

REVIEW ON ENERGY AND CACHE OPTIMIZATION IN DELAY TOLERANT NETWORKS

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ABSTRACT

Delay-Tolerant Network (DTN) is an architecture for networks that can operate in environments where traditional networking protocols do not work well because of high latency, intermittent connectivity, or communications delay that lasts a long time, for example, space exploration, disaster relief, and remote locations. Delay-tolerant networking uses an automated store-and-forward capability to provide data delivery reliability, something that ordinary terrestrial networks usually do not have. Energy optimization in Delay-Tolerant Networks makes devices more durable, save energy, and function reliably even under challenging conditions. Energy consumption is still an issue, particularly in situations where there are limited resources. To address this issue, this work integrates the Epidemic and PROPHET routing protocols to make the energy consumption of DTNs optimal. ONE Simulator may be employed for energy optimization of Delay-Tolerant Networks (DTNs) through the simulation of different factors that affect the energy consumption of nodes and analyzing several strategies to conserve energy without the degenerating network performance.

Keywords: Delay-Tolerant Network (DTN), ONE Simulator, Resource allocation, Performance measure.

1. INTRODUCTION

The modern world relies heavily on stable and continuous network connectivity to facilitate effortless communication between varied domains. But conventional networking models tend to fail in environments with high latency, delayed connectivity, or delayed delays. These harsh environments are especially prevalent in remote and infrastructure-scarce locations, like in space exploration, remote rural areas, military combat zones, and after-disaster scenarios. In these situations, Delay-Tolerant Networks (DTNs) have proven to be a key answer to providing end-to-end communication when traditional network protocols are unable to function optimally.

DTNs are particularly tailored to overcome the shortcomings of real-time, reliable communications channels by adopting an innovative store-and-forward transmission model. Unlike the constant, low-latency connections that traditional IP-based networks require, DTNs permit nodes to buffer data temporarily until an appropriate forwarding opportunity arises. This working model makes it possible to transfer information along network paths that are not contemporaneously connected. Through the addition of custody transfer and opportunistic routing, DTNs provide reliable and robust communication even in highly fragmented and delay-constrained environments.

The effectiveness of DTNs is based on their architecture, which allows nodes to work autonomously and intelligently. Each DTN node is able to accept, cache, and relay messages based on the local knowledge it has and temporal dynamics of the network. This approach is incredibly useful in scenarios where end-to-end paths never exist or become scarce for extensive durations. Applications of DTNs extend across several domains, including interplanetary communications enabled by NASA's space missions, relief coordination in disaster-hit regions, wildlife monitoring in remote areas, and vehicular communication in sparse or mobile environments.

With all the benefits, DTNs are beset with a number of serious challenges, especially in terms of energy efficiency. Nodes in a DTN typically depend on battery-operated devices, which require prudent management of energy usage to extend operational lifetime and make the network sustainable. Excessive use of energy can cause premature failure of critical nodes, leading to lower delivery success rates and possibly fragmented communication. Energy optimization has thus become an essential consideration in DTN protocol design and implementation.

Routing protocols are key to handling both data delivery and energy usage in DTNs. PROPHET strategy optimizes the chances of message delivery through the provision of redundancy so that copies follow varying paths within the network. While such redundancy would incur a lot of energy and buffer resource use, this can prove unsustainable on resource-limited devices.

In contrast, PROPHET proposes a more wise and resource-conscious forwarding mechanism. By keeping track of probabilistic estimates of encounter histories and transitive connections among nodes, PROPHET forwards data to nodes with an increased probability of delivery. This approach minimizes redundant transmissions and saves energy but can achieve lower delivery ratios than Epidemic routing, especially in extremely dynamic or sparse networks.

In order to balance delivery reliability and energy efficiency, newer works have studied hybrid solutions that leverage the merits of both Epidemic and PROPHET protocols. These hybrid schemes look to balance delivery performance and energy usage by adapting forwarding decisions in a dynamic manner as a function of contextual factors like node density, buffer space, and residual energy. Intelligent decision-making using these protocols ensures that high delivery performance is maintained without excessive energy usage.

