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# Characterization of a delay and disruption tolerant network in the Amazon basin

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ABSTRACT

Most cities in the Amazon have no data communication infrastructure, and rivers are most of the time the only access mode to connect small cities to urban centers. In this paper, we investigate the deployment of vehicular ad hoc networks (VANETs) formed by boats along the rivers of the Amazon as an alternative to interconnect the small cities to the capital Manaus. Given that boats will opportunistically connect to each other, we have the scenario of a delay and disruption tolerant network (DTN). In a nutshell, the idea is to take advantage of the contacts between the boats that travel daily transporting passengers and products to small cities, communities, villages, as well as to other states. We evaluate the capacity of a DTN formed by boats, using simulations with real boat traffic and mobility traces captured in the Amazon Basin as input. Results show that potential of raw data transfer in this large-scale DTN can achieve 1.38 TB over a week for some 45 hours of contact time between boats.

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## 1. Introduction

The Brazilian Amazon has the largest river basin in the world, with 20% of the planet's freshwater, comprising over 20,000 km of navigable waterways. The Amazon represents over 40% of the Brazilian territory, which corresponds to more than five times the size of France. However, the Amazon region faces several problems of scarce data communications infrastructure, which affect the level of socio-economic development of the region. The Amazon's geographical characteristics favor the river transportation [1], which is practically the only mode for passenger and cargo transport in the region. Airplane travels between small cities are used, often with multiple stops, increasing operational costs. One major disadvantage of boat transportation is the travel time. Fluvial distances are frequently given in days. For example, 3.5 days from Manaus to Belém and 5 days the other way around (the difference being due to the boat going down or up river).

One alternative to cope with the lack of telecommunications infrastructure in the Amazonian cities is the use of boats in communications systems, in a similar way as VANETs [2–6] use cars [7,8], buses [9,10], and even drones [11] to build the communication system. A large number of cities, communities, villages and states would benefit from VANETs formed by boats that regularly travel in the Amazon basin. Considering that there are over 45,000 of such boats, with a pre-existing infrastructure of ports and terminals, boats can use opportunistic contacts to send messages from one city to another and to exchange data between each other along the river bed, increasing the capillarity of this network. Nevertheless, there are challenges that add to the day-long boat travel times, such as, wireless communication behaves differently in indoor or urban environments, characterizing contacts between boats as well as their trajectories in the river beds. Therefore, this paper investigates a data communication network for the Amazon cities currently living with precarious or no data communication infrastructure. We analyze a VANET implementation in a real scenario of boats navigating in the rivers of the Amazon. Thus, our main goals are: (i) to characterize data transmission of boats in the Amazon, (ii) to characterize the contact times between boats, and (iii) to calculate, based on real data, an estimate of the capacity of data transfer through simulation. In summary, the main contributions of this work are:

- new mobility traces from boats in the Negro and Amazonas rivers.
- the estimation of DTN [12–15] capacity along the Amazonas and Negro rivers, through computer simulations. Results show

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**Table 1**
Comparison with related work.

| Parameter | Zhang et al. [26] | Tournoux et al. [29] | Mitton et al. [31] | Lu et al. [32] | Wang et al. [33] | Present paper |
|---|---|---|---|---|---|---|
| Scenarios | Buses | Rollerbladers | Bikes | Vehicles | Taxis | Boats |
| Mobility | Traces | Traces | Not analyzed | Not analyzed | Traces | Traces |
| Methodology | Simulation | Simulation and analytics | Analytics | Analytics | Simulation | Simulation and measurements |
| Metrics | Delivery delay, number of copies made and hops count | Node degree, connected components, overhead and bundle delay | Amount of data sent and received | Delay and throughput | Throughput | Contact time and amount of data transferred |

that the potential of data transfer between boats is in the order of terabytes over one week.

This paper builds on our previous work [16], where we conduct experimental measurements and derive preliminary estimations of the DTN capacity, based on the assumption of Uniform Rectilinear Motion of boats. In contrast, in this work we use real mobility traces obtained in Baixo Amazonas river channel. Then, by simulating the movement of more than a hundred boats in this channel, we measure the capacity of this DTN. The simulation parameters are tuned according to the values measured in the practical experiments.

This paper is organized as follows. Section 2 presents related work, while Section 3 describes the methodology used in this work, the practical experiments between crossing boats in the Negro river, and the boat mobility trace captured with GPS in a real scenario. The information obtained from the experiments is then used in the simulations presented in Section 4. Finally, Section 5 concludes this manuscript and discusses future work.

