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"LIMITATIONS OF STATIC SHORTEST PATH ALGORITHMS IN DYNAMIC NETWORK ENVIRONMENTS"

Neeraj kumar[1]

Dr. Sudeep Saraswat[2]

Department of Computer Science and Engineering[1,2]

ASIAN INTERNATIONAL UNIVERSITY, IMPHAL WEST, MANIPUR, INDIA

ABSTRACT

The methods of shortest path are the fundamental part of routing, network optimization, transportation planning, and medical imaging systems. Traditional shortest path algorithms are static in nature which means that they assume that the network topology remains constant and that all edge weights are fixed during computation. But the current network infrastructures, such as mobile ad hoc networks (MANETs), software-defined networks (SDNs), Internet of Things (IoT) ecosystems, and real-time medical systems, operate in extremely dynamic environments where topological changes are frequent, and cost of links changes over time. This essay is a critical analysis of the weakness of the shortest path algorithms in the dynamic network contexts. We discuss such issues as computational overhead due to repeated recomputation, low scalability in large-scale adaptive systems, absence of real time responsiveness, and Quality of Service (QoS) degradation in time-varying environments. Comparative analysis of the concept of the regular routing and adaptive routing mechanisms is done to indicate the differences in performance. The paper ends by offering a research agenda on how future research efforts can hopefully overcome the undeniable limitations of the traditional shortest path solutions to the problem.

Keywords- Static Shortest Path, Dynamic Networks, Routing Algorithms, Network Optimization, Adaptive Routing.

1. INTRODUCTION

Shortest path algorithms are the foundation of the graph theory and computer networking which offer effective solutions to any problems that require routing, optimisation and allocation of resources. Arguably the landmark work in this area was the introduction of a polar time greedy algorithm to find the shortest path in a weighted graph having non-negative edge costs by Edsger W. Dijkstra. Initially, since its development, the Dijkstra algorithm, and the Bellman-Ford algorithm, as well as other traditional algorithms, have been widely used in routing algorithms, transportation planning, communication systems, and medical graph modelling. These algorithms are normally programmed to work with fixed graph formations, that is, the topology of the network and the weight values of the edges are fixed during the computation cycle. They are considered the keys to

mathematical beauty, deterministic dynamics and optimality guaranteed under given constraints which has ensured their role as basic tools of theoretical and practical computer science.

Although adopted widely, the use of static shortest path algorithms is based on assumptions that is hardly true in the present day networking context. They make the first assumption that the network topology is fixed, that is, the nodes and links do not vary during execution. Second, they use fixed edge weights, which reflect fixed measures like distance, delay or cost. Third, they are viewed based on the assumption that there are no real-time changes when the path is being calculated or utilized. Such assumptions were valid in early wired and fairly stable networks but the speed at which communication infrastructures are changing has essentially changed the behaviour of networks. Modern systems of mobile ad-hoc networks (MANETs), software-defined networks (SDNs), Internet of Things (IoT) systems, and real-time cyber-physical systems are dynamic by nature. In these kinds of environments, nodes can often become part of or leave the network, links are prone to failure, and traffic loads are likely to change at any given time.

The dynamic networks raise a number of factors that pose challenges to the status of validity of shortest path computation directly. Failure of links may be as a result of faults in the hardware, interference of an environment, or mobility; all such failures would instantly discard the previously calculated paths. The level of congestion also varies with the intensity of traffic, and edge weights are given as time-dependent to indicate a delay and bandwidth availability. The network topology is constantly remodelled by node mobility especially in wireless and vehicular networks. Moreover, the changing conditions of bandwidth and quality-of-service needs require quick adaptation to the service levels. The dynamism of traffic also makes the choice of a routing more complicated, because the applications, which are sensitive to latency, like telemedicine, online streaming, and intelligent transportation systems, must be responsive to the alterations in the network conditions.

The basic incompatibility of the classics assumptions of the shortest path algorithms with the strong dynamics of the contemporary networks leads to profound restrictions in performance and efficiency factors. In cases where topology or link weights are altered, the static algorithms usually need all the paths to be computed again causing higher computational overhead and slower response times. Repeated global recalculations in large scale networks can consume significant processing resources and decrease scaling. Moreover, the calculation of routes based on old information or data can be suboptimal or even non-existent, resulting in the loss of packets and the prolongation of the latency and loss of quality of service. With the further developments of network environments towards more complexity and real time adaptability, the question of the appropriateness of the static shortest path algorithms becomes even more critical as more intelligent and adaptive routing methodologies that can effectively perform under the conditions of dynamism are explored.

