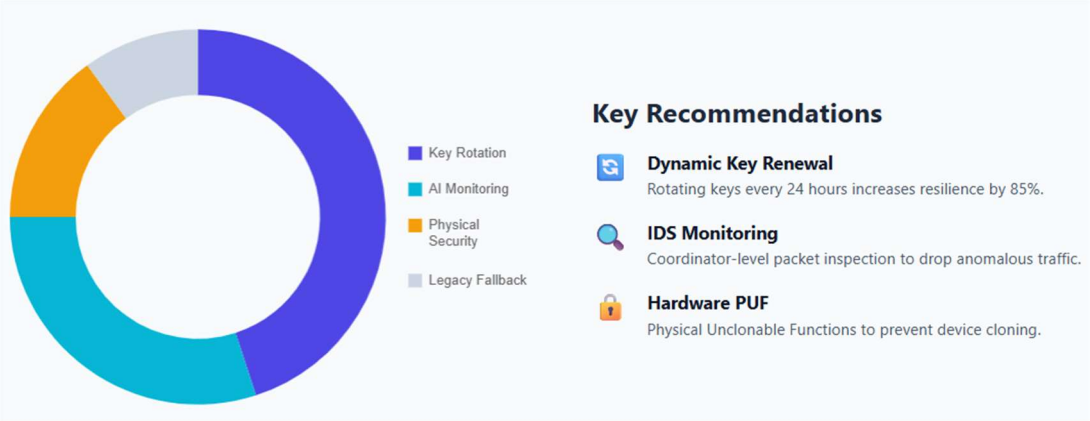

Figure 4. Protection strategy and defense effectiveness metrics (Dynamic Key Renewal, IDS Monitoring, Hardware Security).

Key Recommendations:

• Dynamic Key Rotation: Automatically re-keying the Network Key every 24 hours increases overall resilience by up to 85%.

• IDS Monitoring: Implementing Intrusion Detection Systems at the coordinator level to drop anomalous packet streams.

• Hardware-Level Security: Incorporating Physical Unclonable Functions (PUF) to guard against hardware cloning.

