Mobility Context Aware Routing Protocol in DTN

Jana Koteich
Inria, France
jana.koteich@inria.fr

Nathalie Mitton
Inria, France
nathalie.mitton@inria.fr

Riaan Wolhuter
Stellenbosch University, South Africa
wolhuter@sun.ac.za

***Abstract*—The development of delay tolerant networks (DTNs) has been driven by the need to overcome communication barriers in situations where traditional network assumptions do not apply. DTNs are designed to function effectively in situations where traditional networks fail due to limited connectivity, extended delays, and recurrent disruptions. They are characterised by their ability to store and forward data, adapt to changing network conditions, and maintain communication even in the face of disruptions. They are typically decentralized, self-organizing and fault tolerant. In this paper, we propose 'Baton-relay', a mobility context-aware routing protocol in DTN. This protocol relies on low-cost communication and storage devices that can embed different communication technologies, resulting in a global privacy-preserving data-sharing system based on natural crowd mobility. First, we analyse crowd mobility patterns to assign a delivery probability for a message based on its mobility pattern. The device will estimate its real-life situation, then exploits this information to take a forwarding decision. We tested and validated the approach using the ONE simulator, which is designed for an opportunistic network environment. The idea of Baton-relay is simple, not based on extensive mathematical calculations, does not require a huge memory or buffer, yet is robust, guaranteeing a reasonable probability of delivery and it preserves privacy. Results show that Baton-relay achieves a significant improvement for the buffer time average, number of hops and copies overhead compared to other routing protocols.**

***Index Terms*—Routing protocols, DTN, wireless network, machine learning, mobility models**

I. Introduction

Delay tolerant networks (DTNs) were initially developed for interplanetary communications [1]. As global interconnectivity grew, researchers recognized the potential of DTNs for terrestrial and satellite networking applications. Today, data sharing is fundamental to business, education, social media, and research, necessitating robust network infrastructures. However, challenges persist: remote or isolated regions, especially in Least Developed Countries, often lack adequate infrastructure, and even existing networks are prone to failures from power outages, traffic overload, disasters, or cyber-attacks. Here, DTNs have evolved to address communication barriers in various challenging scenarios, offering innovative solutions to complement traditional infrastructures and deliver data to isolated areas.

The advancement of routing protocols in DTNs represents a persistent effort to balance the trade-offs between delivery probability, latency, and resource utilization. From the early days of flooding-based routing like Epidemic routing [2] and probabilistic methods like PRoPHET protocol [3] 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, etc [4]. 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. Other approaches have made the effort to study human mobility to determine people's fine-grained activities such as using GPS positioning [5], but GPS-based mobility characterisation raises many issues such as spotty coverage and battery consumption [6]. In summary, the difficulties encountered in a DTN highlight the need for advanced techniques to ensure efficient and secure data management and transmission. Thus, in this paper, our aim is to present a new approach for a distributed low cost large scale privacy-friendly and mobility-aware delay tolerant data delivery network based on multi-technology rather than relying on full Internet connectivity between expensive powerful personal laptops or mobile phones. Thus, we introduce *Baton-relay*, a privacy-friendly and mobility-aware routing protocol. This protocol is based on the mobility of nodes in a network. 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 [7]. Compared to other known routing protocols recorded in literature, our protocol achieves significant improvements in average buffer time, number of hops and copies overhead. The paper is organised as follows. First, we discuss the related work in Section II, then in Section III we explain the concept and motivation behind exploiting the devices' mobility for the routing protocol. In Section IV, we describe our routing protocol, followed by the simulation setup in Section V and the results in Section VI. Finally, we conclude in Section VII with the future plan.

