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Mobility Context Aware Routing Protocol in DTN

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Les réseaux tolérants aux délais (DTN) sont conçus pour fonctionner efficacement dans des situations où les réseaux traditionnels échouent en raison d'une connectivité limitée, de délais prolongés et de perturbations récurrentes. Ils se distinguent par leur capacité à stocker et retransmettre les données, à s'adapter aux conditions changeantes du réseau et à maintenir la communication même en cas de perturbations. Dans cet article, nous proposons « Baton-relay », un protocole de routage contextuel et conscient du type de mobilité dans un réseau DTN. Ce protocole repose sur des dispositifs de communication et de stockage à faible coût intégrant différentes technologies, créant ainsi un système global de partage de données respectueux de la vie privée, basé sur la mobilité naturelle des foules. Nous avons testé et validé cette approche à l'aide du simulateur ONE. L'idée de Baton-relay est simple : elle ne repose pas sur des calculs mathématiques complexes, ne nécessite pas de mémoire importante mais reste robuste, garantissant une probabilité de livraison raisonnable tout en préservant la confidentialité. Les résultats montrent que Baton-relay offre une amélioration significative du temps moyen d'utilisation mémoire, du nombre de sauts et du nombre de copies de message nécessaire par rapport à d'autres protocoles de routage DTN.

Mots-clefs : Routing protocols, DTN, wireless network, machine learning, mobility models

1 Introduction

Today, data sharing is fundamental to business, education, social media, and research, necessitating robust network infrastructures. However, challenges persist especially in remote or isolated regions, being prone to failures from power outages, traffic overload, disasters, or cyber-attacks. Here, delay tolerant networks (DTNs) have evolved to address communication barriers in various challenging scenarios, offering innovative solutions to complement traditional infrastructures and deliver data to isolated areas. From the early days of flooding-based routing like Epidemic routing [VB⁺00] and probabilistic methods like PROPHET protocol [LDS03] to more sophisticated techniques that employ social dynamics and probabilistic models, each development has played a role in making DTNs a feasible solution for communication in challenging and sporadically connected environments. Very promising are those approaches that exploit information on the context users are surrounded by, like the other users they met, the places they visit. However, these solutions still assume that people are equipped with laptops and energy supply and data transit has to occur through an external operator, which is a source of potential personal data leaks. Such approaches also require large operational record and memory storage. In summary, the difficulties encountered in a DTN highlight the need for advanced techniques to ensure efficient and secure data management and transmission.

In this paper, we propose *Baton-relay*, a privacy-friendly and mobility-aware routing protocol for a distributed, low-cost, large-scale delay-tolerant network. Unlike approaches relying on full Internet connectivity via expensive personal devices, our solution leverages multi-technology and node mobility for data delivery. The design of such a protocol is simple, yet robust, since the forwarding decision is based on real-time without extensive computations or huge storage history to determine a forwarding probability. It is based on the knowledge of mobility patterns in a privacy-preserving approach. The focus in this work is not on the data itself, thus we assume that an aspect such as data security is dealt with separately. The protocol is evaluated using ONE simulator. Compared to other known routing protocols recorded in literature, our protocol achieves significant improvements in average buffer time, number of hops and copies overhead.

2 Baton-relay Routing protocol

Mobility models are crucial for the performance of routing protocols in DTNs and ad hoc networks, where node movement impacts network dynamics. These models simulate node movement patterns, providing insights into network behavior and aiding to effective routing strategies. Inferring mobility states such as stationary, walking, or driving is critical for many applications. The fact that these days users carry several devices like smartphones, laptops, and smartwatches, each with different services and mobility, offers new opportunities and means for studying human mobility. Based on our objective for designing a routing protocol, Baton-relay relies on the knowledge that could be extracted from natural crowd mobility. In [KM23] we have validated the hypothesis of the capability of determining the devices' context through the observations of wireless traces in the range of a device. Thus in this paper we exploit this information for forwarding the message.

Baton-relay routing protocol prioritises connections with higher mobility values for message forwarding. The logic ensures that messages are sent to nodes with higher mobility, which are likely to carry the message further and faster. If no suitable connections are found, the message is carried by the current host until a better connection is available. We believe such a structured approach would allow efficient message dissemination in a DTN, where the network topology is dynamic and the connectivity is intermittent.