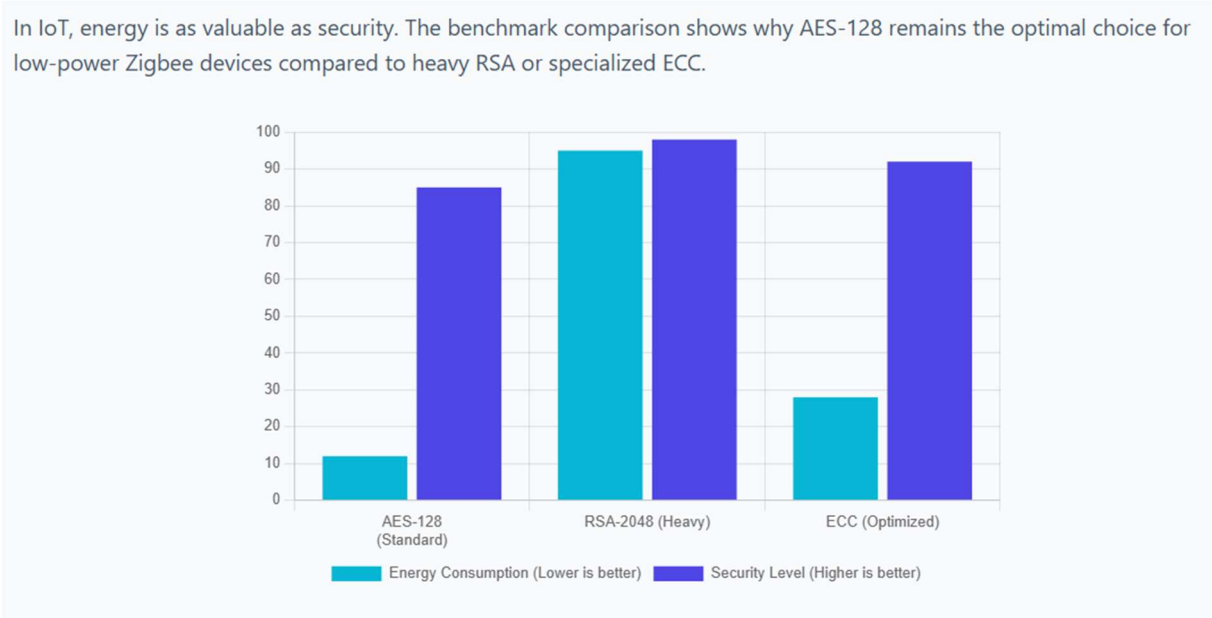

Figure 3. Comparative evaluation of algorithms: Energy Consumption vs. Security Level (AES-128, RSA-2048, ECC).

Cryptographic Formulation: The AES-128 algorithm remains the benchmark for modern symmetric encryption. The encryption operation for data packets is expressed through the following mathematical model:

$$C_i = P_i \oplus E_k(T_i)$$

Where:

- C_i represents the resulting ciphertext block,
- P_i represents the plaintext data block,
- E_k represents the AES encryption function executed with key k,
- T_i represents the unique Frame Counter value for the i-th packet.

Incrementing the Frame Counter with every transmitted frame prevents malicious actors from performing replay attacks.

4. Zigbee 3.0: Evolutionary Leap in Security

In legacy Zigbee profiles (such as Zigbee Home Automation), the most vulnerable phase occurred during initial device commissioning. Network keys were frequently transmitted in plaintext or encrypted using a universally known default key (ZigBeeAlliance09).

Zigbee 3.0 addresses this vulnerability through the Install Codes mechanism. Each device is assigned a unique, factory-set QR code or alphanumeric string printed on its enclosure. During network joining, the device derives an initial link key from this code to securely receive the master Network Key, virtually eliminating over-the-air key interception.

Additionally, Zigbee 3.0 incorporates Dynamic Link Keys (DLK) based on Elliptic-Curve Diffie-Hellman (ECDH) key exchange, guaranteeing unique session key generation for every interaction.

5. Cyberattack Analysis: Real-World Case Studies

Smart building infrastructures are vulnerable to practical attacks beyond theoretical models. The following cases demonstrate the real-world implications:

networks. By 2025, the number of attacks targeting Uzbekistan's digital infrastructure exceeded 107 million, underscoring the urgent relevance of this research.

2. Literature Review and Current State of Research.

Globally, extensive research has been conducted on Zigbee protocol security. Technology leaders such as Silicon Labs and Texas Instruments have published specification guidelines to secure the physical and network layers. Built on top of the IEEE 802.15.4 standard, key management vulnerabilities and Denial of Service (DoS) susceptibility are frequently cited as key weaknesses of the protocol stack.

In Uzbekistan, IoT security issues are predominantly analyzed within specialized cybersecurity centers and technical universities. The Law "On Energy Saving," enacted in August 2024, provided significant legal impetus for smart building construction. However, local scientific literature lacks comprehensive studies on hybridizing Zigbee security architecture with artificial intelligence (AI) and blockchain technologies.

3. Zigbee Security Architecture: Technical Analysis.

Zigbee security operates on an "open trust" model within internal layers, meaning intra-device layers trust one another implicitly while external network communications are strictly encrypted using the AES-128 algorithm.