## 2. Related work

Several papers evaluate the capacity [7,16–18], contact times [19], inter-contact [20–22] times and the mobility [23–25] of VANETs and DTNs. Nevertheless, few papers analyze the data transfer capacity of mobile devices in river scenarios.

Zhang et al. [26] investigate the bus-to-bus contact times and its impact on DTN routing performance in the city of Massachusetts, United States. Buses follow well-defined routes and find other buses that establish pair-wise connections to allow data transfer between them. The authors compute the cumulative distribution function of the inter-contact times and propose a probabilistic model. This probabilistic model is then used in simulations to evaluate DTN routing performance with respect to delivery delay, number of copies made, and hop count metrics, often used in the literature [27,28].

Tournoux et al. [29] analyze the contact time among thousands of participants of a rollerblading tour in Paris. In [30] they further explore those traces to derive an analytical model and evaluate the impact on DTN routing. The authors use graph metrics like the average node degree, connected components, and diameter to characterize the DTN. The routing performance metrics used were bundle delay and overhead. In the present work, we analyze the raw data capacity, and DTN routing is not in the scope of this paper.

Mitton and Rivano [31] propose a mathematical model of a network composed of bikes and base stations, in Lyon, France. Using this model they evaluate the amount of data sent by the bikes, the amount of data received by the base stations, the transmission range of bikes and of base stations, and the relationship between the number of bikes and base stations along the city's streets. Moreover, the time for a bike to upload data to a base station is modeled as a stochastic process. If the upload time is too long or storage capacity of sensors embedded in the bicycle is insufficient, data can be sent to other bikes using opportunistic multi-hop routing.

Lu et al. [32] investigate the asymptotic capacity and delay performance for social-proximity urban vehicular networks. The authors considered a grid-like scenario, with bi-directional road segments. The mobility of the $N$ vehicles follows a discrete time Markovian process. They assume social hotspots in the city. The social hotspot region shows higher vehicle density. On the other hand, unicast communications are concentrated inside these social hotspots. Considering this scenario, they make the interest finding that the per-vehicle throughput and average delay tends to constants, despite the performance degradation with higher vehicle density.

Wang et al. [33] studied the throughput capacity of VANETs considering a content uploading application. The source vehicles generate data and send it to a remote Internet server using the Road Side Units (RSUs). The authors show that with the number of RSUs scaling as $\Theta(\frac{n}{\log n})$, the throughput capacity scales as $\Theta(\frac{1}{\log n})$. Then, they propose a two-hop forwarding scheme to pursue this throughput capacity.

Deng [34] presents a simulation-based evaluation of different DTN routing protocols. The author also proposes to use an Erlang B queuing model to evaluate the performance of DTN routing protocols. The DTN network capacity is assessed based on the routing protocol performances. The author uses a scenario with a map-based mobility, and studies message delivery ratio under different traffic conditions to evaluate the DTN routing protocol.

We summarize in Table 1 the main characteristics of the present paper and the most similar related work, according to the following aspects: scenarios, mobility, methodology, and metrics.

The scenario of our work differs significantly from related work because other factors affect the experiments, like the weather condition (temperature and air relative humidity) and the boat navigation constraints. The proposed VANET river scenario is rarely addressed in the literature. As a consequence, our work combines practical experiments with simulation technique, in order to obtain results closer to reality. Moreover, it is possible to estimate the amount of data transferred in the DTN without the physical risks and large costs involved.

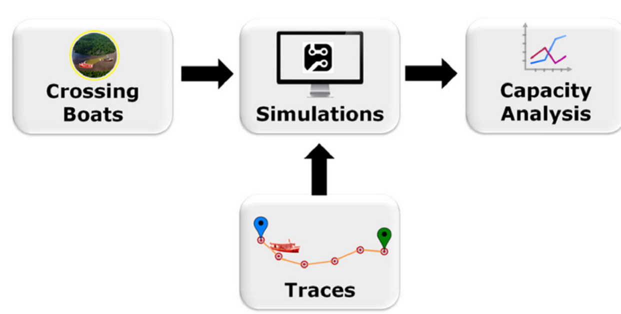


**Fig. 1.** Methodology used in the evaluation of the capacity of a DTN in the Amazon basin.

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