We assume a network $N = \{n_1, n_2, \dots, n_k\}$ be the set of nodes in the network and M , a message to be delivered from a source node n_s to a destination node n_d . We assume each node n_i has a mobility level $\mu(n_i)$ depending on its mobility pattern (eg pedestrian, bus, etc). The logic ensures that messages are sent to nodes with higher mobility, which are likely to carry the message further and faster. So, a car will have a higher mobility level than a pedestrian, and a pedestrian has a higher mobility level than a home, etc. Each node n_i is associated with a threshold T_i associated with its mobility level, i.e., $T_i = f(\mu(n_i))$. For the sake of simplicity, we start with the identity function f defined as $f(x) = x$. The impact of f will be evaluated in future work. When node n_i encounters node n_j , they exchange their mobility levels $\mu(n_i)$ and $\mu(n_j)$ resp.

Algorithm Description: First we start with initialization, where the source node n_s initiates the process with the message M and its mobility level $\mu(n_s)$. Upon encountering a new node n_j , the current node n_i will share its mobility level $\mu(n_i)$ with n_j and receive $\mu(n_j)$, and then compare with its threshold T_i . If $\mu(n_j) > T_i$, then node n_i forwards a copy of the message M to node n_j , otherwise, node n_i retains the message M and continues to carry it. The process continues until the message M reaches the destination node n_d or TTL expires. So, Baton-relay relies on the concept of node mobility as a metric to improve message forwarding in a delay tolerant network. By assigning mobility levels to nodes based on their mobility types, the algorithm ensures that messages are forwarded to nodes with higher mobility, which we believe could have a higher chance of encountering the destination or other high-mobility nodes.

3 Simulation Setup and Results

We evaluated the proposed routing protocol using the Opportunistic Network Environment (ONE) Simulator [KOK09], a Java-based tool for assessing delay-tolerant networking protocols. ONE allows for simulating diverse network scenarios and mobility models, offering comprehensive performance analysis. In our simulation, we configured a runtime of 12 hours (43,200 seconds) and used Bluetooth as the communication interface with a transmit range of 10 meters. The message size varied between 500 KB and 1 MB, and nodes followed the Shortest Path Movement-Based Model (SPMBM). To analyze the impact of storage constraints, we considered different buffer sizes (5 MB, 10 MB, 50 MB, 200 MB, and 500 MB). Furthermore, the Time-To-Live (TTL) values for messages were set at 300, 240, 180, 120, 60, and 30 minutes. We defined 5 groups of nodes each with different mobility types: 80 pedestrians (separated into two groups with different buffer sizes), 40 cars, 6 buses, and 8 fixed nodes, so in total we have 133 nodes in the network. Furthermore, the release contains map data of the Helsinki downtown area (roads and pedestrian walkways) that the map-based movement models can use.

1500 messages are created to be routed in the simulated environment. The source and the destination for each created message is selected randomly in a range from 0 to 133, where 133 is the total number of nodes in the network as defined in the previous section. The selection of the nodes of the message origin and destination is randomised to ensure a broad representation of possible network interactions. This variability

in the traffic files helps to test the protocols under a range of conditions, thus enhancing the validity of our findings. To ensure the robustness and reliability of our simulation results for the different Delay Tolerant Network (DTN) routing protocols, we employed a comprehensive simulation strategy involving multiple runs and various traffic scenarios. This approach aims to reduce the likelihood of unrealistic results caused by particular message structures or network conditions.

3.1 Results and Discussion

In this section, we first analyse the routing protocol individually, then in the second part, we compare the results of Baton-relay with other routing protocols known in the literature. The performance of the protocols is investigated with different traffic patterns and TTL values[†]. Performance is evaluated using the following five metrics: Copies overhead, that is the ratio of the number of copies against the number of original messages. This metric will calculate the cost of extra generated copies in the network. Delivery Ratio, which is the ratio of successful message deliveries to the total number of original messages created and sent. Buffer time average, that is the average time that a message spends in a node buffer before it is successfully delivered or dropped. Average Latency, the average time the message takes to be forwarded from the source to the destination, and Hop count average.

3.2 Performance Analysis of Baton-relay Protocol

As explained in Section 2, the decision to forward or carry a message in Baton-relay protocol is based on the node with a higher mobility. To validate this intuition and validate its effectiveness, we implemented a reverse version of Baton-relay which is called 'BatonRelay-reversed'. The message in BatonRelay-reversed is forwarded to the node with a lower mobility. So, if the sender is in a car and has in its range a bus and a pedestrian, the message will be forwarded to the pedestrian and not to the bus. The simulation is done for both protocols under the same conditions and traffic file. Table 1 displays the results after comparing the approaches.

