IoT Routing: Types, Challenges, and Recent Intelligent Methods

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Abstract. This study explores the diverse challenges and issues associated with Internet of Things (IoT) routing, underscoring the importance of efficient protocols in terms of data and performance. The utilization of artificial intelligence emerges as an important strategy to overcome these challenges. The paper under examination emphasizes significant challenges in IoT routing that necessitate innovative solutions.

Keywords: IoT · routing · intelligent computing methods · artificial intelligence

1 Introduction

The Internet of Things (IoT) is a technological paradigm where both physical and virtual devices are interconnected, creating a vast network that is expanding at an exponential rate. With the number of IoT networks increasing, the complexity of those networks also grows, aggravating the need for "intelligent" devices that can communicate efficiently without any human intervention. A key point to achieving this efficiency is the development and implementation of advanced routing algorithms. These algorithms are designed with the intent to identify the fastest and most efficient paths for communication between a source and a destination, significantly influencing the network's overall performance.

The quality of service (QoS) and performance of IoT networks are critical, with routing decisions often based on criteria such as maximizing network lifetime, package delivery rate, minimizing losses, delays, and link failures, and optimizing reliability. These are some factors essential for choosing the best path through the network, ensuring that data is transmitted efficiently and effectively. However, the quality and performance of the networks are negatively affected by the nature of the IoT devices themselves, which vary a lot in terms of capability and connectivity. As such, the design and optimization of IoT networks require a careful balance between leveraging the potential of these devices and addressing their limitations. While, at the same time, aiming to create a seamless and robust system capable of supporting the vast and growing ecosystem of interconnected devices.

2 Related Works

All the solutions listed in the survey aim to overcome a specific set of challenges, using different methods, all of which are powered by AI algorithms. There is barely any overlap in what these methods try to accomplish, each focusing on different performance measures:

Supports	Fully	Partially	Doesn't
Dynamic Topology	ROSA(IIoT), ACO, BFOA, WL-DCNN	IOP	-
Low-Energy Consumption	ROSA(IIoT), IOP, BFOA, WL-DCNN, CPN	-	Salp-PSO
Minimal Transmission Delay	ROSA(IIoT), QI-RM, IOP, WL-DCNN, FRA-IWDRA	-	-
Bandwidth	ROSA(IIoT), QI-RM, IKTRP	-	IOP
High Throughput	ROSA(IIoT), IOP, IKTRP, FRA-IWDRA	Salp-PSO	-
Minimal Packet Loss	ROSA(IIoT), QI-RM, BFOA, IOP, FRA-IWDRA	-	-
High Package Delivery Rate	ROSA(IIoT), BFOA, IKTRP, FRA-IWDRA	-	-
Load Balancing	ROSA(IIoT), QI-RM	-	-
Multi-Path	BFOA, CPN, FRA-IWDRA, Salp-PSO	-	-
Failure Management	WL-DCNN	-	-
Data Security	WL-DCNN, CPN, SerIoT, Salp-PSO	-	IKTRP, FRA-IWDRA
Multi-Hop Routing	ACO, BFOA	-	-
Heterogeneity	-	-	-
Scalability	-	-	-
Local Path Repair	WL-DCNN	-	-
Context Sensitivity	ACO	-	-
Content Relevance	-	-	-

It is noteworthy that all of the solutions were tested in a simulated environment, which is by no means enough to verify the methods' effectiveness in a real network. Therefore, more robust testing in a real-world environment is required.

3 Types of Routing Protocols

The tables below illustrate the different possible classifications for the listed methods.

Table 1. Types of routing protocols (I)

According to	Type	Description	Critical
network topology	flat	The objects are equivalent: same roles and same functionalities. Any object can communicate with any other object.	Among its advantages, simplicity since communications can be established without additional cost (only information from direct neighbors is necessary). In addition, links are formed on the fly without synchronization: routes are formed only in regions where there is data to be transmitted. If there is a central point (base station), all the traffic arriving to it will necessarily pass through the objects which are close to it. For this, the density of communications can cause overloading of the central point and nearby objects. Excessive power consumption and increased latency can be results for this overload.
	hierarchical	The transmissions are carried out on at least two levels. The system is based on clustering. Data from custer objects are aggregated by the cluster-head before sending them to the final destination.	The benefits of the constitution of clusters and selection of cluster-heads: optimize energy consumption objects, improve the overall lifetime of the system and the scalability. The disadvantages: a local and global synchronization to form the links is necessary, the overload caused by the formation of the clusters, the process of electing the cluster-heads consumes more resource when the size of the network increases.
	geographical	Routing is based on geographic location information. They are used to calculate the distance between objects and evaluate/estimate the amount of energy required to transmit the data.	It represents several advantages over other types: the memory cost is relatively low, the control cost is reduced, the scalability, the locality, the addressing is simple, the routing is optimized, the join to the network is simple. On the other hand, it is necessary to have a localization mechanism. This routing type increases the cost of treatment. In addition, there is a risk of getting stuck nodes and negative progress.
	direct	All objects are within a single hop distance of the base station. Data transmission takes place directly from the object to the base station.	A rare architecture used in some specific applications.

