PRIVO: A PRIvacy-preserVing Opportunistic routing protocol for Delay-Tolerant Networks

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Outline

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1. Introduction

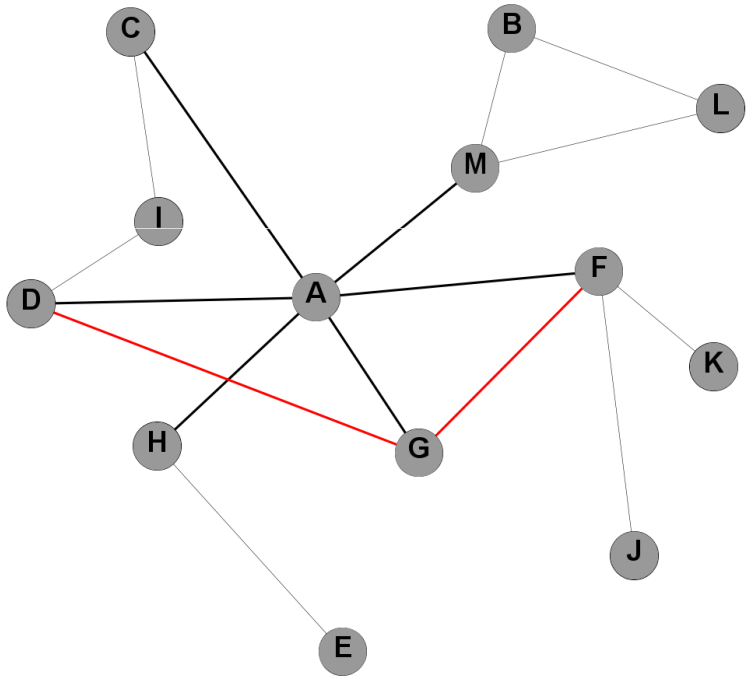
- Delay-Tolerant Networks (DTNs) are networks in which end-to-end connectivity between a source and target node may never exist.
- DTN routing involves the challenging task of **finding suitable nodes** to forward messages to.
- In DTNs there is information that may be **private**, such as the entities owning and managing DTN nodes and their relationships.
- If it is considered that some nodes might misbehave, **private information** such as contacts' history, list of neighbors, etc., which is required for computing some routing metrics **should not be disclosed to misbehaving nodes**.
- Privacy-preservation techniques allow **protecting privacy** through masking, modification and/or generalization of the original data without sacrificing the data utility.

2. Background and related work (1/2)

- Privacy can be understood as the **users' willingness to disclose or not** his/her information to others.
- Privacy **breaches** can be classified as
  - Identity disclosure
  - Link disclosure
  - Attribute disclosure.
- Anonymization methods
  - **protect** the privacy of information if sensitive information needs to be processed elsewhere.

2. Background and related work (2/2)

- **Homomorphic encryption**
  - a node to carry out computations on encrypted values, without needing to decrypt them first.
- **Centrality** of a node in a network
  - is a quantitative measure of the structural importance of this node in relation to others within the network.
- **Ego network**
  - consists of a central node along with its direct neighbors and all links among these neighbors.
- Betweenness centrality vs **Ego** betweenness centrality
- **Similarity** expresses the amount of common features of a group in social networks.



3. The PRIVO protocol

- PRIVO detects and utilizes the inherent social network structure to facilitate packet forwarding in DTNs
- PRIVO models a DTN as a time-varying neighboring graph
- PRIVO ensures privacy by means of anonymization and homomorphic encryption.
  - It uses **anonymization** to ensure **link privacy**, i.e., to avoid disclosing historical information associated to each node's *neighboring graph*.
  - It uses **homomorphic encryption** to ensure **attribute privacy**, i.e., to allow nodes to compare their *routing metrics* in a private manner.

3.1 Construction of the neighboring graph

- The **average separation period** is given by

$$\delta_{i,j}(x) = \frac{\int_{\tau} x_{i,j}(t)dt}{n_{i,j}}$$

where

- $x_{i,j}(t)$ denotes the separation period between nodes i and j
- τ denotes the elapsed time
- $n_{i,j}$ be the number of times that nodes i and j were away from each other.

- The **normalized** average separation period $\hat{\delta}_{i,j}$ is given by

$$\hat{\delta}_{i,j} = 1 - \frac{\delta_{i,j}}{\tau}$$

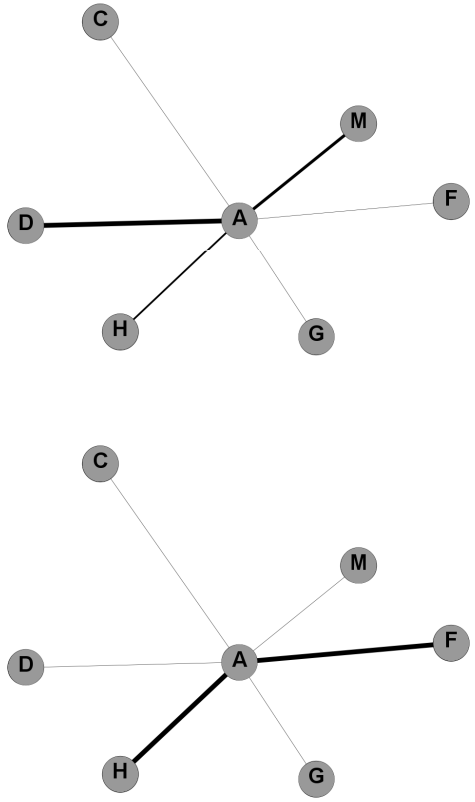
- The time-varying PRIVO weight (***pweight***) is given by

