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Towards mobility management in next-generation wireless systems networks from a multi-objective perspective

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Abstract

The rapid expansion of mobile applications and consumer demand for uninterrupted connectivity necessitate advancements in mobility management within next-generation wireless networks. This paper evaluates various mobility management protocols, including satellite networks, wireless asynchronous transfer mode (ATM), mobile Internet Protocol (IP), and public land mobile networks (PLMN). Through a comprehensive multi-objective analysis, we explore the integration and comparative effectiveness of these protocols. Our findings indicate distinct performance trade-offs among mobility management strategies. Specifically, strategies based on registration areas outperform those utilizing reporting cells, except in scenarios characterized by high paging costs. Moreover, we demonstrate that various paging methods excel in different regions of the objective space, with blanket paging consistently identified as the least efficient. The improvements in network design technologies notably enhance the capabilities of mobile graphy, facilitating higher-quality multimedia streaming, quicker processing of high-resolution content, and better utilization of mobile graphy hardware such as advanced camera sensors and graphics processors. This study guides network operators and mobile graphy practitioners in selecting optimal strategies aligned with their specific operational requirements, highlighting unresolved issues critical to future network evolution.

Keywords: Location update, Mobilegraphy, Mobility management, Multi-objective optimization, Next-generation networks, Paging strategies, Public land mobile networks (PLMN).

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1. Introduction

A new network design is required because of the advent of numerous wireless technologies and the rapid rise in mobile consumers' demand for high-quality network services. The goal of this new design is to combine and benefit from several networking strategies, including the agility of an ad hoc communication network, the bandwidth of wired connections, and the coverage of wireless networks [1]. As a result, by integrating these infrastructures, users can balance various networks, reduce the likelihood of calls being blocked or dropped, and boost system capacity by implementing a small number of new technologies and additional infrastructures at a low cost.

The existing centralized network design presents a significant challenge in handover management and service enhancement, given the enormous growth in mobile Internet traffic in NR 5G and the constraints in mobility support [2]. For end users who travel and change locations frequently, mobility management is very important, as are application requirements and desires. Transparent data path management to the MN's Internet Protocol (IP) stack is lacking in the centralized design. All the MNs' IP traffic flows, regardless of their significance, must go through the same mobility mechanism under this centralized infrastructure. Instead of using the best route offered by local IP routing or a direct link, the communication peers' end-to-end data path in Figure 1 must pass via the packet data network gateway (PGW) of the MN core network. As a result, it poses a risk of scaling issues, single points of failure, inefficient routing, and needless access to mobility resources. Although this design prioritizes straightforwardness, it raises overall latency and performance costs, which are unattractive for radio access carriers operating in 5G and further.

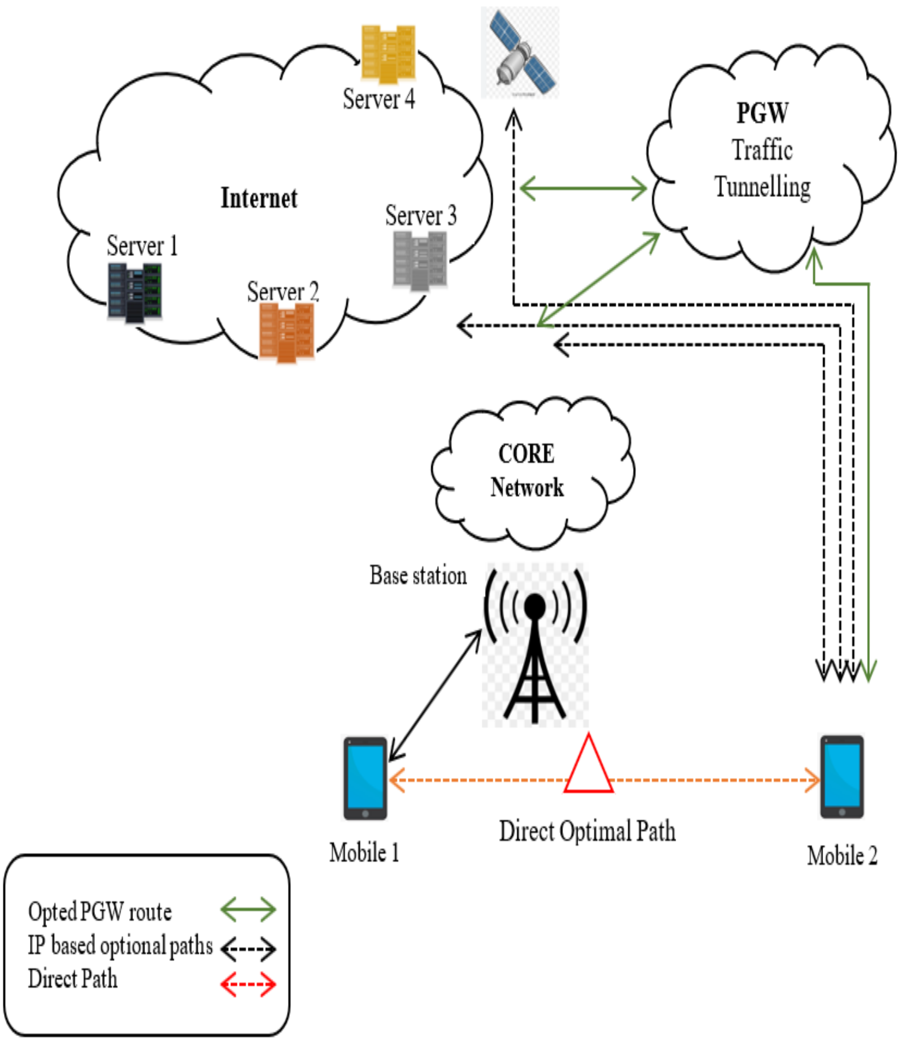

Figure 1.
Mobility in one place: Management of IP data flow.