II. State of the Art

To generate a comprehensive review of the state of the art, we structure the information chronologically, focusing on the evolution of routing approaches, the importance of human mobility and the rationale for studying node mobility in routing protocol design. The early development of routing protocols for Delay Tolerant Networks (DTNs) primarily focused on addressing the challenges of intermittent connectivity and long delays. Epidemic Routing [2] was one of the pioneering protocols, employing a flooding-based approach to disseminate messages across the network, although at the cost of high resource consumption. PRoPHET protocol [3] introduced a probabilistic method, leveraging the history of node encounters to estimate delivery probabilities. MaxProp [8], designed for vehicle-based DTNs, prioritized packet transmissions and buffer management to optimize delivery. Spray and Wait [9] limited the number of message copies by distributing a fixed number of replicas and waiting for one to reach the destination. The main weaknesses of these approaches are high resource consumption, poor adaptability to changing network conditions, and limited use of social patterns. This has led to the development of advanced methods to better optimise resources and use social metrics to improve routing decisions. To overcome these limitations, recent work from literature exploits the advantages of context-awareness to sense the physical environment of the devices and adapt their behavior for forwarding the message accordingly to improve routing in DTN. To this end, in [10] the authors proposed a new routing protocol named Habit, a novel multi-layered approach to content dissemination in DTN that enables relevant content to reach interested nodes while minimising the load on uninterested intermediaries. While in [6] the authors presents a routing protocol named interest based prediction routing protocol (InP), which is based on the self-interest and second-interest information to predict the future meet opportunities. Based on the importance of context-aware forwarding protocols, different mobility models should be investigated to help design protocols with less communication overhead and used resources. Very recently, some studies investigate the use of human mobility but mainly in the COVID-19 context in order to anticipate contamination [11]. The literature records widely investigated mobility models, but rather to measure their impact on network performances and not to leverage their characteristics to improve them [12]. Recent work has explored using machine learning techniques to predict human mobility patterns and optimize routing decisions. These approaches leverage ML techniques to predict node behavior, optimize routing decisions, and improve overall network performance. The following are some key insights and references from recent research: In [13], the authors design an intelligent DTN routing system based on machine learning techniques. The system aims to classify and predict the best routing paths by leveraging historical data and node behavior patterns. But this approach requires memory storage to manage historical data and model parameters. [14] discusses using machine learning classifiers to predict the most suitable neighbor nodes for message delivery in DTNs. The approach involves analyzing network traffic statistics and historical delivery information to make informed routing decisions, but this approach demand significant computational resources and memory to handle historical data and model parameters. While such approaches are promising for DTN routing, further research is needed to address these challenges and improve the applicability of ML-based methods in varied and resource-limited DTN scenarios.

Our approach offers a new perspective, as we aim to develop a routing protocol that incorporates mobility knowledge, promising improved efficiency, reliability and performance in DTNs, thereby making a significant contribution to the field.

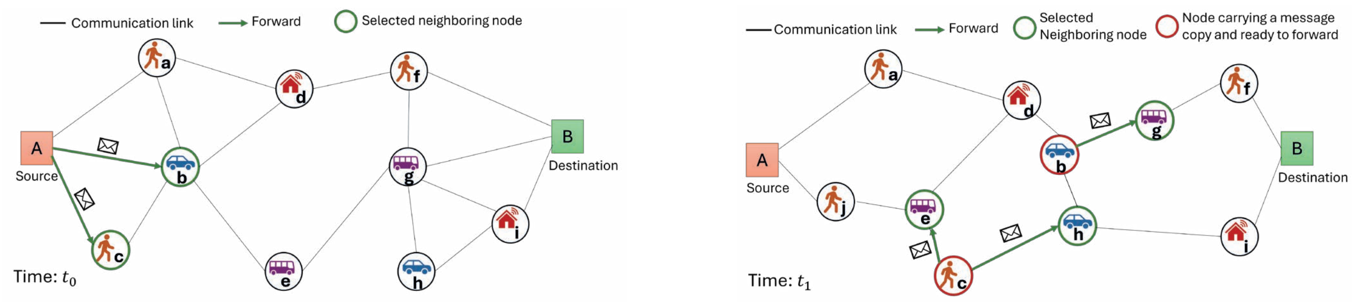
III. Leveraging Natural Mobility

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. Understanding human and device mobility is essential in mobile computing, influencing network design, location-aware technologies, and urban planning [15]. 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, our approach will rely on the knowledge that could be extracted from natural crowd mobility to translate each 'real-life' situation into a network model. As a 'real-life' situation, the latter referred to as context, we refer to the mobility and environment of a device: static, low mobility (e.g. pedestrian), high mobility (e.g. car, bus), at home, in a public place, in an urban or rural environment, etc. We define as a network pattern the number, density, and stability of the wireless links that a device can observe at a given time for each wireless technology. To achieve so, in [16] 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. We have proposed a novel approach for inferring human mobility by determining a device's status within its network context through wireless communication technologies, namely WiFi and BLE, working in conjunction. In our approach, we achieved 94% accuracy in classifying among 10 scenarios using a lightweight classical machine learning algorithm (XGBClassifier). More details are provided in [16]. After validating this approach, in this paper we exploit this information for forwarding the message, which is explained in the next section.