2. HISTORY OF STATICALLY SHORTEST PATH ALGORITHMS.

The static shortest path algorithms are developed by using the framework of the static network whereby the form of the graph and the cost of the linkage in the graph do not change throughout the process of running the algorithm. A stationary network can mathematically be expressed as G(V,E) where V corresponds to the collection of the nodes or the vertice, and E corresponds to the collection of the linkages or the edges between these nodes. The edges are weighted with the weight possibly corresponding to distance, delay, cost, or bandwidth usage. One of the major assumptions of the static model is that these weights on the edges are held constant during the calculation process. It later follows that as soon as the shortest route is found between a point of origin and a destination, it is taken to be true unless the whole calculation is repeated. It is a deterministic structure in which this is amenable to a precise mathematical analysis and ensures optimality in fixed conditions and so is considered to be the theoretical basis of many classical routing protocols.

Dijkstra, an algorithm that was initially introduced by Edsger W. Dijkstra, is one of the most commonly used shortest path algorithms in a static environment. This algorithm is based on a greedy approach, where the vertex that has the smallest tentative distance to the source is picked and relaxed on multiple edges. The algorithm maintains the shortest known distances and therefore guarantees that once a vertex has been completed, it has a shortest path when the edge weights are non-negatives. The time complexity of the Dijkstra algorithm is

determined by the way the algorithm is implemented. The time complexity in its simplest construction based on an adjacency matrix is O(V 2). Using a binary heap or priority queue with adjacency list, the complexity becomes (E log V) and so it is efficient with sparse graphs. The algorithm has found wide application in network routing, GPS navigation and communication infrastructure planning because of its efficiency and optimality when using non-negative weights.

The Bellman-Ford algorithm is another important static algorithm, which generalizes shortest path computation to graph whose weight of edges may be negative, but without negative weight cycles. In contrast to the greedy strategy of Dijkstra, BellmanFord is based on a dynamic programming principle, repeating the relaxation of all edges as many times as possible (up to V-1 times) to find convergence to the shortest distances. It has a time complexity of O(VE) which is more than the Dijkstra algorithm hence not very efficient on a large network. Its capability to identify negative weight cycles and to deal with negative costs however is useful in some optimisation problems and distance-vector routing protocols.

The Dijkstra and the Bellman-ford algorithms are both based on the assumption that the graph does not change in the course of the implementation. They calculate shortest routes using a static view of the network condition, and do not take note of online updates or structural changes. Although this assumption makes the analysis of the system much easier and ensures the best solutions in a static environment, it becomes a restrictive factor when it is used to dynamically structured systems where topology and weights change over time.

3. THE ENVIRONMENT OF DYNAMIC NETWORKS POSSESSES CHARACTERISTICS

The only difference between dynamic network environments and the static graph models is in the fact that the former have constantly changing structure and parameters of operation. Weight of the edges in such networks does not have constant values. The price of a link can vary within a short period of time in some form of delay, bandwidth, power used, or the level of congestion. Consequently, what was optimal at a particular time would be inefficient or invalid the next. This time variability is a direct challenge to the assumptions which make standard static shortest path algorithms.

The other characteristic of dynamic networks is that there is often a topology change. The nodes can enter and exit the network at any time, and new and old communication connections can emerge and disappear as a consequence of the environment, hardware failures, or mobility. In wireless and distributed systems, connectivity is generally volatile and affected by signal strength, interference and physical motion. This unsteadiness is further exacerbated by node mobility especially in the vehicular and mobile communication systems where devices keep moving, and this varying pattern of network connectivity can be observed. These organizational changes need routing systems that can be adapted quickly.

