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Design and Optimization of Antenna Systems for Campus Wi-Fi Infrastructure: A Study for Educational Environments

Khurshid Samatov[1*], Shohida Shodiyeva[2], Ugiloy Shukurova[3], Jamshid Khayitov[4], Feruza Bakaeva[5], Valisher Sapayev[6], Alisher Doniyorov[7]

[1]*Department of social sciences, Samarkand Branch of Tashkent University of Information Technologies,*
[2]*Department of Distance Education in Preschool and Primary Education, Jizzakh State Pedagogical University, Uzbekistan*
[3]*Associate Professor Of Gulistan State Pedagogical Institute, PhD in in Psychology Gulistan Street, Sirdarya region, Uzbekistan*
[4]*Lecturer of the Department of Fruits and Vegetables, Urganch State University, Uzbekistan;*
[5]*Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University,39, Kari Niyazov ave., Tashkent, 100000, Uzbekistan.*
[6]*Department of General Professional Subjects, Mamun university, Khiva, Uzbekistan,*
[7]*Tashkent State University of Oriental Studies, Uzbekistan*

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Abstract

Antenna systems are important in improving Wi-Fi infrastructure in campuses, which helps in smooth connectivity for educational activities. Efficient wireless communication is also important to support e-learning, video conferencing, and digital collaboration in the modern educational institutions. Poor coverage and interference limit most of these existing methods' signals, hence not guaranteeing satisfactory user experience as well as optimal network performance. These have been worsened by the typical dense usage nature as well as various campus environments within educational places. This paper aims to present a framework based on Access Point Placement using Wireless Coverage Modeling (APP-WCM) tools. It uses advanced simulation and optimization techniques to find optimal antenna configurations and placements that minimize coverage gaps and interference. The proposed approach uses electromagnetic simulation tools and optimization algorithms to develop antenna systems optimized for specific campus topologies. It is useful in efficient use of resources while meeting the needs of remote learning, multimedia streaming, and a high user density. The signal coverage, throughput, and reliability of the proposed framework are considerably improved, ensuring a robust and scalable Wi-Fi infrastructure for educational campuses.

Author's e-mail: samatov_1084@mail.ru, shohidashodiyeva1989@gmail.com, u-u-shukurova@gmail.com, xayitovjamshid2@gmail.com, feruzabakaeva048@gmail.com, sapayev_valisher@mamunedu.uz, doniyorov_alisher@mail.ru

Author's Orcid id: 0000-0001-6027-7472, 0009-0007-5559-9355, 0009-0000-3359-6427, 0009-0003-5181-0943, 0009-0003-7354-3559, 0000-0002-6751-5864, 0000-0001-8710-5398

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Introduction

Increasing dependence on Wi-Fi infrastructure has altered the manner of learning in educational institutes of late decades.[1] It is a common fact that the foundation of any contemporary educational initiative of today is resting upon the venues of wireless networks, which enabler e-learning platforms, video conferencing, digital collaboration tools, as well as multimedia streaming.[10,13,19] Therefore, the success of these initiatives largely relies upon stability, scalability, and quality of infrastructure in Wi-Fi.[3,23] However, with campus Wi-Fi, there are many moving parts involved.[6] There are different building layouts, environmental conditions, and high-density user populations, which altogether make it challenging to provide a constant and quality connection .[21, 25] Thus, the antenna systems constitute the core of the Wi-Fi network and must be designed and optimized in a structured way.[17]

Because educational institutions are fluid, the specific needs to connect can be very different from one part of the institution to another.[5, 24] Wi-Fi network performance varies from place to place, such as in outdoor spaces, libraries, dorms, administrative offices, and lecture rooms. High-density classrooms and auditoriums can create congestion on the network, whereas older buildings with thick walls and other structural elements may attenuate signals, creating dead zones. In the open-air environment, and because there is no boundary set physically, things become much more complex as outdoor environments are becoming increasingly popular in collaborative learning as well as entertainment. This would require extensive understanding of campus topology as well as users' behaviors to efficiently optimize the performance of networks across these topologies.[14]