To better illustrate these limitations, a visual study has been conducted to analyze data flows through the centralized network architecture. Figure 2 presents the visual results of this study, clearly highlighting inefficient data paths through PGW, latency bottlenecks, and potential scalability issues inherent in current architectures.

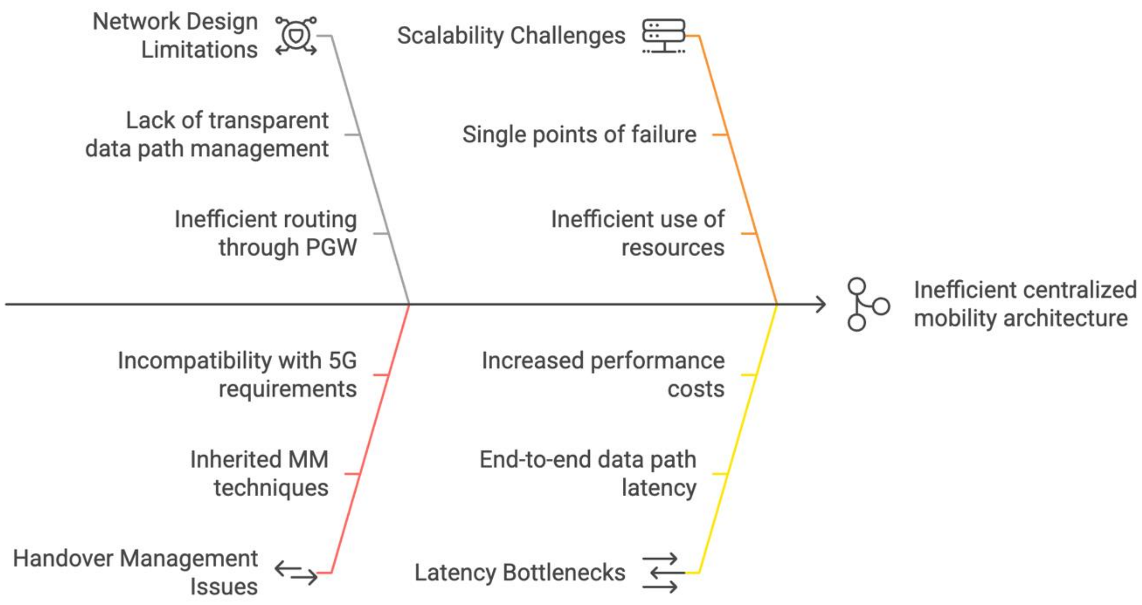

Figure 2.
Visual Study of Current Centralized Mobility Architecture.

The advancement in network design technologies directly impacts the utilization of mobilegraphy hardware. Improved network management and reduced latency ensure higher-quality multimedia streaming, quicker uploads and downloads of high-resolution content, and enhanced performance for real-time photo and video editing apps. Consequently, mobilegraphy enthusiasts and professionals benefit significantly, as hardware such as camera sensors, graphics processing units (GPUs), and storage capabilities can be fully leveraged without network-related constraints.

In a telecommunications network, handoff refers to the process of moving an ongoing data or conversation session from one channel to another; MM mechanisms found in 3G, 4G, LTE, or LTE-A networks can assist in doing this. When devices are moved from the actual area where they were first connected, these systems ensure uninterrupted connectivity and continuity of service. However, because these inherited MM techniques are ineffective, incompatible, or even unusable Mukhtar et al. [3] we are unable to utilize them effectively in 5G network conditions.

The development of 4G networks and associated standards from organizations such as ETSI, IETF, and 3GPP has resulted in various strategies and methodologies that significantly enhance wireless network flexibility and reliability. Despite these advancements, current strategies exhibit practical limitations when applied to heterogeneous network environments, industry-specific economic considerations, and strategies that emphasize software deployment.

Researchers have explored advanced mobility management (MM) techniques like software-defined networking (SDN) and multi-radio access technology (RAT) to address these shortcomings. However, these approaches have not fully resolved the challenges posed by mobility management in emerging 5G networks and beyond. Issues related to complexity, scalability, and real-world implementation hurdles continue to hinder the comprehensive adoption of existing mobility management solutions.

Furthermore, the multifaceted nature and fundamental network signaling issues in 5G and future networks cannot be adequately managed by current MM techniques like group transfer or progressing cell organization. Consequently, researchers have initiated a significant evolution in MM processes for 5G and future networks, driven by these practical constraints. Adapting existing MM methods to 5G requirements is challenging due to its architectural complexity, which demands diverse services and meets stringent customer expectations. Moreover, 5G aims to guarantee minimal latency while ensuring reliability for delay-sensitive applications such as real-time multimedia, augmented reality, and emergency services.

The remainder of the paper is structured as follows. Section 2 discusses the motivation and relevant related work. Section 3 presents the proposed methodology, including additional visual studies for clearer conceptualization. Section 4 provides detailed experimental setup descriptions and results, complemented by visual analyses for enhanced clarity. Section 5 concludes the paper with final observations and recommendations for further research.