IV. Baton-relay Routing protocol

This routing protocol prioritises connections with higher mobility values for message forwarding. The logic ensures that



(a) Scenario at time 0

(b) Scenario at time 1

Fig. 1: Illustration of Baton-relay protocol

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. Thus, to prove this claim, we first provide an outline of the algorithm and the behaviour of the protocol. Figure 1 illustrates the scenario for forwarding a message in 2 consecutive time-slots. First, each device will determine its local context through a machine learning model by scanning its network environment as illustrated in [16], then share this information with its neighboring devices. In Figure 1a, device *A* which is static, wants to send a message to the destination *B*. From the knowledge of device's *A* context, a delivery probability (*f* to be defined later) is computed to decide whether to forward the message or carry it. Then device *A* estimates whether it needs to send two copies of the message to devices *b* and *c* because they have a higher mobility than itself. Then crowds move and wireless connections dynamically appear and disappear. In Figure 1b, device *b*, which has carried the message, will repeat the same process of forwarding the message to the devices with higher mobility, thus it will exclude device *h* since it has the same mobility context as itself and thus there is no added value to forward the message for such device. This process will be repeated on each device that is holding a copy of the message until the message reaches its destination.

A. System model

We assume a network $N = \{n_1, n_2, \ldots, n_k\}$ 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). 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.

1) 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 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. Algorithm 1 explains the behavior of the routing protocol.

Algorithm 1 Baton-relay, run on node n_i holding a message M to destination n_d

```
Input: M, μ(n_i)
for each encountered n_j do
        ▷ Step 2: Share mobility levels between n_i and n_j
    receive μ(n_j)
    send μ(n_i)
        ▷ Step 3: Check if n_j's mobility level is greater than n_i's threshold
    if μ(n_j) > T_i then
            ▷ Step 4: Forward the message M from n_i to n_j
        forwardMessage(n_i, n_j)
            ▷ Decide if n_i will carry or remove the message based on the threshold T_i
        carry(M, n_i) or remove(M, n_i)
    end if
end for
```

V. Simulation Setup

In this section, we provide an overview of the environment (ONE simulator) that is used to implement the Baton-relay and other approaches from the literature: Epidemic, Spray &

Wait, and Prophet protocols. Next, we define the settings for the simulation and the metrics for evaluation.

A. Tools and Scenario Description

We evaluated the proposed routing protocol using the Opportunistic Network Environment (ONE) Simulator [7], a Java-based tool for assessing delay-tolerant networking protocols. ONE allows for simulating diverse network scenarios and mobility models, offering comprehensive performance analysis. Its strong DTN simulation capabilities, integrated mobility models, and network configurations make it ideal for evaluating mobility-based routing protocols, as it effectively displays network performance data and node movements.

B. Parameters

Table I summarizes the general configuration of the simulation used to evaluate and analyze the performance of the routing protocols. However, Table II shows in more detail the configuration for each mobility type used (number of nodes and buffer size).

TABLE I: Routing Protocol Parameters

Parameter	Value
Simulation Time	43200 seconds (12 hours)
Interface Class	Bluetooth
Transmit Speed	250 KBps
Message Size	500KB to 1MB
Transmit Range	10 meters
Number of Node Groups	14
Movement Model	Shortest Path Movement (SPMBM)
Buffer Size	5M, 10M, 50M, 200M, 500M
TTL	300, 240, 180, 120, 60, 30 minutes

TABLE II: Group nodes Parameters

Group ID	Number	Buffer Size
Pedestrian P1	40	5M
Pedestrian P2	40	10M
Cars C1	40	50M
Bus B1	6	200M
Fixed F1	8	500M

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.

C. Performance Metrics

To evaluate our routing protocol, we investigate the performance of all four protocols, i.e. Epidemic [2], Spray and Wait [9], PRoPHET [3], and Baton-relay, through simulations. The performance of these four protocols are investigated with different traffic patterns and TTL values. Performance is evaluated using the following five metrics:

- Copies overhead (CO) = 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: the ratio of successful message deliveries to the total number of original messages created and sent.
- Hop count average: the average number of hops each node has relayed on to reach the destination.
- Buffer time average: 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.

D. Statistical Robustness in Simulation

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.

1) Message Creation: 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.