The demands of modern campuses are much too high to be met with traditional approaches to setting up Wi-Fi networks, usually involving the haphazard placement of Aps.[26] Problems such as insufficient coverage, interference, and waste of resources will arise because such methods do not take into consideration the specific spatial and use features of an educational setting.[15] Accordingly, innovative answers that may probably deal with these are highly needed right away. The proposed methodology can be made more successful by adding new technologies like machine learning and big data analytics .[16] The system would be able to anticipate user behavior patterns and adjust the network appropriately through the analysis of past use data and real-time measurements of the network's performance.[7] For example, it might dynamically steer more resources into the high-demand regions during peak times of usage to avoid bottlenecks. The network can be adjusted during unoccupied periods to save power without giving up coverage.[2] Because of this adaptability, the network is flexible and can meet user changes without exposing its robustness and scalability.

Related works

With the help of smart campus initiatives, universities may improve campus sustainability, decision-making, and services. Malaysian universities are among those throughout the world actively implementing the programs. A digital revolution in education is necessary in light of the recent COVID-19 epidemic.[18] Teaching and learning experiences, as well as administrative chores, have been greatly enhanced by the use of digital technology, leading to more efficient job management. The availability of Wireless Local Area Network (WLAN) infrastructure, WLAN logical architecture, and WLAN populated coverage area are the three indicators used to determine whether or not a public higher education institution in Malaysia is prepared to establish smart campus initiatives.

The Information Communication Technology (ICT) revolution is often credited for making higher education institutions more efficient. Understanding how registered users, developers, implementers, and adopters of wireless local area networks at universities see them is crucial.[8] The project aims to determine how these networks might improve learning at University of Johannesburg campuses in South Africa.[9] Universities employ Wi-Fi networks to provide an effective learning environment, and wireless local area network connections allow Wi-Fi-enabled devices to be used for education. Wi-Fi-enabled laptops, mobile devices, and electronic gadgets have revolutionized communication, boosting internet coverage on campuses and in student dormitories. This research examines how campus and student house Wi-Fi networks and hotspots promote learning engagement.

Contact tracking in public places like colleges is essential for fighting epidemic illness outbreaks like the COVID-19 pandemic. A contact tracking system (CTS) may alert close contacts of confirmed patients to self-quarantine.[20] The key limitations of existing automated contact tracking systems, which employ smartphone sensors like GPS and Bluetooth, are (1) maintaining user privacy and (2) depending on GPS, which does not perform well inside and in many metropolitan situations.[11]. However, Wi-Fi positioning systems are one of the most popular technologies for real-time indoor positioning systems (IPS), particularly on university campuses where the infrastructure is available. This research investigates if Wi-Fi location monitoring technologies can be used to create a university campus privacy-preserving contact tracing system. A contact tracking system uses cellphones linked to the central Wi-Fi system's access points and their Mac addresses to notify at-risk users .[4, 12] A thorough literature analysis examines the application, limits, and future research directions of such contact tracking devices.. This technique might improve university automated contact tracking by highlighting the necessity to utilize smartphone apps while safeguarding users' privacy.

Proposed method

This paper offers original concepts for designing and optimizing university Wi-Fi systems. The first is on the creation of antenna systems to increase connectivity and opportunities for learning. Second offers efficient wireless coverage by use of Apple-WCM capabilities for selective access point setup. Both systems manage dead zones, network load balancing, and performance evaluation to provide perfect, consistent, user-friendly campus Wi-Fi.