$$w_{i,j} = \frac{1}{\eta}\sum_{k=1}^{\eta} \hat{\delta}_k$$

where $\eta = |\tau|$ is the number of timeslots.

3.2 The link privacy mechanism

- Neighborhood randomization
  - consists in **partially hiding** each node's neighboring graph containing its historical encounter information.
  - nodes only exchange the **random least possible** number of nodes in their neighboring graphs.
- Binary anonymization
  - consists in **replacing the *pweight*** associated to a given link with 1 or 0, if the weight is above or below a given anonymization threshold, respectively.
  - The selection of the anonymization threshold is limited by the **utility** of the neighboring graph.

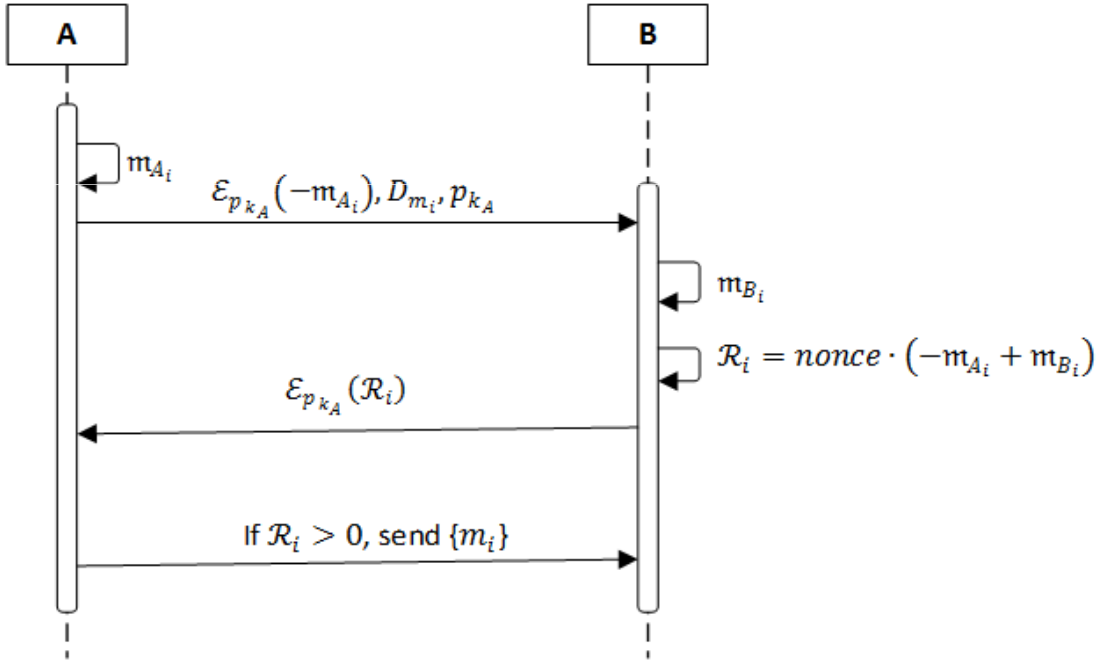


3.3 Routing algorithm (1/3)

- Let node A be a node carrying a set of messages $\mathcal{M}$ and node B be a neighbor of A.
- Upon an encounter, A wants to know if B is the best forwarder to carry message $m \in \mathcal{M}$ destined to D.
- Let each node have a public (p_k) and private (s_k) keys.

3.3 Routing algorithm (2/3)

- The attribute privacy mechanism works as follows:



3.3 Routing algorithm (3/3)

- Four variants of PRIVO were considered:
  - PrivoASP uses as routing metric *pweight*.
  - PrivoMTTE uses as routing metric the mean time to encounter.
  - PrivoSDBC which is the social version of PRIVO, uses as routing metric weighted similarity to the destination and ego betweenness centrality.
  - PrivoCOMBINED is a combination of PrivoMTTE and PrivoSDBC
- All buffered are sorted based on their TTL.
- PrivoSDBC compares
  - First: the nodes' weighted similarity to the destination
  - Then: the ego betweenness centrality