2) Confidence Interval Calculation: Each routing protocol was subjected to 20 independent simulation runs. For each simulation, a unique traffic file was used. To determine whether 20 simulation runs are sufficient to provide reliable results, we calculated the confidence intervals (see [17] for more details) for key metrics: delivery probability and average latency. The confidence interval gives us a range in which we can expect the true population parameter (mean in this case) to fall with a certain level of confidence. For our simulations, the resulting confidence intervals for both delivery probability and latency is [0.898, 0.905], which is considered narrow, indicating a small difference between the lower and upper bounds. This consistency across simulations suggests that the sample of 20 runs is sufficiently robust, reflecting stable and reliable results under varying network conditions.

VI. 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 the other routing protocols known in the literature.

A. Performance Analysis of Baton-relay Protocol

As explained in Section IV, 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 III displays the results after comparing the approaches.

TABLE III: 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

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.

B. Comparison with existing Protocols

After validating the choice of Baton-relay protocol for choosing the nodes with higher mobility to relay on, in this section we investigate the performance of Baton-relay routing protocol compared to Epidemic [2], Spray&Wait [9] and PRoPHET [3] protocols. Having established confidence in our simulation setup, we proceeded to compare the performance of each routing protocol across the 20 simulations. To ensure that the results reflect the typical performance of the protocols under a variety of scenarios, we averaged the results (e.g., delivery ratio, latency, buffer time) of each protocol from the 20 simulations. Table IV 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 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.

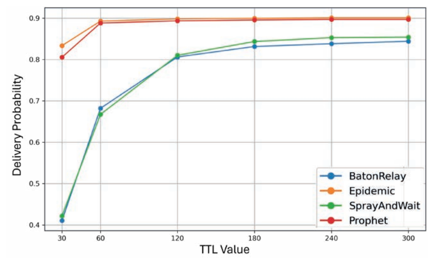
1) TTL Analysis: To explore the dynamics of the Baton-relay protocol, we analyzed the impact of varying Time-to-Live (TTL) settings on performance metrics like delivery probability, latency, average buffer time, and copies overhead. The results are shown in Figures 2a, 2b, 2c, and 2d. We considered TTL values of 300, 240, 180, 120, 60, and 30 minutes. Figure 2d displays the copies overhead for different TTL values across four routing protocols. Figure 2c shows average buffer time, Figure 2b depicts average latency, and Figure 2a illustrates the delivery ratio. For Baton-relay, the number of copies increases linearly, making it the most conservative in terms of resource usage, beneficial in constrained environments. Baton-relay also shows the most favorable buffer time, with an initial increase that quickly stabilizes. Epidemic and Prophet protocols produce the highest copies and buffer times, indicating higher resource usage and potential drawbacks in time-sensitive applications.

VII. Conclusion and Ongoing Work

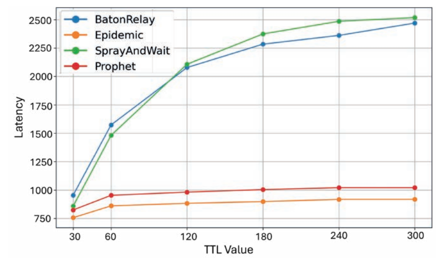
To analyze the impact of devices' mobility on routing decisions, we implemented the Baton-relay protocol. This balanced protocol is ideal for environments requiring efficient resource utilization without significantly compromising delivery probability and latency. Baton-relay leverages high-mobility nodes to forward messages, making it suitable for urban areas with mixed vehicular and pedestrian traffic. 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. We are currently analysing the algorithm under various conditions, such as node density and mobility models, to determine its optimal performance. This will help to understand how different node concentrations and mobility patterns affect the protocol's efficiency and reliability. Additionally, we are examining delivery probability, latency and the number of hops to evaluate performance. An updated version of the protocol is being implemented to enhance delivery probability and reduce

TABLE IV: Comparison of routing protocol performance

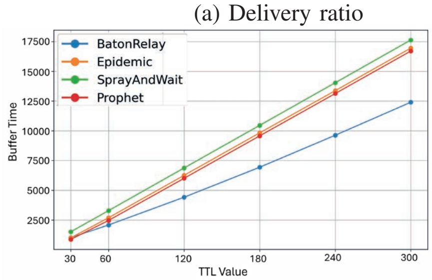
Protocol	Delivery Probability	Latency Avg (s)	Buffer Time Avg (s)	Hop Count Avg	Copies Overhead
Baton-relay	0.85	2556.89	12492.7	2	15.70
Epidemic	0.90	936.67	13000.3	4	71.34
Prophet	0.90	1037.99	13800.4	4	68.55
Spray and Wait	0.85	2521.55	17649.72	2	3.21