2. Related Works

For mobile networks to be controlled and managed, different nodes must be self-organizing and intelligently organized to recognize and respond to their surroundings automatically [4]. In cellular networks, the number of nodes has grown along with the number of network characteristics that have intricate relationships and need to be further evaluated and optimized. One way to accomplish these goals is by self-organization. The system purpose is to find a structure with acceptable functioning by creating consistency, and it has lately become a global method. Through interaction with the environment and every other component of a network, self-organization components must be able to act without the need for planned activity or modifications to their structure or functionality. In wireless systems, self-organization falls into three categories: selfconfiguration, self-optimization, and self-healing. By putting these capabilities into practice, operators may reduce their investment and operating costs while improving network quality of service (QoS), scaling, and reliability.

Machine learning's big data processing capabilities may make it easy to handle the wireless traffic data in Torrance. For instance, it is anticipated that over the next ten years, the traffic volume from on-demand entertainment and information would significantly expand in a 5G system, and by 2020, according to de Carvalho Rodrigues et al. [5], the average cell phone may use 4.4 GB of data monthly. The enormous volume of data creates a sizable training set that can be statistically used to identify internal relationships and perform analysis and forecasting using machine learning methods. In NGWNs, modelling and parameter estimates are crucial. For example, a precise estimation of the channel state information (CSI) may significantly increase the system's overall capacity in huge multiple-input multiple-output (MIMO) devices. In typical time-varying circumstances, systems may not be adequately described by traditional mathematical approaches. A different method of adaptive modelling and calculating parameters that depends on historical learning is offered by machine learning.

The increased number of interrelated orders of size, rapid data transfer, near real-time responsiveness, and the ability to meet a variety of NG-IoT requirements are all made possible by next-generation cellular interactions, which are a major enabler of the wider adoption of NG-IoT-based methods [6]. The use of higher frequencies is directly linked to increased security, improved quality of service (QoS), decreased end-to-end latency, and faster data rates; however, this also results in increased power consumption, new software and hardware relationships, and inefficiencies. Particularly in ad hoc and distant sensing applications, the previously described criteria, needs, and concerns greatly restrict the range of viable low-power devices that are available and add power, effort, and networking overhead. As more and more features are introduced in an ad hoc, decentralised fashion, new orchestration mechanisms tailored to next-generation cellular networks enable and advance a more sophisticated periphery.

Some of the research on the virtual network functional placement problem, which is an extension of the NP-hard virtual network embedding problem, is presented in this section. While some authors just take QoS metrics into account while addressing the network's function location issue, others also take dependability into account [7]. In order to decrease network load while meeting data-plane latency restrictions, the authors suggest an Integer Linear Programming (ILP) model for the best placement of network functions in cellular networks. Using a greedy algorithm and a tabu search-based heuristic, a coordinated method for map and arranging VNFs to minimize various parameters like cost, revenue, and service processing duration is described.

Despite the quick development of PMMS, research has so far mostly concentrated on building data systems for PMMS, such as performance prediction algorithms and data collection optimization [8]. Establishing decision-making models and integrating decision-making technology into PMMS have received less attention. Furthermore, benefits analysis and multi-attribute analysis continue to form the foundation of the technologies utilized for maintenance decision-making. More research is still needed to determine how to accomplish several strategic objectives in the same latitude. Furthermore, as research goals get more complex, the width of the gap between the target values increases, and as high-dimensional complex models are embedded, the optimization challenge in decision-making becomes more challenging.

The position-locating system and mobilizer are two examples of extra application-dependent components that can be connected to a WSN node. These sensor nodes get multiple functions by integrating these various parts into a compact gadget. Stated differently, sensor node structure and properties are determined by application-specific needs as well as electrical, mechanical, and communication constraints [9]. One of the biggest problems WSNs face is using these limited resources of sensor nodes to satisfy specific application needs, such as end-to-end latency, network longevity, and sensing radius. Sensor nodes are usually arranged into clusters, with a node serving as the cluster head and possessing greater computational and resource capacity than the other cluster members.

3. Methods and Materials

3.1. Mobility Management Strategies in PLMN

The two network processes of position update and paging make up any mobility management approach of idle UEs in PLMNs [10]. For the network to help track subscribers' travels to some extent and limit location uncertainty to fewer network cells, UEs utilize the position update procedure to seek confirmation of their position in the main network databases. Conversely, when a UE receives an incoming call, the network uses paging to identify the precise cell in which the UE is located and appropriately reroute the incoming call.

3.2. Location Update Strategies

The subscribers' movements within the network cells are monitored through the use of location update techniques. Fundamentally, these tactics are divided into two categories based on whether the network or the UEs make the decisions. Current PLMNs use methods that let the network decide where the UEs need to request a location update. The rationale is that when UEs are in charge of the place update process, decisions are made without considering network load data. The focus of this work is on network-assisted location updating techniques because of this. Within this group, the most widely used tactics are those based on Reporting Cells (RC) and Registration Areas (RA) [11].