The congestion-dependent routing costs are also observed in dynamic environments. In contrast to the graph model, where the weight of the edges is determined and fixed, real-life networks tend to compute the weights of the edges, depending on traffic conditions. Another effect is that high data rates may increase the latency and packet loss rates effectively altering the cost of a link dynamically. As a result, the decision on routing should take into account the varying amounts of congestion to ensure a performance and reliability. Also, new applications demand severe real-time Quality of Service (QoS). Video streaming, telemedicine, cloud computing, and autonomous systems are services that require low latency, high availability, and bandwidth that is responsive. The routing strategies required to satisfy these QoS constraints in dynamic environments will require a method to react swiftly to the dynamic network conditions.

A number of modern systems are characterized by dynamic networks. Mobile Ad Hoc Network (MANET) systems are wireless systems comprising of mobile nodes that lack centralised infrastructure and therefore, their topologies are in a state of constant flux. The Internet of Things (IoT) systems connect heterogeneous devices that produce changing traffic patterns, and work in different environmental conditions. The wireless sensor networks are characterized by energy limitations and intermittent connectivity, which calls on adaptive routing decisions.

The systems of intelligent transportation are based on the idea of communication network of vehicles where mobility and density of the traffic directly impact the efficiency of the routing process. In a similar fashion in medical imaging, real-time angiography graph modelling is done by updating vascular graphs dynamically according to image acquisition and image segmentation processes where path computation is required to keep up with the varying structural data.

All these features shed light on the complicated nature of dynamic network environments and suggest the reason why using a fixed shortest path approach to the problems is not very useful in them.

4. LIMITATIONS OF STATIC SHORTEST PATH ALGORITHMS.

The nature of the algorithms of the shortest paths is focused on a static environment and thus they have serious drawbacks when used in dynamic networks. Their inflexibility is one of the most serious weaknesses. These algorithms are calculus of the optimum route given a given snapshot of network condition and with the assumption that the topology and weights of the edges of the network do not vary in the process of computation and usage. After calculating a route this route is fixed unless the whole algorithm is re-run. Such a strict behaviour is problematic in those conditions when the network conditions change regularly.

When we have link failures in place, then the automatic response of a static algorithm is not possible. When the signal is interrupted because of some hardware failure, environmental interference or node failure, the way that has already been calculated as optimal is no longer valid. As no built in mechanisms of incremental update are built in to the static algorithms, the system is forced to recalculate everything to come up with a new optimal path. It is computationally expensive and creates more time-latency than is permissible in real-time systems like emergency communication or industrial control systems.

Traffic congestion is persistent and this is one of the main barriers to the functionality of modern communication systems. In this category of systems, real-time vehicle and data traffic regularly affect link cost measures. Increased congestion over a given route is therefore bound to increase end-to-end delay and packet loss which increases its effective cost. However, the weights used by the traditional statical shortest-path algorithms are not re-calculated dynamically unless a specific trigger is specified; as a result the traffic is always focussed on routes that are already congested, even though there may exist pathways that are not only much shorter but also quicker. Such absence of dynamism leads to the poor use of the network resources and consequently to poor Quality of Service (QoS).

These restrictions are further increased by node mobility especially in wireless and mobile network architectures. The spatial coordinates of the nodes are continuously varying and in Mobile Ad Hoc Networks (MANETs) can vary abruptly, resulting in the continual and repetitive connection changes. A route which was correct a few minutes previous may then become impassable because of the shifting of nodes. The response of static routing protocols to such variations can only be reactive; when a topology update is received a full recalculation will be necessary. These redo cycles add end-to-end delays, limit scaling, and place high processing costs on large scale or resource limited systems.

On the whole, the above discussion has demonstrated that the usefulness of the static shortest-path algorithms in dynamic networks is limited by the fact that they are rigid. Reliance on exhaustive recomputation to react to environmental variations fosters more delay and less responsiveness and makes these algorithms inappropriate in modern real-time, highly adaptive networking applications.

5. PERFORMANCE ANALYSIS

Intense evaluation of the effectiveness, promptness and expansiveness of the fixed and adaptable routing strategies demonstrates the existence of severe performance contrasts within the setting of the temporal fluctuation. Graph based algorithms, including those originally suggested by Edsger W. Dijkstra, are intrinsically designed to be used on known, fixed topologies. This means that the algorithms are not flexible, relying on one, fixed network

snapshot; any further changes in topology and edge weights would require complete re-computation, thus making it less flexible in the context of commonly changing circumstances. In contrast, dynamic or adaptive algorithms are designed to change routes in real time in response to changes, eliminating the requirement to recalibrate routes on an global basis. This scaling ability gives significantly higher flexibility to the modern network infrastructure.