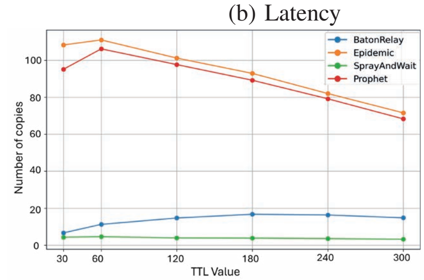
(a) Delivery ratio



(b) Latency



(c) Buffer time



(d) Copies overhead

Fig. 2: Performance comparison of routing protocols under different TTL values

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.

Acknowledgment

This work has been partly supported by the LIRIMA programme and the Agrinet associated team.

References

[1] C. Caini, H. Cruickshank, S. Farrell, and M. Marchese, "Delay-and disruption-tolerant networking (dtn): an alternative solution for future satellite networking applications," *Proceedings of the IEEE*, 2011.

[2] A. Vahdat, D. Becker *et al.*, "Epidemic routing for partially connected ad hoc networks," 2000.

[3] A. Lindgren, A. Doria, and O. Schelén, "Probabilistic routing in intermittently connected networks," *ACM SIGMOBILE mobile computing and communications review*, 2003.

[4] C. Boldrini, "Design and analysis of context-aware forwarding protocols for opportunistic networks," in *Proc. 2nd International Workshop on Mobile Opportunistic Networking*, New York, NY, USA, 2010.

[5] G. M. Vazquez-Prokopec, D. Bisanzio, S. T. Stoddard, V. Paz-Soldan, A. C. Morrison, J. P. Elder, J. Ramirez-Paredes, E. S. Halsey, T. J. Kochel, T. W. Scott, and U. Kitron, "Using gps technology to quantify human mobility, dynamic contacts and infectious disease dynamics in a resource-poor urban environment," *PLOS ONE*, vol. 8.4, 04 2013.

[6] L. Liu, "Interest-based prediction routing protocol in socially-aware opportunistic networks," in *Proc. 2nd Int. Symposium on Instrumentation and Measurement, Sensor Network and Automation (IMSNA)*, 2013.

[7] A. Keränen, J. Ott, and T. Kärkkäinen, "The one simulator for dtn protocol evaluation," in *Proceedings of the 2nd international conference on simulation tools and techniques*, 2009, pp. 1–10.

[8] J. Burgess, B. Gallagher, D. D. Jensen, B. N. Levine *et al.*, "Maxprop: Routing for vehicle-based disruption-tolerant networks." in *Infocom*, 2006.

[9] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and wait: an efficient routing scheme for intermittently connected mobile networks," in *Proc. SIGCOMM workshop on Delay-tolerant networking*, 2005.

[10] A. J. Mashhadi, S. B. Mokhtar, and L. Capra, "Habit: Leveraging human mobility and social network for efficient content dissemination in delay tolerant networks," in *IEEE WoWMoM*, 2009.

[11] E. Hernández-Orallo and A. Armero-Martínez, "How human mobility models can help to deal with covid-19," *Electronics*, vol. 10, 2021.

[12] T. Alam, "Fuzzy control based mobility framework for evaluating mobility models in manet of smart devices," *Journal of Engineering and Applied Sciences*, vol. 12, 08 2017.

[13] S. C. K. Tekouabou, Y. Maleh, A. Nayyar *et al.*, "Towards to intelligent routing for dtn protocols using machine learning techniques," *Simulation Modelling Practice and Theory*, vol. 117, p. 102475, 2022.

[14] R. Dudukovich and C. Papachristou, "Delay tolerant network routing as a machine learning classification problem," in *NASA/ESA Conference on Adaptive Hardware and Systems (AHS)*, 2018.

[15] A. Trivedi, "Human mobility monitoring using wifi: Analysis, modeling, and applications," Ph.D. dissertation, University of Massachusetts Amherst, USA, 2021.

[16] J. Koteich and N. Mitton, "Machine learning approach for mobility context classification using radio beacons," in *Proc. Int. Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS)*, 2023.

[17] https://en.wikipedia.org/wiki/Confidence_interval.