3.2.1. Registration Areas

The most popular method for updating locations in PLMNs is this one. With this method, the network cells are arranged in contiguous, non-overlapping sets, with each set of cells being referred to as a Registration Area (RA). Figure. 2(a) shows a Registration Area setup. After deploying a Registration Area setup, the UEs just need to start a Location. When they transfer from one Registrant Area to another, they update (LU) requests. This limits the location uncertainty and, hence, the paging process to the cells of the most recent Registration Area update. Each eNodeB periodically communicates its cell ID and Register Area ID Khan et al. [10], allowing UEs to determine whether they are in a particular cell of another Register Area.

$$f_1 = min\{LU = \sum_{t=T_{ini}}^{T_{fin}} \sum_{u=1}^{N_u} \alpha t, u\} \quad (1)$$

3.2.2. Reporting Cells

Identifying the optimal Reporting Cell configuration is a multi-objective NPhard optimization problem. The goal is to identify the arrangement that minimizes the number of pacing processes and position updates. Equations provide a description of these two objective functions (2) and (3), in which $\beta t, u$ is an integer that is only set to 1 when the UEu makes a visit to another Reporter Cell at instant t [12].

$$f_2 = \min\{LU = \sum_{t=T_{ini}}^{T_{fin}} \sum_{u=1}^{N_u} \beta t, u\} \quad (2)$$

3.3. Paging Strategies

The network employs paging techniques to locate the UE's cell when a new call is placed to that UE so that the call can be appropriately redirected. The network does this by sending a paging request to each networking cell where it is likely to locate the requested UE. Upon receiving the paging request, the requested UE promptly requests a connection to the network in order to get the incoming call. The process that sends a paging request and waits for a certain period of time before receiving a connection request from the UE is referred to as a paging procedure for notation [13]. The intended UE is not in that cell, the network concludes, if no connection request is received. This operation mode is formulated in Equation 3.

$$f_3 = \min\{PA = \sum_{t=T_{ini}}^{T_{fin}} \sum_{u=1}^{N_u} \delta t, u \,.\, \partial t, u\} \quad (3)$$

3.4. Multi-Objective Optimization Issue in Wireless Sensor Networks Generically

First, inputs; second, needed output; third, objectives; and fourth, constraints make up the general multi-objective optimization problem. Several options for every aspect of the problem are shown in Figure 3. In a standard resource distribution problem, the regulatory authorities or network operators set the input parameters and decision variables. The regulatory regulations and the immediate radio frequency environment, for instance, have an impact on the transmit frequency choices. The choice of frequency can impact the sensors' transmission range as well as a number of crucial performance metrics, including delay, bit error rate, and coverage. Transmit power can have a big impact on a lot of desirable goals, like improving the efficiency of energy, link quality, network uptime, dependability, coverage, cost, and packet error rate [14]. The authors have suggested an optimized formulation to preserve sensing coverage in wireless networks of sensors by limiting the number of active nodes for sensors and energy usage. The use of energy has been taken into account by using a multi-objective optimization approach to simultaneously meet reliability and delay. The nodes' total and residual energy can also have an impact on a number of performance metrics, including packet error rate, protection, productivity, and network lifetime.

Energy usage and packet error rate have been traded off using a multi-objective formulation. The overall cost and the network's performance in terms of observability, coverage, transmission range, dependability, and energy consumption are determined by the sensors' location and density. Numerous constraints, including connection to the network, disruption, level of service, transmission energy, protection, structure, density, cost, latency, dependability, and delay, limit the practical optimization challenges associated with wireless sensor networks. The best sensor locations, best sensor counts, best scheduling, best transmit power, best coverage, best throughput, best latency, best cost, best packet error rate, fairness, and dependability are all anticipated to arise from these limited optimization issues. According to specific input parameters, the objective function that must be optimized, and the limitations imposed by the particular sensor network deployment area, the nature of the multi-objective optimization issue will vary.