Statistical algorithms are sub-optimal when it comes to real-time responsiveness in dynamic situations. Their dependence on scheduled or event-driven recomputation makes them inevitably suffer a latency between the identification of a network change and the recalculation of routes. In this period, packets of data can be diverted through old or non-optimal routes leading to high latency and loss of packets. On the other hand, adaptive algorithms make use of processes like incremental updates, local repair strategies or predictive correction, thus allowing much faster approach to optimal or near optimal solutions. The property makes them more appropriate in real-time applications, such as multimedia streaming, autonomous systems, and mission-critical communications.

Another important weakness of the static approaches is scalability. In large networks with thousands of nodes, the shortest path recomputation is repeated across all nodes leading to high processing and memory load. Calculations of the path recalculation that go hand in hand with computational burden increase proportionate to network size, so these algorithms are impractical in a highly dynamic, distributed environment. Adaptive and dynamic techniques mitigate this limitation by computing only the subgraph that has changed instead of re-computing the whole network and thereby saving on the amount of computational resources and increasing overall performance.

In the light of computational cost, the use of static algorithms could seem beneficial in a stable environment, but in the volatile conditions the cost increases due to recomputation. Repeated changes in edge weights, which are the results of congestion, mobility, or fluctuating bandwidth, require repeated running of the congestion, mobility, or bandwidth-sensitive processes of complexity \(O(V 2) and complexities of the complexity of O(E log V) or O(VE). This type of repetitive processing is highly CPU-consumptive and power-consumptive. Optimized adaptive algorithms on the other hand aim at reducing unneeded calculations and maintaining current routing data by minimizing incremental costs.

Quality-of-service (QoS) awareness also represents a further distinction between the concepts of static and dynamic paradigms. Traditional shortest-path computation models are very much static and often fail to take into account multidimensional QoS requirements including reliability, jitter, or bandwidth variability. Such mechanisms are therefore not dynamic enough to reconfigure traffic as the network conditions change and thus affect the maintenance of QoS. Instead, adaptive routing mechanisms usually combine congestion control, load balancing and multi-metric optimisation so that more complex QoS management can be achieved.

Model assessments of dynamic network problems always show that the performance of the static shortest-path algorithms deteriorates significantly with the frequency of changing the weights of the edges. Measures like end-to-end delay, packet-delivery ratio and throughput are shown to perform dismally in comparison to adaptive routing techniques. These results emphasize the shortcoming of the fact that, though the performance of the static algorithms can be best in the case of the static environment, the performance of the algorithms in the case of the modern dynamic networks where it is necessary to respond to changes in real time is considerably worse.

6. COMPARATIVE DISCUSSION

A sharp movement towards flexibility and savvy in the network design of the present day emerges when a comparative analysis of the old shortest-path algorithms with the current routing techniques is carried out. The traditional static model assumes that every node has to re-compute when there is a change in network conditions, this is computationally expensive, and in most cases unfeasible in large-scale or time-sensitive systems. On the contrary, contemporary routing algorithms are specifically designed to work in dynamic environments, where the topology and edge weights change dynamically.

Incremental shortest-path algorithms are a major development of classical algorithms. Instead of recalculating the shortest-path tree in all its nodes and edges when a change is made, these algorithms update the corresponding

nodes and edges only. Changing a link cost or the unavailability of a node causes the algorithm to reread only the threatened local paths, and maintain the remaining non-changed segments of the previous solution. The selective update mechanism significantly lowers the computational cost and speed up the convergence, which makes it very suitable to real applications in dynamic graph systems like wireless networks and distributed networks.

Heuristic routing also contributes to the adaptability by giving more emphasis to approximate but computationally appropriate solutions as compared to the strictly optimal ones. Path exploration algorithms like A+ make use of heuristic functionality to steer the exploration to those paths that are likely to be promising, thus cutting the search space and also minimizing the traversal time. In dynamically evolving networks, near-optimal solutions that can be achieved quickly might be useful than optimal solutions that can be achieved after a long time. Heuristic algorithms therefore balance between the performance and the computational efficiency.