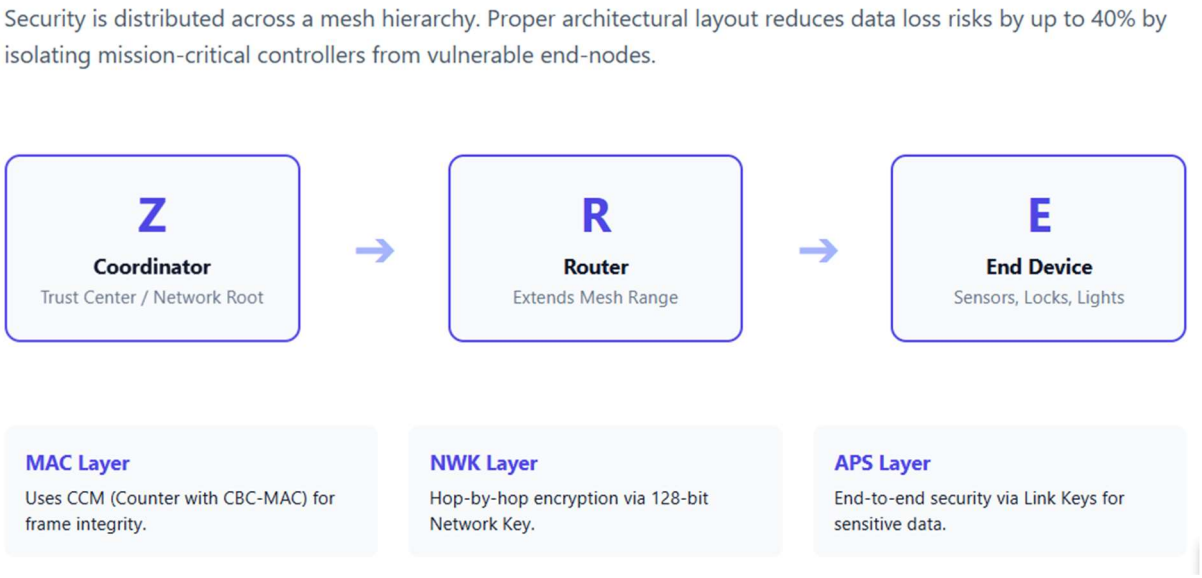

Figure 2. Network architecture of a smart building (Coordinator-Z Router-R End Device-E). Proper architectural layout reduces data loss risk by up to 40%.

Layer-by-Layer Protection (Stack Security):

MAC Layer (Media Access Control): Responsible for packet formatting and utilizes the CCM (Counter with CBC-MAC) mode specified in IEEE 802.15.4. This mode simultaneously ensures data encryption and message integrity.

Network Layer (NWK): Implements hop-by-hop encryption across the mesh network using a 128-bit Network Key.

Application Layer (APS): Establishes end-to-end security between two endpoint devices. The Link Key at this layer is reserved for sensitive transactions, such as transmitting electronic door-unlock commands.

ENSURING DATA SECURITY IN SMART BUILDING SYSTEMS BASED ON THE ZIGBEE PROTOCOL: TECHNOLOGICAL ANALYSIS AND CYBER-RESILIENCE ISSUES IN THE CONTEXT OF UZBEKISTAN

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Abstract. This paper provides a comprehensive analysis of the security of the Zigbee protocol, which serves as the foundation of modern Smart Building infrastructure. The research examines the protocol's multi-layered protection mechanisms, updates introduced in the Zigbee 3.0 standard, and real-world cyber-physical attacks (including the Dubai Smart Tower and Omni Hotels incidents). Furthermore, within the framework of Uzbekistan's digital strategy through 2030, author recommendations are proposed for integrating artificial intelligence and blockchain technologies to ensure the security of intelligent buildings. In terms of scope and content, the paper fully complies with the standards and requirements of the Higher Attestation Commission (OAK).

Keywords: *Zigbee 3.0, smart building, IoT security, AES-128, Trust Center, cyberattacks, Uzbekistan 2030 strategy, blockchain, RBF neural networks, cyber-physical systems.*

1. Introduction: The "Hidden" Risks of Smart Buildings.

In the era of digital transformation, buildings are no longer merely physical structures for living or working; they are evolving into "thinking" systems. Major initiatives in Uzbekistan, such as the "New Toshkent" project, aim to transition urban infrastructure entirely onto smart platforms. The nervous system of such environments consists of Internet of Things (IoT) devices, and the primary protocol facilitating communication among them is Zigbee.