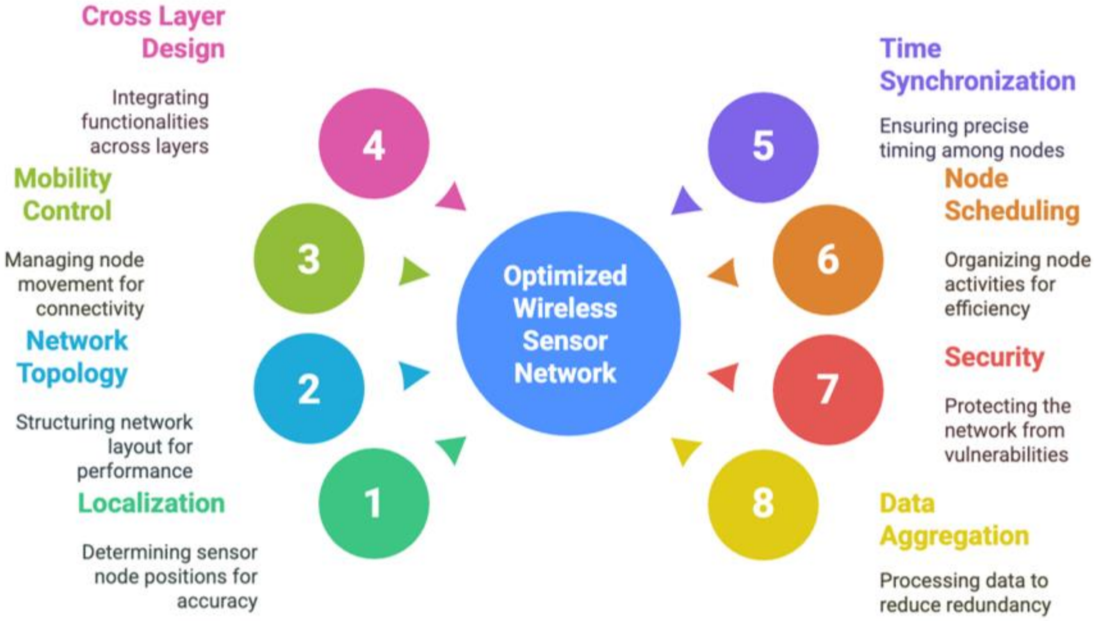

Figure 3.
Wireless sensor network optimization issues with several objectives

3.4.1. Multi-Objective Optimization Targeting Design-Related Issues in Wireless Sensor Networks

The quality, affordability, and efficiency of real-world sensor applications are only a few of the performance factors that are greatly impacted by the somewhat complex task of designing WSNs. Making the most of the sensor network's lifespan while ensuring that sensors efficiently monitor the area of interest and relay the data they observe to the main processing station is one of the design objectives. The design challenge of beam design optimization has been approached as a multi-objective approach in order to suggest a technique for minimizing energy usage.

4. Implementation and Experimental Results

We have employed two distinct approaches for assessing the Pareto fronts that NSGA-II was able to acquire for each of the mobility management solutions that were discussed. The first is a comparison using the hypervolume (IH), one of the most widely used multi-objective metrics.

4.1 Markov Chain-Based Paging

Four more probability thresholds have been employed for this paging approach. Table 1 displays the results of this paging process for a location updated strategy based on register regions, and Table 2 displays the results for a location update strategy based on reporting cells. The hyper-volume data are displayed in these two tables as the median ± interquartile range. These tables also display the outcome of the statistical methods mentioned above. It is evident that in every instance, those variations are statistically meaningful. These two tables show that our quasi-optimal solution, which is based on a second-order polynomial approximated value, is the optimum way to decompose Π in m paging regions in both locations update procedures.

Table 1.
Markov chain-based hyper volume statistics for registration areas and paging.

	Rome	Hong Kong	London	Paris
Reverse	98.72±0.08	99.26±0.05	99.57±0.01	99.76±0.03
Semi -Reverse	98.64±0.06	99.18±0.04	99.50±0.03	99.67±0.04
Uniform	97.99±0.11	98.74±0.04	99.09±0.03	99.34±0.04
Quasi-optimal	99.77±0.03	99.91±0.03	98.15±0.02	98.26±0.02

4.2. Evaluation of Several Approaches to Mobility Management

The hypervolume indicator is used in this section to compare the outcomes of each mobility management approach. Table 4 displays statistical data for this metric. Table 3 also displays the findings of the statistical approach previously mentioned. The results of the research demonstrate that the mobility management approach based on registration regions with a Markovian paging mechanism yields the greatest overall outcomes, with improvements and differences being statistically significant in every instance.

Table 2.
Hypervolume statistics for Markov chain-based paging and cell reporting.

	Rome	Hong Kong	London	Paris
Reverse	98.37±0.1	99.07±0.03	99.41±0.02	99.61±0.02
Semi-Reverse	98.36±0.02	98.98±0.02	99.35±0.02	99.54±0.02
Uniform	97.76±0.02	98.59±0.02	98.97±0.02	99.23±0.02
Quasi-Optimal	99.54±0.02	99.72±0.02	99.99±0.02	98.08±0.02

Table 3.
Hyper-volume statistics for every method of mobility management.

	Rome	Hong Kong	London	Paris
RA+BP	95.17±0.14	96.71±0.03	97.36±0.05	97.85±0.05
RA+G-PA	98.73±5.94e−3	99.25±2.89e−3	99.52±1.58e−3	99.71±1.99e−3
RA+Tprms	99.61±0.05	99.87±0.03	98.06±0.02	98.18±0.02
RA+Markov	99.77±0.03	99.93±0.03	98.15±0.02	98.26±0.02
RC+BP	94.83±0.03	96.54±0.02	97.21±0.05	97.68±0.03
RC+G-PA	98.47±0.03	99.14±0.01	99.41±0.02	99.59±0.02
RC+Tprms	99.41±0.02	99.75±0.00	99.95±0.01	98.06±0.01
RC+Markov	99.54±0.02	99.72±0.02	99.99±0.02	98.08±0.02