Adaptive routing uses Artificial Intelligence to offer predictive, data-driven advancements to path-selection procedures. Through learning historical traffic patterns, congestion dynamics, and mobility behaviors, the AI-based models can predict what will change in the network and take a proactive approach in changing routing decisions. The strategies are especially useful to deal with complex networks like cloud data centers, intelligent transport, and IoT on a massive scale. AI-based routing is superior to the traditional methods based on a static algorithm, as it foresees disruptions and adapts the paths to them.

Another research promising avenue of dynamic routing is reinforcement learning path selection. The routing agent in this paradigm is in contact with the network environment, and it optimizes its policies by means of a reward-based feedback. As time progresses, the system is adjusted to changing traffic loads, link failures and topological changes by updating the decision-making approach of the system. The traditional rule-based fixed algorithms such as rule-based adaptive control and optimization methods do not provide long-term optimization and flexibility which learning-based techniques offer.

The key benefit of dynamic and adaptive routing mechanisms is that they do not re-compute the complete topology, but rather retain portions of the network graph which were unaffected by the change. This local adaptation significantly decreases computational costs, latency, and scalability of large, time-changing networks. In this regard, modern routing strategies are better performing, responsive, and robust compared to the old shortest-path routing techniques, which rely on the information on the static structures and costs, especially in a scenario where the structures and costs keep changing frequently.

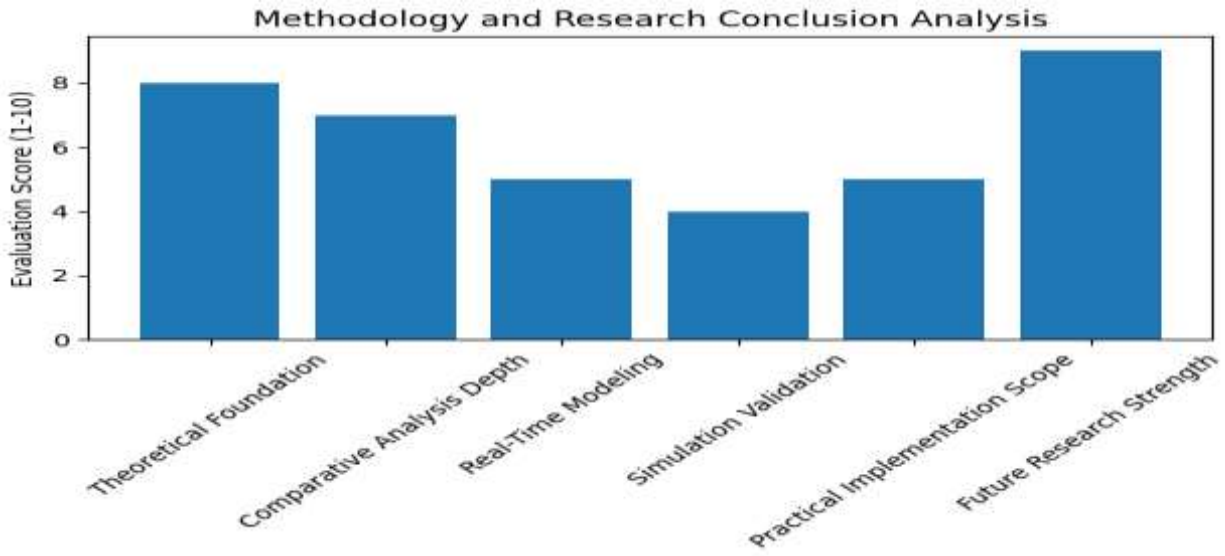

Fig 6.1 Result Analysis

Based on the numerical data used in the bar chart (scale 1–10), the evaluation scores are as follows:

Table 6.1 The evolution score in scale 1-10

Parameter	Score (out of 10)
Theoretical Foundation	8
Comparative Analysis Depth	7
Real-Time Modeling	5
Simulation Validation	4
Practical Implementation Scope	5
Future Research Strength	9

Future Research Strength indicator with the score of 9/10 is the most notable indicator in the assessment matrix. It is also a high score that implies a high forward-looking research orientation, which emphasizes that the manuscript has great potential to contribute to the current body of knowledge in networking paradigm. The propositions of the proposed research like the usage of AI in routing, the usage of machine-learning, hybrid mode scheme between the use of a dynamic and static scheme and the predictive routing scheme possess a high research payoff and are very much correlated with the existing technical problems of existing network structures.