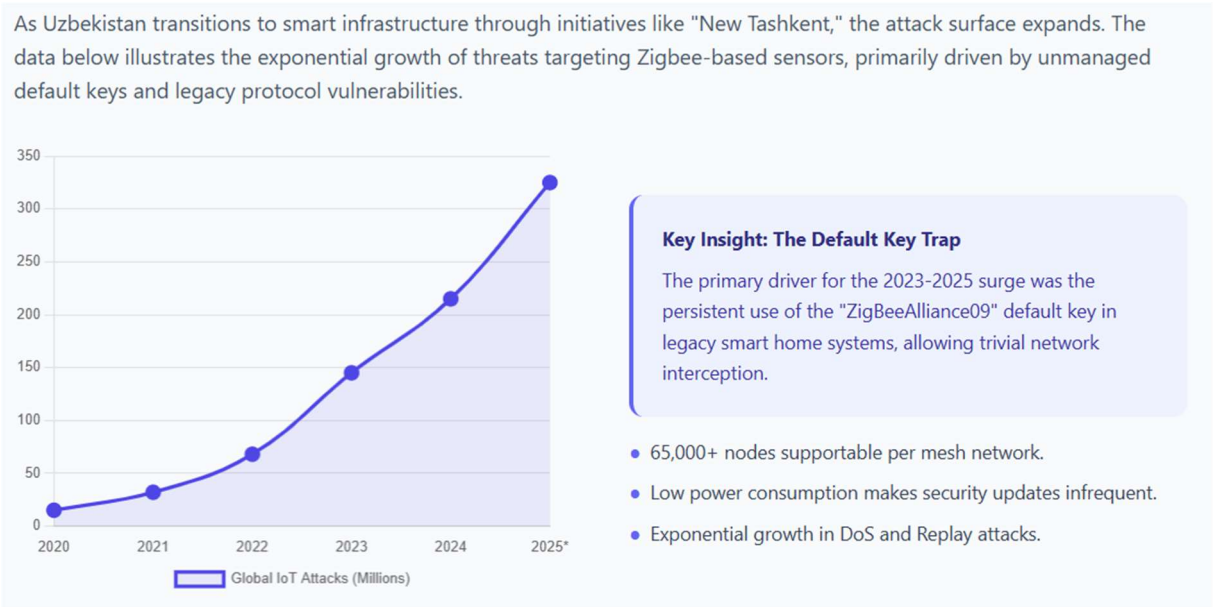

Figure 1. Dynamics of cyberattack growth on IoT devices.

(Note: Over the past 5 years, attacks on Zigbee-based sensors and smart devices have grown exponentially, primarily due to unmanaged default security keys.)

Why Zigbee? Because it operates on low power consumption and can connect up to 65,000 devices within a single mesh network. However, behind this operational convenience lie serious cyber threats. Imagine a scenario where a simple temperature sensor in an office building allows attackers to lock down the entire access control system or disable fire safety

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yutadi, ammo bunday strategiyalarning ham energiya narxi bor va resurs cheklovi kuchli bo‘lganda ular ham optimal bo‘lmay qoladi. Shunday qilib, muhim ilmiy xulosa shundaki, dinamiklik ortishi bilan protokol mexanizmlarining foydasi “lokal” bo‘lib qoladi, ya’ni muayyan parametr mintaqasida yutadigan mexanizm boshqa mintaqada zarar keltirishi mumkin; demak, protokol dizayni va sozlashda universal yechimlardan ko‘ra holatga mos adaptatsiya tamoyillari ustuvor.

Natijalarni MQTT va CoAP kabi ilova qatlamlari amaliyotiga taalluqliroq talqin qilganda, adabiyotlarda ko‘rsatilganidek, nashr/obuna va so‘rov/javob paradigmalari trafik xarakterini keskin belgilaydi hamda tarmoqdagi portlashsimon yuklama bilan o‘zaro ta’sirga kirishadi [5]. Bizning baholash ramkamiz trafik aralash rejimida ishlagani sababli, aynan portlashsimon yuborishlar bufer bandligini tez oshirib yuborishini va dinamiklik sharoitida bu ta’sir kuchayishini ko‘rsatdi. Demak, faqat protokolning “nomi” emas, balki u qanday trafik profili bilan birga qo‘llanayotgani ham tanlov mezoniga aylanishi kerak.