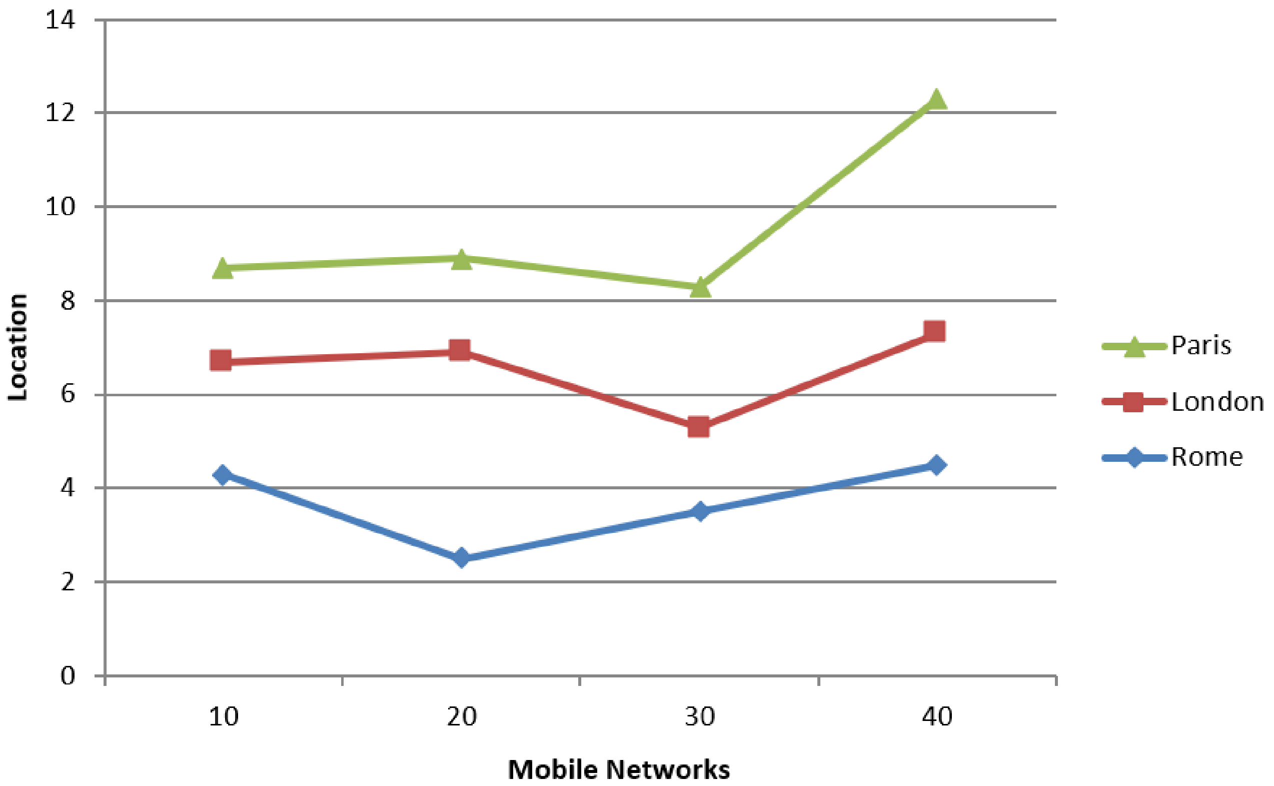

Figure 4.
For a location update approach based on registration regions, Pareto fronts were obtained using various paging processes.

We combined all of the paging methods and the non-dominated solutions for a location update strategy to create a new set of workable solutions [15]. The outcome of this process is shown in Figure 4 for the location update strategy based on registration areas.

Table 4.
Analyzing the hypervolume samples from every experiment statistically.

	RA+BP	RA+G-PA	RA+Tprms	RA+Markov	RC+BP	RC+G-PA	RC+Tprms	RC+Markov
RA+BP	–	✓	✓	✓	✓	✓	✓	✓
RA+G-PA	✓	–	✓	✓	✓	✓	✓	✓
RA+Tprms	✓	✓	–	✓	✓	✓	✓	✓
RA+Markov	✓	✓	✓	–	✓	✓	✓	✓
RC+BP	✓	✓	✓	✓	–	✓	✓	✓
RC+G-PA	✓	✓	✓	✓	✓	–	✓	✓
RC+Tprms	✓	✓	✓	✓	✓	✓	–	✓
RC+Markov	✓	✓	✓	✓	✓	✓	✓	–

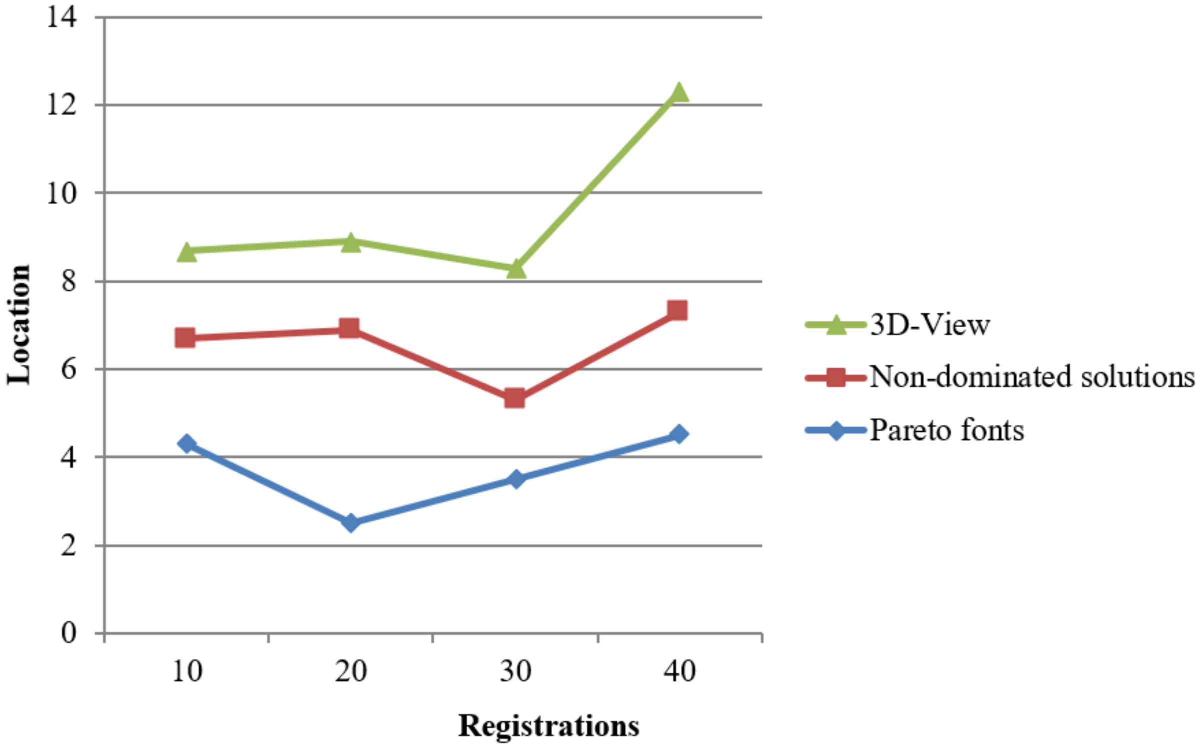

Figure 5.
Multi-criteria comparison of reporting cells and registration areas.