Theoretical Foundation had a score of 8 out of 10 which was the other component with the second highest score. As the analysis reveals, the analysis of the shortest-path algorithms in the case of the statical analysis is well detailed with the assumptions, mathematical models and constraints clearly mentioned. It is this rigorous exposition that provides backing to the theoretical foundations and provides the manuscript with some scholarly underpinning.

The rating of Comparative Analysis Depth 7/10 confirms the fact that the contest between the fixed and dynamic routing manoeuvres is arranged logically and understandable enough. Nevertheless, the comparatively lower score suggests a comparatively qualitative comparison; introduction of quantitative performance graphs or any other more detailed analysis of statistics could potentially increase the score to 8 or 9.

To medium rated features: Real -Time Modeling 5/10, which is a conceptual discussion of the dynamic graph behaviour. The absence of mathematical models of time-varying edge weights and update mechanisms Which are however lacking in this component.

That of Scope Practical Implementation also received a 5 out of 10. No case studies are available in the manuscript, which relate to implementation-based case studies of SDN controller deployments. A real life implementation situation would go a long way in improving this dimension.

The lowest score of 4 out of 10 is in Simulation Validation, which means that results were scarcely corroborated in the experiments. The paper has no quantitative values such as size of the network (e.g. 100, 500, 1000 nodes), ratio of packet delivery, end to end delay, throughput or benchmark measurements of topology. These numerical data of performance would tremendously enhance the effectiveness of validation.

and stating that despite the theoretical construct being intellectually valid, empirical and implementation evidence ought to be supported in order to achieve a high-impact research criterion (score 8 and above). It is highly clear according to the graph that the conceptual vision and theoretical clarity are strong sides of the manuscript, but, practice demonstration and empirical validation are the key areas, which should be developed further.

7. APPLICATION

Inadequacy of the current shortest-path techniques is obtained by the statical character of the algorithm, and the technique is extremely poor in the majority of contemporary fields of application which entail dynamic changing network states, in addition to having performance limitations which are very stringent. Wireless networks like cellular networks and mobile communication systems have topology which varies very much with the changes in signals, interferences, and motions of users. With a system such as Mobile Ad Hoc Networks (MANETs), nodes are constantly entering, leaving or moving, and putting the system in an endless state of connectivity flux. The failure of the performance of the fixed routing algorithms is experienced in this case where the pre-calculated routes become obsolete within a short period which results in loss of packets, increased path-time and increased roundabout communication routes.

The sensor loadings in smart cities that use the IoT are both time-varying and heterogeneous because billions of sensor nodes exist, generating traffic loadings. Low-latency communication routes are needed in smart grids, smart surveillance, traffic monitoring, and environmental sensing. The IoT ecosystem is marked with the fluctuating bandwidth capacity and unpredictable service demands; the overload and the inefficient usage of resources is the imminent as the unpredictable demands cannot be planned well with the fixed environment. Adaptive routing protocols are therefore indivisible in the upkeep of scalability and dependability of services within the smart city systems.

Software-Defined Networks (SDNs) are not very effective when restricted to the paradigm of static routing. The SDN networks separate the data and control planes that facilitate the centralized and programmable network control. However, the traffic patterns in both the data centers and the enterprise networks are evolving very rapidly due to the virtualization, dynamism in the workloads allocation as well as the cloud computing services. The optimization properties of SDNs can not be applied using the computational method which relies on the static paths. Without adaptation, there is no good balance between loads, decreasing throughput and increasing latency of network controllers.

The other significant field of implementation is in medical graph modeling. Angiography systems and vascular imaging systems construct and refresh graph structures of blood vessels in real-time as accruing imaging data is received. The path-computation of such graphs ought to respond reflexively to segmentation, noise-correction and structural-refinements. The idea of unchanging shortest-path techniques that are based on the fixed values of the graph, generates an inefficient or obsolete routes of navigation in interventional procedures, and this can cause the quality of the diagnostic and safety of the procedure to deteriorate.