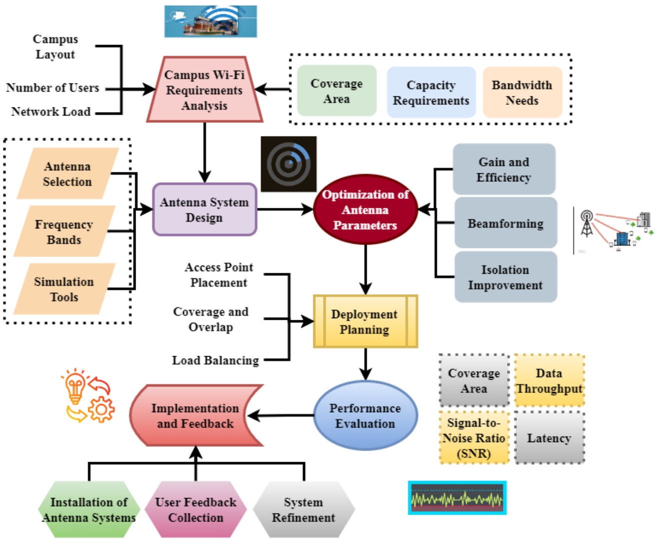

Figure 1: Smart Signal Design: Optimizing Antennas for Seamless Campus Wi-Fi

Figure 1 shows the methodical design and optimization approach used to create antenna systems particularly for university Wi-Fi infrastructure. Analyzing Wi-Fi starts depending on user density and network demand; thus, antenna selection and parameter modification guarantee great performance. Strategic access point selection under deployment planning helps to balance network load and reduces dead zones. Coverage, throughput, and latency in metrics help to control performance assessment. The last stage guarantees a strong and user-friendly Wi-Fi network for learning settings by including practical deployment, feedback collecting, and iterative improvements. This architecture improves dependability, connection, and learning opportunities.

$$vf_r\, [lo\text{-}sn'']:\rightarrow Ns[w\text{-}9\upsilon'']*Vs[w\text{-}9\upsilon q''] \quad (1)$$

The velocity and frequency of radio signals denoted as , should be optimized for data rate. The location or signal-to-noise ratio, abbreviated as , should be adjusted to account for interferences. For customized campus coverage, the number of signal providers or access points is denoted by and the number of signal strengths or volumes is denoted by on the equation 1.

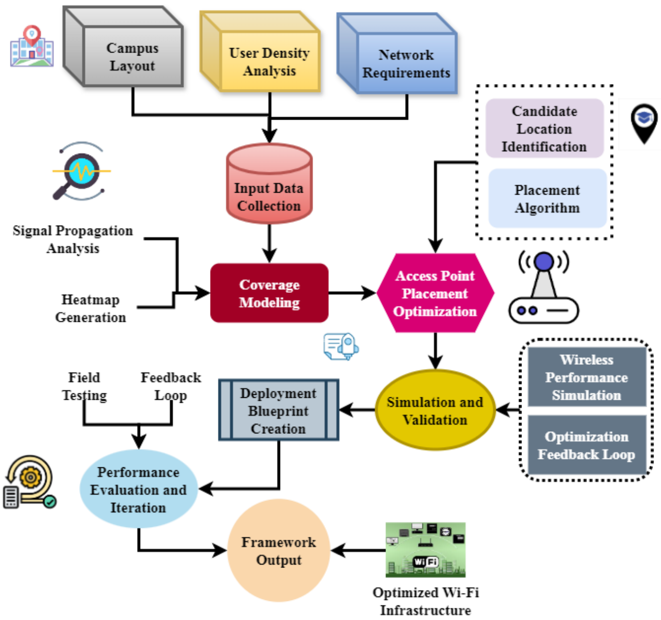

Fig. 2: Smart Coverage Framework: Optimizing Access Point Placement with APP-WCM

Figure 2 presents a methodical strategy for effective use of APP-WCM technologies. It starts with gathering basic facts about campus design, user density, and network needs. Coverage let one create heatmaps for good viewing and examine signal propagation. Ideal AP placements help to minimize dead zones and interference by means of best approaches. Constant development of the placement strategy lets simulations assess performance metrics like SNR and throughput. A final deployment strategy drives AP installation; field testing and continuous development depending on feedback follows. Design for learning environments offers perfect, consistent, faultless wireless connection.