The outcome of this process is seen in Figure 5. In all of the objective space, the zones with large paging costs, the location update approach based on registering areas outperforms the location update strategy based on reporting cells, as shown in the final figure. Consequently, we may say that the location update approach based on increasing the size of the registration regions the more inefficient they become.

The most common position updating method based on reporting cells is geometric paging. With a few network configurations linked to a high location update cost, it does, however, marginally contribute to an area update approach based on registration regions.

In conclusion, the research shows that network operator constraints have a significant impact on how effective a mobility management strategy is. The mobility management approach based on registration zones with Markovian posting would be the ideal option, for instance, if the network provider finds value in network designs with minimal paging costs. On the other hand, the mobility management approach based on submitting cells with Markovian paging would be the ideal option if the network operator is looking for network configurations with minimal location update costs. Additionally, the mobility management approach based on registering areas with a paging method based on dwell duration would be the ideal option if the network operator is looking for network configurations that offer the optimal balance between position update and paging expenses. This is where the strength of a multi-objective analysis lies. Each network operator can select the mobility management strategy and network configuration that best suits its requirements. Location information and faxing expenses may be the primary basis for this nomination process, or it may be based on another KPI, such as peak communication bandwidth.

5. Conclusion

In the realm of public land mobile networks (PLMNs), managing mobility effectively is paramount for ensuring efficient service delivery. Various mobility management techniques play crucial roles in tracking user devices as they navigate through network service areas. This response evaluates several prominent strategies, underscoring the interactions between paging techniques and location updates. The integration of paging techniques—namely, blanket paging, symmetrical paging, approximate paging based on dwell time, and Markov chain-based paging—will be examined in conjunction with either registration area updates or reporting cells, revealing the context-specific efficacy of each approach.

The location update methodologies associated with registration areas generally have superior performance compared to reporting cells, particularly when accounting for typical operational conditions [16-18]. However, registration area updates can become less effective when paging costs escalate, as indicated by empirical observations in real-world scenarios evolving from theoretical models [19, 20]. Signal traffic analysis serves as an essential metric in corroborating these findings, reinforcing the dynamic relationship between the paging techniques under variable conditions [2, 21]. It has been noted that Markov chain-based paging excels under registration area strategies, particularly within high-traffic contexts, due to its adaptability in managing unpredictable user mobility patterns. In contrast, geometric paging often dominates in scenarios characterized by elevated location update costs, particularly when optimized for resource allocation [22].

In examining specific paging performance, various results emerge. For instance, dwell-time-based paging consistently achieves superior outcomes in optimizing the balance between latency and resource consumption [16, 17, 23]. Meanwhile, for systems employing reporting cells, geometric paging again shows strong performance, especially when update costs are significant. Dwell-time strategies yield competitive results in mid-range operational conditions, while Markov chain paging is often reserved for high-cost situations, illustrating the trade-offs inherent in these strategies [17, 21].

The advancements in mobility management practices derived from this study have far-reaching implications beyond basic telecommunications. As mobile networks enhance their capacity to manage high-resolution multimedia content, real-time editing functionalities, and overall data handling more effectively, hardware components such as advanced camera sensors and graphics processing units can be fully utilized [2, 24]. This outcome underscores the necessity for practitioners to make informed decisions regarding mobility management techniques, aligning operational implementations with performance metrics tailored to specific network demands.

In conclusion, the evaluation of mobility management methods in PLMNs reveals complex interactions dictated by various network conditions. Each strategy exhibits distinct strengths, suggesting a need for careful consideration when selecting appropriate techniques for diverse operational environments. Continuous exploration and adaptation of these methods will be vital for ensuring optimal performance in the evolving landscape of mobile communications.

References

[1] O. Abdelkhalek, S. Krichen, and A. Guitouni, "A genetic algorithm based decision support system for the multi-objective node placement problem in next wireless generation network," *Applied Soft Computing*, vol. 33, pp. 278-291, 2015. https://doi.org/10.1016/j.asoc.2015.04.001

[2] M. U. A. Siddiqui, F. Qamar, M. Tayyab, M. N. Hindia, Q. N. Nguyen, and R. Hassan, "Mobility management issues and solutions in 5G-and-beyond networks: A comprehensive review," *Electronics*, vol. 11, no. 9, p. 1366, 2022. https://doi.org/10.3390/electronics11091366

[3] M. Mukhtar, F. Yunus, A. Alqahtani, M. Arif, A. Brezulianu, and O. Geman, "The challenges and compatibility of mobility management solutions for future networks," *Applied Sciences*, vol. 12, no. 22, p. 11605, 2022. https://doi.org/10.3390/app122211605

[4] A. Mirzaei Somarin, M. Barari, and H. Zarrabi, "Big data based self-optimization networking in next generation mobile networks," *Wireless Personal Communications*, vol. 101, pp. 1499-1518, 2018. https://doi.org/10.1007/s11277-018-5774-6

[5] E. de Carvalho Rodrigues, A. V. Rial, and G. Geraci, "Towards mobility management with multi-objective Bayesian optimization," presented at the In 2023 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 1-6). IEEE, 2023.