Cheklov sifatida shuni qayd etish joizki, taklif etilgan holatlar modeli soddalashtirilgan bo‘lib, radio darajadagi murakkab interferensiya va ko‘p kanalli rejalashtirishning barcha tafsilotlarini to‘liq qamrab olmaydi. Biroq ilmiy qiymat aynan shundaki, soddalashtirish evaziga izohlanadigan parametrlar olinadi va barqarorlik mintaqalarini aniqlash imkoniyati paydo bo‘ladi; bu esa protokolni amaliy joriy etishdan oldin tezkor tahlil va dastlabki sozlash uchun foydali.

Xulosa

Tadqiqot yuqori darajada dinamik va resurslari cheklangan IoT tarmoqlarida protokollar samaradorligini baholash uchun simulyatsiya va analitik yaqinlashuvni birlashtiruvchi modelga asoslangan ramkani taklif etdi. Natijalar dinamiklik ortishi bilan ishonchlilik, kechikish va energiya sarfi o‘rtasidagi murosalar keskinlashishini, protokol parametrlarining esa barqarorlik chegaralarini sezilarli siljitishini ko‘rsatdi. Ilmiy hissa sifatida barqaror ishlash mintaqalari va parametr sezgirligi asosida protokol tanlash hamda moslashuvchan sozlash tamoyillari asoslandi. Amaliy jihatdan, taklif etilgan yondashuv tarmoqni loyihalash bosqichida ish rejimlarini sinflashtirish, riskli yuklama mintaqalarini oldindan aniqlash va resurs byudjetini rejalashtirishga xizmat qiladi. Kelgusida tadqiqotlar ko‘p kanalli muhit, bir nechta radio interfeysli tugunlar va o‘rganishga asoslangan adaptatsiya siyosatlarini modelga integratsiyalash yo‘nalishida davom ettirilishi maqsadga muvofiq.

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boshqaruv harakatlari energiya narxini nolinear oshiradi. Shuningdek, kontaktlar qisqa bo‘lgan stsenariylarda “tez yetkazishga urinish” strategiyasi ko‘pincha foydali bo‘lib chiqdi, ya’ni yuborishni kechiktirish yoki ortiqcha tasdiqlash kutish kontakt oynasini boy berishga olib keladi. Bularning barchasi model parametrlari orqali ifodalangan bo‘lib, keyingi amaliy sozlash qoidalarini chiqarishga asos bo‘ldi.

Muhokama

Olingan natijalar IoT tarmoqlarida protokol samaradorligini baholashda “dinamiklik-resurs” o‘zaro ta’sirini markaziy omil sifatida ko‘rish zarurligini tasdiqlaydi. Constrained tarmoqlar uchun IPga moslashuv, sarlavha siqish va yengil protokollar konsepsiyasi odatda overheadni kamaytirish orqali samaradorlikni oshirishni ko‘zlaydi, biroq natijalar shuni ko‘rsatdiki, overheadni minimallashtirish doimo umumiy foydali ishlashga olib kelmaydi, chunki uzilishlar sharoitida soddalashtirilgan ishonchlilik mexanizmlari yo‘qotishlarni keskin oshirishi mumkin [1]. Demak, yengillik va ishonchlilik o‘rtasidagi murosa dinamik topologiyada boshqacha shakl oladi: statik tarmoqda foydali bo‘lgan parametrlar yuqori dinamiklikda zararli bo‘lib qolishi ehtimoli katta.

Marshrutlash protokollari bo‘yicha adabiyotlarda ko‘pincha topologiya o‘zgarishiga moslashish tezligi samaradorlikning asosiy garovi sifatida talqin qilinadi [2]. Bizning natijalar bu fikrni qisman qo‘llab-quvvatlaydi, chunki o‘rta dinamiklikda adaptiv yangilanishlar yetkazib berishni yaxshilaydi, ammo yuqori dinamiklik va tor energiya sharoitida boshqaruv trafigining “narxi” ortib, tarmoqning foydali ish koeffitsienti pasayadi. Bu Kuznetsov va hammualliflar tomonidan ko‘tarilgan energiya-ustuvor cheklovlar masalasiga hamohang bo‘lib, ular resurs yetishmovchiligi sharoitida boshqaruv mexanizmlarini haddan tashqari ko‘paytirish tarmoq umrini qisqartirishini ta’kidlaydi [7]. Biroq bizning yondashuvimiz bu xulosani faqat umumiy bayon sifatida emas, balki barqarorlik mintaqalari va parametr sezgirligi orqali miqdoriy talqin qilinadigan konseptual modelga joylaydi.