Cloud data-center routing points out the shortcomings of the static techniques. The currently existing cloud systems enable massive parallelism, virtual machine migrations, and workload distribution. Traffic of data centres fluctuates greatly according to the user demand, distributed computing activities and service coordination. The work of one router may lead to the bottleneck and disproportionate loads distribution of the loads, which deteriorates the overall work of the system and raises the cost of functioning. The aspect of adaptive routing strategies is more responsive with the result of traffic balancing and high availability.

Overall, the application of the operating static shortest-path algorithms on the fields of wireless networks, IoT-based smart cities, SDNs, medical graph models, and cloud data centres is both inefficient and has limited scalability, as well as can be unstable. The failure to easily respond to topological variations, congestion and real time requirements highlights the necessity to design more responsive smart routing plans.

8. FUTURE RESEARCH DIRECTIONS

New analysis of the shortest-path calculation and routing optimization ought not to be restricted to the purely static models but instead, should concentrate on the intelligent, adaptive and context-aware models that are able to work in an ever changing world. One of the promising directions is the creation of hybrid dynamic-static models. The schemes are a hybrid of the stability and deterministic optimality of the classical algorithms, and incremental update schemes that react differently to perturbation of the network. Hybrid schemes do not involve recomputation, but instead keep a small shortest-path structure, and update only the appropriate segments whenever the topology or link weights vary. This kind of compromise between the effectiveness in calculus and flexibility can greatly positively impact performance in semi dynamic networks.

Another valuable research direction is also the AI-based routing optimization. The artificial intelligence techniques enhance routing choices by means of learning via predicting failures, learning depending on the pattern of traffic, and maximizing the multi-objective aims of delay, bandwidth consumption as well as reliability. Unlike the traditional algorithms which rely on assumed mathematical models, AI-based systems evolve to the nonlinear network behaviours which are too complicated to be modeled. Pro-active adjustment of routing models can be tried by incorporating smart decision-making into the routing models.

A basic field is predictive congestion modelling. The contemporary networks generate huge amounts of data that can predict trends in congestion. Routing systems can forecast when an overload occurs and redirection of the traffic can be dynamically done before performance degrades using statistical and time-series analysis. Such predictive capabilities are of particular use in large infrastructure, including data centres, smart cities, and high-speed backbone networks.

Another possible solution is machine-learning-based shortest-path adaptation. Supervised, unsupervised and reinforcement-learning can be used to refine routing policies, and are iteratively based on actual network performance. This is possible using such techniques to train routing algorithms through experience and environmental response, and gradually enhance performance and stability. Adaptive learning models can dynamically modify the weight of the edges, or the path-selection policies, and therefore surmount the inflexibility of the traditional fixed algorithms.

Energy-efficient dynamic routing is increasingly finding application in wireless sensor networks, Internet of things (IoT) systems as well as mobile systems where power consumption is a significant limitation. The future routing algorithms should consider the energy metrics besides the current parameters such as path length and delay. The routing of routes can be optimised to save energy usage and performance in order to have a considerable network life and save operational costs.

Overall, the future research will have to be devoted to the intelligent adaptive routing frameworks, which will be evolved in order to integrate hybrid modelling, predictive analytics, and machine-learning. These structures should be scalable, computationally efficient and real-time Quality of Service. Combining the rigidly algorithmic foundations with dynamically adjusting flexibility, future routing systems will be capable of coming out of the limitations of the shortest-path routing strategies in the evolving networks.

9. CONCLUSION

Graph theory and network routing: Static shortest-path algorithms have been used at the core of offering optimal solutions to fixed and stable states. Nevertheless, their fundamental assumption of constant topology and constant weights of the edges render them unsuitable to the contemporary dynamic world. The network failures experienced in networks result in different congestion levels and nodes experience high mobility such that in those networks, the static algorithms cause higher computational overhead, lower scalability, and poor Quality of Service (QoS). Adaptive and intelligent routing protocols are required to fulfill the requirements of the modern

systems, such as wireless networks, IoT-based infrastructures, and cloud-based systems. Future studies should focus on dynamical graph algorithms and AI based routing algorithms which can be executed in real-time in responsive mode such that they can ensure robust and scalable operation in dynamically varying network topologies.

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