[6] G. Amponis *et al.*, "Drones in B5G/6G networks as flying base stations," *Drones*, vol. 6, no. 2, p. 39, 2022. https://doi.org/10.3390/drones6020039

[7] H. D. Chantre and N. L. da Fonseca, "Multi-objective optimization for edge device placement and reliable broadcasting in 5G NFV-based small cell networks," *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 10, pp. 2304-2317, 2018.

[8] W. Chen and M. Zheng, "Multi-objective optimization for pavement maintenance and rehabilitation decision-making: A critical review and future directions," *Automation in Construction*, vol. 130, p. 103840, 2021. https://doi.org/10.1016/j.autcon.2021.103840

[9] Z. Fei, B. Li, S. Yang, C. Xing, H. Chen, and L. Hanzo, "A survey of multi-objective optimization in wireless sensor networks: Metrics, algorithms, and open problems," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 550-586, 2016. https://doi.org/10.1109/COMST.2016.2610578

[10] W. U. Khan, X. Li, A. Ihsan, M. A. Khan, V. G. Menon, and M. Ahmed, "NOMA-enabled optimization framework for next-generation small-cell IoV networks under imperfect SIC decoding," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 11, pp. 22442-22451, 2021.

[11] A. I. Aravanis, B. S. MR, P.-D. Arapoglou, G. Danoy, P. G. Cottis, and B. Ottersten, "Power allocation in multibeam satellite systems: A two-stage multi-objective optimization," *IEEE Transactions on Wireless Communications*, vol. 14, no. 6, pp. 3171-3182, 2015.

[12] L. Pallavi, A. Jagan, and B. T. Rao, "ERMO2 algorithm: An energy efficient mobility management in mobile cloud computing system for 5G heterogeneous networks," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 3, pp. 1957-1967, 2019.

[13] G. Zhou, L. Zhao, G. Zheng, Z. Xie, S. Song, and K.-C. Chen, "Joint multi-objective optimization for radio access network slicing using multi-agent deep reinforcement learning," *IEEE Transactions on Vehicular Technology*, vol. 72, no. 9, pp. 11828-11843, 2023. https://doi.org/10.1109/TVT.2023.3262959

[14] B. Li, S. Xiao, and Y. Li, "Networking and communications for the next generation IoT," *Mobile Networks and Applications*, vol. 24, pp. 1411-1413, 2019.

[15] H. A. Hashim and M. A. Abido, "Location management in LTE networks using multi-objective particle swarm optimization," *Computer Networks*, vol. 157, pp. 78-88, 2019. https://doi.org/10.1016/j.comnet.2019.04.009

[16] Y. B. Lin, R. H. Liou, and C. T. Chang, "A dynamic paging scheme for long-term evolution mobility management," *Wireless Communications and Mobile Computing*, vol. 15, no. 4, pp. 629-638, 2015. https://doi.org/10.1002/wcm.2371

[17] T. Baghaie, "Track paging an optimal method for minimizing paging and signaling cost in mobile IP," *Journal of Computer and Communications*, vol. 1, no. 4, pp. 6-12, 2013. https://doi.org/10.4236/jcc.2013.14002

[18] H.-S. Jang and J.-H. Baek, "Modeling and performance analysis of three zone-based registration scheme in wireless communication networks," *Applied Sciences*, vol. 13, no. 18, p. 10064, 2023. https://doi.org/10.3390/app131810064

[19] J. Baek, T. Lee, and C. Kim, "Performance analysis of 2-location distance-based registration in mobile communication networks," *IEICE Transactions on Communications*, vol. 96, no. 3, pp. 914-917, 2013. https://doi.org/10.1587/transcom.e96.b.914

[20] K. H. Seo, J. H. Baek, C. S.-H. Eom, and W. Lee, "Optimal management of distance-based location registration using embedded Markov chain," *International Journal of Distributed Sensor Networks*, vol. 16, no. 2, p. 1550147720904611, 2020. https://doi.org/10.1177/1550147720904611

[21] A. A. Alsaeedy and E. K. Chong, "Tracking area update and paging in 5G networks: A survey of problems and solutions," *Mobile Networks and Applications*, vol. 24, pp. 578-595, 2019. https://doi.org/10.1007/s11036-018-1160-6

[22] K. Hong and S. Lee, "Dynamic multi-step paging scheme in PMIPv6-based wireless networks," *Wireless Networks*, vol. 18, pp. 33-44, 2012. https://doi.org/10.1007/s11276-011-0385-0

[23] S. L. Lai and N. P. Tey, "Deficiency in civil registration and vital statistics reporting in remote areas: The case of Sabah, Malaysia," *Genus*, vol. 77, no. 1, pp. 1-19, 2021.

[24] A. Agarwal, C. Mohanta, and G. Misra, "Principle of 6G wireless networks: Vision, challenges and applications," *Journal of Information Technology and Digital World*, vol. 3, no. 4, pp. 243-258, 2022. https://doi.org/10.36548/jitdw.2021.4.001