$$P_d\, r[ki\text{-}sn'']:\rightarrow Ns[e\text{-}mw'']*Bs[w\text{-}9ui'']*vsw'' \quad (2)$$

stands for signal characteristics, for bandwidth allocation, for the total amount of access points, r[ki-sn^"] for the receiver's sensitivity adjusting for environmental factors, and for the power volume of the antenna signal. Effective and dependable Wi-Fi coverage for the whole campus is guaranteed by this enhancement on equation 2.

One for design of an antenna system, focusing excellent performance by means of strategic planning and iterative improvements, and another for access point placement using APP-WCM tools, therefore guaranteeing continuous coverage and preventing interference. The systems are intended to maximize campus Wi-Fi. Together, in educational environments, they improve connectivity, reliability, and user experience, therefore fostering effective digital learning and cooperation.

Result and Discussion

Significance performance improvements using the APP-WCN architecture instead of traditional WLAN, ICT, and CTS are highlighted as critical. Through coverage, reliability, and speed of signal increase Wi-Fi services robustly provided over educational institutions. Mathematically, other efficiency models validate that the overall performance of instructional activities is efficiently optimized in networks using the architecture.

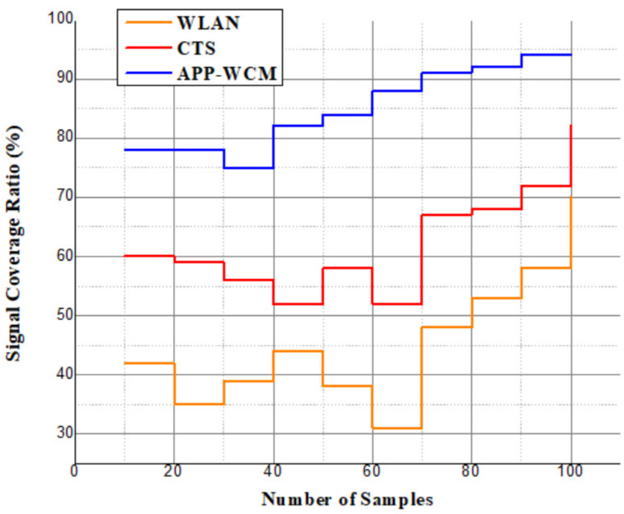

Fig. 3: Analysis of signal coverage

As indicated in Figure 3, comparing traditional WLAN, and CTS systems with APP-WCN architecture, its signal coverage improves by an additional 94.13%. Such high improvement serves as an excellent example of the entire framework covers each campus area with Wi-Fi. It will ensure all operations of instructional activities undergo smoothening.

$$N_j\ r[l\text{-}snj'']:\rightarrow Nsp[w\text{-}9vr'']*Vs[w\text{-}9ur''] \quad (3)$$

With N_j r denoting the receiver's adjustment to environmental conditions and representing the number of signaling joints or nodes, it seems probable that is the variable in equation 3. The number of source signals or access points is denoted by **, and the signal intensity or volume is represented by *Vs*[*w-9ur''*]. The analysis

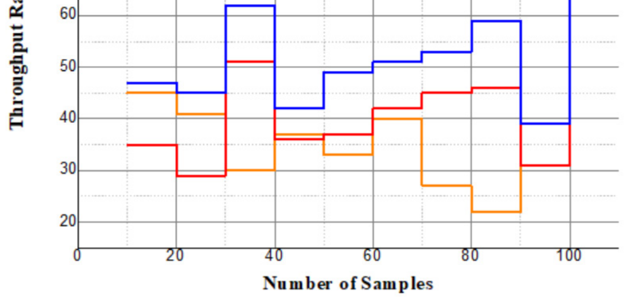

Fig. 4: Analysis of throughput

As illustrated in Figure 4, the APP-WCN architecture provides 91.83% higher than that of traditional WLAN, and CTS systems. This significant increase in throughput indicates the framework's ability to support high data transfer rates, thus enhancing the overall performance of the network on educational campuses.