This paper is concerned with the design and evaluation of an energy-efficient routing protocol that integrates the delivery robustness of Epidemic routing and the energy-conscious operation of PROPHET. The given method is compared and evaluated using the Opportunistic Network Environment (ONE) Simulator a well-established simulation environment for modeling and analyzing DTN behavior. Through simulation of different network conditions and energy settings, this work seeks to achieve insights into the energy-efficiency, energy consumption, and delivery ratio trade-offs.

Ultimately, the objective is to work towards the development of DTNs that are dependable and sustainable, and can effectively operate in hostile environments without jeopardizing node longevity. Through structured simulation and analysis, this research aims to create a framework for attaining dependable communication in delay-tolerant environments, under the limitations presented by limited energy supplies.

Table 1: Comparison Table

S.No	Title	Year	Objectives	Limitations	Advantages	Performance metrics	Gaps
[1]	HP- ECD: Heuristic Prophet protocol based on energy balance, cache optimization, and asynchronous dormancy	2024	Energy balance mechanism, Cache optimization mechanism, Asynchronous dormancy mechanism	Requires accurate node history, Limited to opportunistic networks.	Reduces routing overhead rate, Enhances average remaining energy, Optimizes cache space usage.	Increases the delivery rate, reduces the overhead rate, higher residual energy levels after simulations.	Integrate machine learning techniques, Improve energy harvesting methods.
[2]	Delay/Disruption-Tolerant Networking-based the Integrated Deep-Space Relay Network: State-of-the-Art	2024	Analyze deep-space communication systems, Explore routing strategies.	High resource consumption, Complexity in routing strategies, Complexity in routing strategies.	Overcomes TCP/IP limitations, Flexible for unstable connectivity, Supports complex routing strategies.	Maximum delivery ratio, Reduced delays, Minimized overhead.	Lack of empirical data, Limited real-world applications.
[3]	Cognitive Routing Strategy in Space DTN	2024	Optimize bundle routing, enhance energy efficiency, Minimize bundle loss rates	Dependency on battery models, Limited to specific network topologies, Complexity in implementation	Improved network lifetime, Reduced bundle loss rates, Low power consumption	Bundle loss rates, Network lifetime improvements, Average response time.	Explore alternative battery models, Test in diverse environment, Enhance algorithm efficiency
[4]	Development of Delay-Tolerant Networking Protocols for	2024	Evaluate DTN protocols, Assess	Dependent on pre-scheduled contacts, Inefficient	Resilient under delays, Effective in sporadic	Increased message delivery rate, Reduced	Need for dynamic modeling, Scalability

	Reliable Data Transmission in Space Networks		performance metrics	with unexpected disruptions, High memory demand	connectivity, Enhanced interplanetary communication	routing overhead rate, Lowered storage time, Enhanced energy efficiency.	in large deployments, Integration with new technologies
[5]	Impact of Renewable Energy Resources on the Performance of DTN Networks in the Context of Hierarchical Routing Tree Topology (HRTT)	2024	Evaluate energy resource impacts, improve energy efficiency in DTNs, Integrate renewable energy sources.	Single renewable energy source, High energy consumption during connections.	Extended operational lifespan, Improved energy efficiency.	Increased Energy Efficiency, Enhanced Network Sustainability , Lower Energy Consumption	Lack of multi-source evaluation, Insufficient real-world application data,
[6]	Learning for Multiple-Relay Selection in a Vehicular Delay Tolerant Network	2023	Improve message delivery, optimize node buffer management, Address selfish node behavior.	Not lowest latency, Buffer optimization may become obsolete, Performance affected by selfish nodes	High delivery probability, Low message latency, Reduced network overhead	Increased Delivery Probability, Reduced Overhead Ratio, Buffer Optimization, Decreased Performance with High Speed.	Enhance buffer management techniques, Explore adaptive routing strategies.
[7]	Energy Balance and Cache Optimization Routing Algorithm Based on Communication Willingness	2023	Mitigate the uneven energy consumption among nodes	Some algorithms using flooding mechanisms, can lead to high overhead rates due to the excessive number of messages are forwarded.	EC-CW optimizes energy consumption by avoiding the excessive calculation of key nodes.	EC-CW reduces the average latency	Investigating the integration of EC-CW with existing routing protocols could yield hybrid solutions.
[8]	An adaptive multiple spray and-wait routing algorithm based on social circles in delay tolerant networks	2023	To improve the performance of message delivery in DTNs by reducing unnecessary message copies	Limited network resources, such as energy, cache, and bandwidth.	Improved Delivery Rates	Delivery rate improved	Integration with Other Network Models .