Modelga asoslangan baholashning metodik qiymati shundaki, simulyatsiya natijalari “stsenariyga xos” bo‘lib qolmasdan, holatlararo o‘tishlar va navbat dinamikasi kabi umumlashtiriladigan mexanizmlar bilan izohlanadi. Bu nuqtada diskret-hodisali simulyatsiya bilan analitik yaqinlashuvni birlashtirish IoT tarmoqlarini baholash bo‘yicha xalqaro amaliyotga mos keladi, chunki aynan ko‘p mualliflar real protokol xatti-harakatini tushuntirish uchun gibrid metodlardan foydalanishga chaqiradi [4; 6]. Shunga qaramay, bizning natijalar gibrid yondashuvning yana bir afzalligini ko‘rsatadi: parametr sozlash uchun “qoidalar”ni hosil qilish. Masalan, qayta uzatish taymerini uzaytirishning foydasi faqat uzilishlar qisqa bo‘lgan sharoitlarda sezilarli, uzilishlar uzoq davom etsa esa bu faqat navbatni to‘ldiradi va kechikishni oshiradi; bunday holatni simulyatsiya ko‘rsatishi mumkin, ammo analitik holatlar modeli bu hodisani sabablari bilan birga ochib beradi.

O‘zbek ilmiy maktabida IoT va simsiz sensor tarmoqlarining energiya samaradorligi, shovqinga chidamlilik va adaptiv boshqaruv masalalari bo‘yicha bir qator izlanishlar mavjud bo‘lib, ularda amaliy tarmoqlar uchun resurslarni tejashga yo‘naltirilgan yechimlar ilgari surilgan [8]. Ushbu maqola mazkur yo‘nalishdagi ishlarga metodik qo‘shimcha beradi: taklif etilgan ramka protokolni tanlashni alohida laboratoriya natijasiga tayanib emas, balki dinamiklik va resurs darajasi bo‘yicha sinflashtirilgan ish rejimlarida asoslashni ko‘zda tutadi. Bu yondashuv mahalliy sharoitlarda uchraydigan heterogen tarmoqlar, masalan, sanoat monitoringi va mobil obyektlar bilan ishlovchi tizimlarda ham dolzarb bo‘lishi mumkin, chunki bu yerda kontaktlar uzilib-ulanib turishi odatiy.

Xalqaro adabiyotlarda mobil va uzilishli tarmoqlar uchun tolerant yondashuvlar, jumladan, store-carry-forward tamoyillari muhokama qilingan bo‘lib, ular yuqori dinamiklikda “doimiy yo‘l mavjud” farazini rad etadi [9]. Bizning natijalar ushbu fikrga mos ravishda shuni ko‘rsatadiki, qisqa kontaktlar sharoitida tez uzatishga yo‘naltirilgan strategiyalar ko‘pincha

Рис. 1. Проблемы и пути их решения в процессе развития «зеленой» экономики Узбекистана

Тем не менее реализуемые реформы создают основу для формирования экологически устойчивой, конкурентоспособной и инновационной экономики, ориентированной на долгосрочное устойчивое развитие страны.

Заключение

Переход к «зелёной» экономике является необходимым условием устойчивого развития, обеспечивающим баланс между экономическим ростом и экологической безопасностью.

Анализ показал, что интеграция экологических принципов в маркетинг, менеджмент, финансы и логистику способствует формированию новой модели экономического развития. Опыт Узбекистана демонстрирует положительную динамику реализации «зелёной» стратегии, включая развитие возобновляемой энергетики и привлечение инвестиций.

В перспективе ожидается дальнейшее расширение «зелёных» технологий, рост инвестиций и усиление роли устойчивого развития в национальной экономике.

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