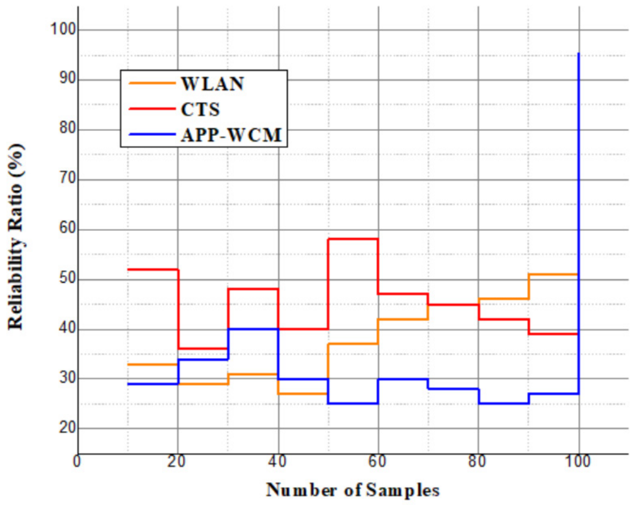

Fig. 5: Analysis of reliability

APP-WCN architecture is about 95.826% more reliable, as shown in Figure 5. Because of such great dependability, Wi-Fi connections all over the campus are not only consistent and reliable but provide smooth activities throughout the campus educational endeavors. Improvement on reliability decreases possibilities of link breaks, and, therefore, user's experience increases.

It is probable that the variable stands for the signal's distribution factor, accounts for environmental fluctuation, represents bandwidth allocations, and stands for the strength of the signal or volume. Efficient and strong Wi-Fi coverage across campuses is guaranteed by this method in equation 5.

APP-WCN architecture recorded a 94.13% improvement in the coverage of signal, 91.83% increase in throughput, and a 95.826% improvement in reliability. Such improvements ensure reliable, high-speed, and stable Wi-Fi within campuses, making instructional operations flow smoothly. Equations 3, 4, and 5 highlight how the framework can optimize network connectivity and user experience.

Conclusion

Optimization of campus Wi-Fi infrastructures through antennas is critical as these support ever-growing demands for modern educational environments. This study introduced a full-fledged framework: Access Point Placement using Wireless Coverage Modeling, to solve the dense population of users, complex building layouts, and diverse usage patterns. Integrating advanced simulation tools, optimization algorithms, and emerging technologies, the APP-WCM has come up as a robust solution that enhances the coverage of signal strength, minimizes interference, and builds a reliable network.

This approach, emphasizes adaptability and resource efficiency in terms of the specific network configurations designed to fit into a unique set of campus requirements. The network can therefore accommodate diverse activities such as remote learning and multimedia streaming to collaborative work outside. Integration with machine learning and big data analytics will also make it more responsive in terms of predicting user behavior and making adjustments in the network dynamically.

The performance benefits of APP-WCM, coupled with the fact that it consumes less energy and makes the best use of resources, would make it a sustainable framework. Thus, this will prove to be an economical method of implementation for budget-constrained educational institutions, helping meet the global calls for adopting sustainable technology practices. Besides, the flexibility and scalability of the framework enable it to be used in public libraries, community centers, or other remote learning centers, among other settings.

Finally, this paper will unveil revolutionary potential design of advanced antenna systems that could facilitate robust and scalable building of Wi-Fi infrastructures in the educational environment. With this respect, the APP-WCM framework addresses technical, operational, and economic challenges of campus connectivity in order to empower institutions deliver high-quality digital learning experiences. As educational needs and technology evolve, it provides a basic framework which ensures that, in equal as well as fair access to digital tools, innovations bridge the gap or divide in education.

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