[9]	Multi-hop routing under short contact in delay tolerant networks	2022	The protocol breaks large messages into smaller chunks, enabling more efficient data forwarding	protocol's performance may be affected by the storage capacity of the nodes.	Enhanced Delivery Rate	Probability of Delivery rate is increased.	Integration with Other Protocols
[10]	Context aware self adaptive routing for delay tolerant network in disaster scenarios	2022	Optimizing DTN performance in disaster scenarios by selecting the most suitable routing protocol.	The protocol may not perform as effectively in sparse environments where node encounters are infrequent.	Maximized Delivery Rate.	Minimized Energy Costs	Performance Analysis Without PreDisaster Calibration.
[11]	Delay aware energy efficient opportunistic node selection in restricted routing	2022	To propose a novel protocol, DA EEORR, that balances energy efficiency and end-to end delay in sensor networks	The reliance on specific design parameters like buffer capacity and link quality	DA-EEORR outperforms existing hierarchical mobile sink routing schemes in terms of energy consumption and network lifetime	Lower energy consumption, reduced control packet overhead, improved packet delivery ratio.	The issue of higher end-to end delay when traversing multiple rendezvous nodes in large scale wireless sensor networks remains unaddressed.
[12]	Performance Evaluation of the Probabilistic Optimal Routing in Delay Tolerant Networks	2021	explores how sending data through multiple channels or paths can improve communication, when connections are not always available.	Assumes that future connection opportunities can be predicted, which is not realistic in unpredictable situations.	An approach to routing that improves data transmission in networks with unreliable connections, making communication more reliable.	Reduction of Transmission Delays, Reduced Disruption Impact, Energy Consumption	Looks at a basic two-link setup, which doesn't show the full complexity of real-world networks.
[13]	Medium Term Disruption Tolerant SDN for Wireless TCP/IP Networks.	2021	MDT-SDN aims to buffer packets during link disruptions.	Medium-term disruptions may still incur high end-to-end delays. Limited buffer space at intermediate	MDT-SDN improves throughput over existing SDN models. EAPMST enhances throughput in	Improves throughput, Reduction in Buffering Time	Limited focus on SDN controlled buffering in existing literature.

					group and random mobility cases.		
[14]	Adaptive DTN Routing: A Neuromorphic Networking Perspective	2020	The objective is to define adaptive routing for DTNs. It aims to utilize neuromorphic computing for routing decisions.	Rewards in reinforcement learning are often delayed. Delayed rewards can lead to suboptimal routing decisions.	The method improves bundle delivery performance under congestion. It reduces response times compared to Contact Graph Routing. .	Minimize power usage, Minimize fluctuations in response time	The initial routing decisions may be suboptimal. Rewards are delayed, complicating routing decisions.
[15]	Vehicular Delay Tolerant Network Routing Algorithm Based on Bayesian Network.	2020	The objective is to improve VDTN routing efficiency. It aims to predict node movement patterns accurately.	Traditional routing algorithms do not consider vehicle movement patterns well	The proposed algorithm improves delivery ratio significantly. It reduces overhead compared to traditional algorithms.	Reduce overhead, maximize throughput, Reduce power consumption.	The paper does not explicitly mention any gaps. Further research may explore additional attributes for prediction.