TABLE 1: Comparative Performance of Baton-relay vs. BatonRelay-reversed Routing Protocols

Metric	Baton-relay	BatonRelay-reversed
Delivery Probability	0.85	0.59
Latency Average (s)	2556.89	4306.34
Buffer Time Average (s)	12492.70	12475.54
Copies Overhead	15.70	15.19

Protocol	Delivery Probability	Latency Avg (s)	Buffer Time Avg (s)	Hop Count Avg	Copies Overhead
Baton-relay	0.85	2556.89	12492.7	2	15.70
Epidemic	0.90	936.67	13000.3	4	71.34
Prophet	0.90	1037.99	13800.4	4	68.55
Spray and Wait	0.85	2521.55	17649.72	2	3.21

TABLE 2: Comparison of routing protocol performance

The better performance of the Baton-relay protocol compared to BatonRelay-reversed is due to its strategic use of high-mobility nodes for message delivery. By selecting nodes with higher mobility, such as buses or cars, messages are carried over larger distances faster, increasing delivery probability and reducing latency. High-mobility nodes encounter more additional nodes, enhancing message dissemination. In contrast, BatonRelay-reversed routes messages to low-mobility nodes like pedestrians, which limits travel distance and speed, leading to increased chances of delays and lower delivery probability. Thus, while both protocols theoretically test the impact of mobility on routing effectiveness, Baton-relay's strategy of using higher-mobility nodes capitalises on the rapid and extensive spread of messages across the network. This was proven by simulation and thus validates our assumption.

[†]. Results of TTL values are not mentioned here due to page limitation

3.3 Comparison with existing Protocols

In this section we investigate the performance of Baton-relay routing protocol compared to Epidemic [VB⁺00], Spray&Wait [SPR05] and PRoPHET [LDS03] protocols. Having established confidence in our simulation setup, we proceeded to compare the performance of each routing protocol across the 20 simulations. Table 2 displays the statistical results of the four routers with the main metrics that are important to give a logical comparison between the different approaches. From the results, we can see that Baton-relay achieves a delivery probability of 0.85, indicating reliable performance, slightly lower than the Epidemic and Prophet protocols, which both exceed a delivery probability of 0.90. Although Epidemic and PRoPHET protocols display exceptionally low latency averages of 936.67 s and 1037.99 s respectively, Baton-relay exceeds these protocols in terms of buffer time average, hop count, and copies overhead. Epidemic and PRoPHET have a higher average hop count, which increases the network overhead and complexity. Similarly for the copies overhead, as it presents a clear trade-off between delivery assurance and network resource utilisation. Epidemic and Prophet have high overheads of 71.34 and 68.55 respectively, which can lead to network congestion and increased power consumption, while Baton-relay, with a copies overhead of 15.70, provides a balanced approach, ensuring reasonable delivery success without excessive resource usage. Spray&Wait outperforms Baton-relay in copies overhead while maintaining the same delivery probability, latency, and hop count. However, Baton-relay significantly optimizes average buffer time compared to Spray&Wait and other protocols. The choice of routing protocol depends on application requirements. In environments with limited storage or buffer capacities, Baton-relay is preferable due to its lower copies overhead, lack of historical storage requirements, and privacy guarantees.

4 Conclusion and Future Work

In this paper, we implemented Baton-relay routing protocol that leverages devices' mobility for routing decisions. This protocol is ideal for environments requiring efficient resource utilization without significantly compromising delivery probability and latency. It is simple, does not rely on extensive mathematical calculations, does not require a huge memory or buffer and guarantees a reasonable delivery probability while preserving privacy, as it does not share or violate users' sensitive information, such as their location or device identifiers. All data is processed anonymously, ensuring user privacy throughout the communication process. Future work will include analysing the algorithm under various conditions, such as node density and mobility models, to determine its optimal performance. An updated version of the protocol is being implemented to enhance delivery probability and reduce overhead by refining the algorithms for assigning delivery probabilities (f function). Improvements will focus on better predicting node interactions based on past connections and current network conditions, increasing message delivery rates, while also giving some attention to the data security aspect.

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