Table 2. Types of routing protocols (II)

According to	Type	Description	Critical
route formed from source to destination	proactive	The routes are pre-calculated	The routes are established from the beginning and ready to use. The main advantage is the saving of time when requesting a route since it is already established and there is no reaction time. It is suitable for dense networks, medium sizes and high mobility. On the other hand, an additional memory cost is necessary since there is a need to memorize the routes. In addition, there is a risk of establishing and calculating useless routes if there are no requests for transmissions. Therefore, updating the routing tables and necessary control messages can contribute to the waste of network resources since there are established and unused routes. This makes it possible to have a limited network exchange capacity and significant energy consumption.
	reactive	Routes are only established on demand. After routing the data to the destination, the used routes are deleted.	Unlike proactive protocols, there are no established and unused routes. Therefore, no control message loads the network without utility, which makes it possible not to waste network resources. It is suitable for large networks. On the other hand, a density of requests for routes for simultaneous transmissions can cause significant delays before the establishment of the route. This allows to exceed the expected delays and may cause the inability to connect. This type of routing is not suitable for high mobility networks.
	hybrid	A combination of reactive and proactive routing.	The hybrid protocol combines the advantages of two types of routing: proactive and reactive. It is based on the notion of cutting the network. Indeed, proactive routing is used for the close neighborhood. Reactive routing is used for other zones. The hybrid protocol offers reduced energy consumption. On the other hand, it combines the disadvantages of both types of routing: proactive and reactive. This type of routing is suitable for large networks.

Table 3. Types of routing protocols (III)

According to	Type	Description	Critical
the operation of the protocol	based on negotiation	The transmission of data is preceded by an exchange of negotiation messages containing data descriptors. This is to avoid the transmission of duplicate information.	This type of routing has the advantage to prevent sending redundant data. However, it can cause network congestion and waste of resources by exchanging negotiation messages.
	multi-path	Several paths are established to the destinations. Then, if the main route fails, an alternative route can be found and used	The advantages of this type are: improving the robustness and performance of the network, helping to ensure load balancing. On the other hand, an additional memory cost is necessary to memorize the established paths. In addition, updating routing tables and establishing multiple paths can waste network resources.
	based on service quality	It makes it possible to try to meet some quality of service requirements (transmission delays, throughput, packet delivery rate, level of reliability, etc.).	This type of routing must find a compromise between the satisfaction of the quality of services and the energy consumption. It is used in applications which have special requirements (monitoring applications, Multimedia networks, time-sensitive applications, security-sensitive applications, intrusion detection, etc.). The transmissions reliability is ensured by the quality of the communications.
	non-coherent	Before sending the data, the objects process them locally. Then the data is transmitted to other objects (aggregators) where further processing is performed	The load of aggregator objects is reduced. On the other hand, it increases energy consumption.
	coherent	A minimum of data processing is carried out locally by the objects before sending them (for example: deletion of duplicates, time registration, addition of the date). Then the processed data is sent to other objects which do more processing (aggregators).	This type of routing is efficient for energy consumption. On the other hand, there is the risk of reducing the lifetime of aggregator objects by increasing their load.
	data-oriented	This type of routing is query-based. Indeed, when an object needs the data, it queries the other objects by broadcasting requests expressing its interests in the network. Then it waits for answers. Objects that hold the required data must respond by sending them through the reverse path of the request.	Multiple copies of the requested information may be generated by broadcasting the request to the neighborhood. It is necessary to implement mechanisms to overcome the excessive energy consumption. In addition, the queries must describe the information queried. In other words, it is necessary to define a system of naming and attributes to characterize them.

4 Conclusions

In conclusion, this study has achieved its first objective by thoroughly examining recent works that employ intelligent computing methods and artificial intelligence (AI) to enhance IoT routing performance. The summary and comparison of these works reveal a notable reliance on intelligent techniques; however, they often target a limited range of parameters.

Moving forward, the second objective has been addressed by presenting various types of IoT routing, categorized by specific criteria. This not only provides a comprehensive overview but also serves as inspiration for future research endeavors. By highlighting major challenges identified in the preceding sections, this study aims to encourage the development of more efficient IoT routing solutions.

Additionally, this research recognizes the dual focus on solving both the IoT routing and deployment problems. It positions this dual emphasis as a crucial direction for ongoing research efforts. In essence, this study serves as a critical analysis of the current state of AI applications in IoT routing and, simultaneously, as a catalyst for future advancements. The outlined key areas for improvement and research provide a roadmap for researchers and practitioners working towards enhancing the effectiveness of IoT routing solutions.

Our analysis revealed that the underlying work was incomplete and left its conclusions unaddressed, although providing insightful observations. Recognizing the importance of these gaps, we began a thorough investigation. To guarantee the accuracy of our study, we carefully reviewed the primary sources mentioned in the chosen work while we conducted our research. As a result, our conclusions build upon and go beyond the findings of the foundational study. Our results highlight how crucial it is to interact directly with primary sources in order to improve knowledge and critically reevaluate accepted theories.

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