2. CONCLUSION

They are crucial in ensuring data can still be transmitted during natural disasters, in remote and rural regions, and even in space. One of the primary objectives in enhancing DTN performance is improved resource utilization, particularly minimizing energy consumption and storage (cache) utilization. Because DTN devices usually have limited battery life and memory, efficient utilization of these resources is critical to making the devices last longer and maintaining the network in good working condition.

To achieve this, important configurations such as scan energy, initialization energy, rate of delivery, buffer capacity, and simulation duration have been fine-tuned towards reduced energy consumption and storage requirement. Machine learning usage also facilitates by selecting the above settings better, depending on the prevailing network conditions. It is this intelligent, adaptive design that results in improved network functionality and enables DTNs to become more efficient, reliable, and functional even during resource scarcity.

3. REFERENCES

- [1] Elewaily, D. I., Ali, H. A., Saleh, A. I., & Abdelsalam, M. M. (2024). Delay/disruption tolerant networking-based the integrated deep-space relay network: State-of-the-art. *Ad Hoc Networks*, 152, 103307.
- [2] Chen, G., Duan, W., Sun, J., Zeng, Q., & Zhang, Y. D. (2024). Social-Aware Assisted Edge Collaborative Caching Based on Deep Reinforcement Learning Joint with Digital Twin Network in Internet of Vehicles. *IEEE Transactions on Intelligent Transportation Systems*.
- [3] Lent, R. (2024). Experimental Evaluation of a Cognitive Routing Strategy for Efficient Energy Management in DTN. *IEEE Journal of Radio Frequency Identification*.
- [4] Al Mamun, M. A., Li, M., & Pramanik, B. K. (2024). Development of Delay-Tolerant Networking Protocols for Reliable Data Transmission in Space Networks: A Simulation Based Approach. *IEEE Access*.

- [5] EL MASTAPHA, S. A. M. M. O. U. (2024). Impact of Renewable Energy Resources on the Performance of DTN Networks in the Context of Hierarchical Routing Tree Topology (HRTT). *Procedia Computer Science*, 236, 185-193.
- [6] Dong, Y., Zhang, F., Joe, I., Lin, H., Jiao, W., & Zhang, Y. (2023). Learning for multiple-relay selection in a vehicular delay tolerant network. *IEEE Access*, 8, 175602-175611.
- [7] Chen, J., Xu, G., Wu, X., Wei, F., & He, L. (2023, March). Energy balance and cache optimization routing algorithm based on communication willingness. In *2021 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 1-6). IEEE.
- [8] Wu, L., Cao, S., Chen, Y., Cui, J., & Chang, Y. (2023). An adaptive multiple spray-and wait routing algorithm based on social circles in delay tolerant networks. *Computer Networks*, 189, 107901.
- [9] Le, T. (2022). Multi-hop routing under short contact in delay tolerant networks. *Computer Communications*, 165, 1-8.
- [10] Rosas, E., Garay, F., & Hidalgo, N. (2022). Context-aware self-adaptive routing for delay tolerant network in disaster scenarios. *Ad Hoc Networks*, 102, 102095.
- [11] Anees, J., Zhang, H. C., Lougou, B. G., Baig, S., & Dessie, Y. G. (2020). Delay aware energy-efficient opportunistic node selection in restricted routing. *Computer Networks*, 181, 107536.
- [12] Babu, S., Rajeev, A., & Manoj, B. S. (2021). A medium-term disruption tolerant SDN for wireless TCP/IP networks. *IEEE Transactions on Network and Service Management*, 17(4), 2318-2334.
- [13] Wu, J., Guo, Y., Zhou, H., Shen, L., & Liu, L. (2021). Vehicular delay tolerant network routing algorithm based on bayesian network. *IEEE Access*, 8, 18727-18740.
- [14] Lent, R. (2020). Adaptive DTN routing: A neuromorphic networking perspective. *IEEE Transactions on Cognitive Communications and Networking*, 7(3), 871-880.
- [15] Lent, R. (2020, June). Performance evaluation of the probabilistic optimal routing in delay tolerant networks. In *ICC 2020-2020 IEEE International Conference on Communications (ICC)* (pp. 1-6). IEEE.