4. Simulation model

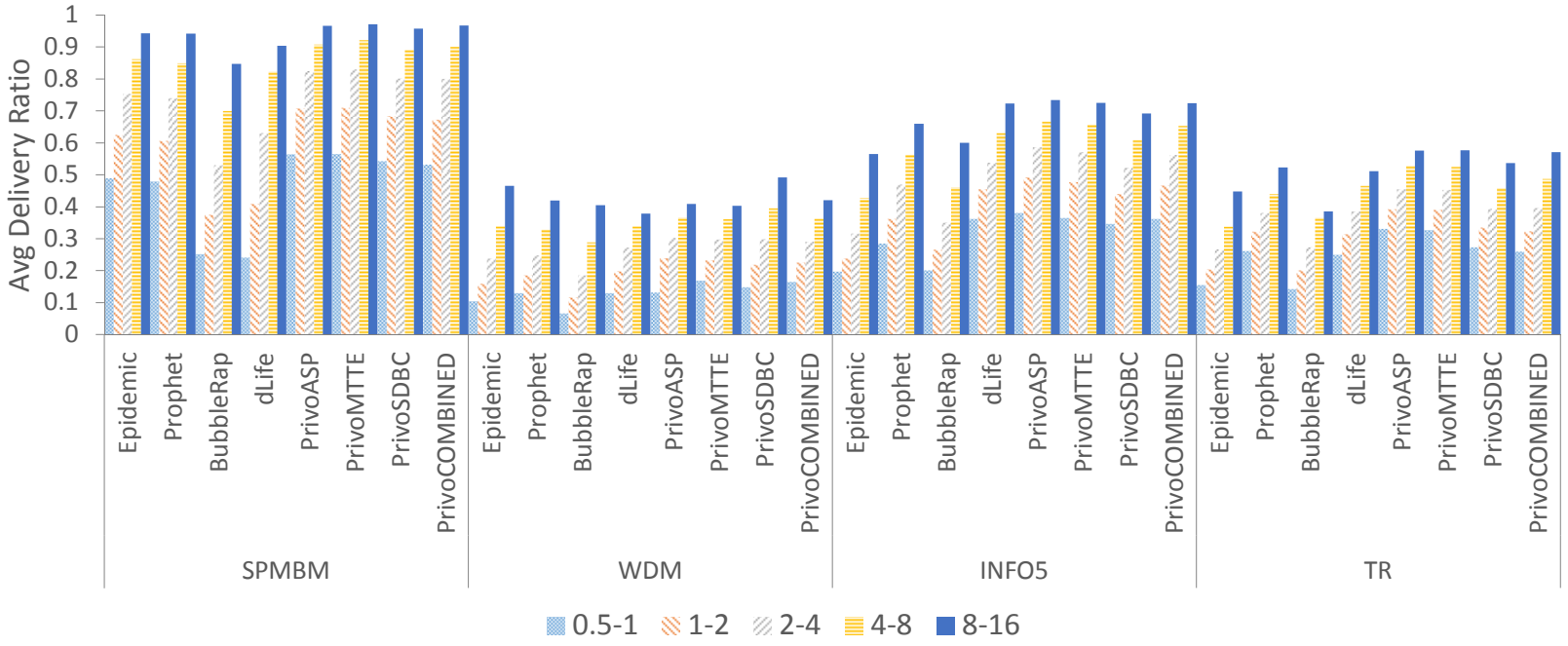
- The ONE Simulator
- Message generation rates: 0.5-1 min, 1-2 min, 2-4 min, 4-8 min, 6-12 min and 8-16 min.
- The length (number) of the timeslots was set to 5 min (288 slots), 10 (144), 15 (96), 30 (48) and 60 (24)
- Synthetic mobility models: Shortest-path Map-Based Movement (**SPMBM**) and Working Day Movement (**WDM**)
- Real mobility traces: CRAWDAD Haggle-one-infocom2005 (**INFO5**) and CRAWDAD Taxicabs in Rome (**TR**)
- Simulation time was set to 7 (synthetic) and 3 (real) days.
- The TTL attribute of each message was around 24 h.

5. Simulation results

- PRIVO variants were evaluated with well-known DTN routing protocols:
  - Two non-social-based routing protocols: Epidemic and Prophet
  - Two social-based routing protocols: BubbleRap and dLife.
- 15 independent simulations using different message generation seeds for statistical confidence.
- PRIVO was evaluated according to the following metrics: delivery ratio, overhead ratio and crypto-graphic cost.
- Information loss (or data utility) due to the use anonymization methods will also be evaluated.

5.2 Routing performance

- Delivery ratio



5.3 Cryptographic costs (1/2)

- Additive homomorphic encryption
  - PC specifications: Intel® CORE™ i7-2600 CPU @ 3.40GHz, 16 GB RAM and Windows 10 Pro (64-bits).

Average Paillier Execution Times (ms)

Key Size	$\mathcal{E}(a)$	$\mathcal{D}(c)$	$\mathcal{E}(a+b)$	$\mathcal{E}(a-b)$	$\mathcal{E}(k \cdot a)$
512	1.73	1.74	0.01	0.38	0.02
1024	11.03	11.29	0.03	0.74	0.05
2048	83.49	83.9	0.06	1.74	0.14

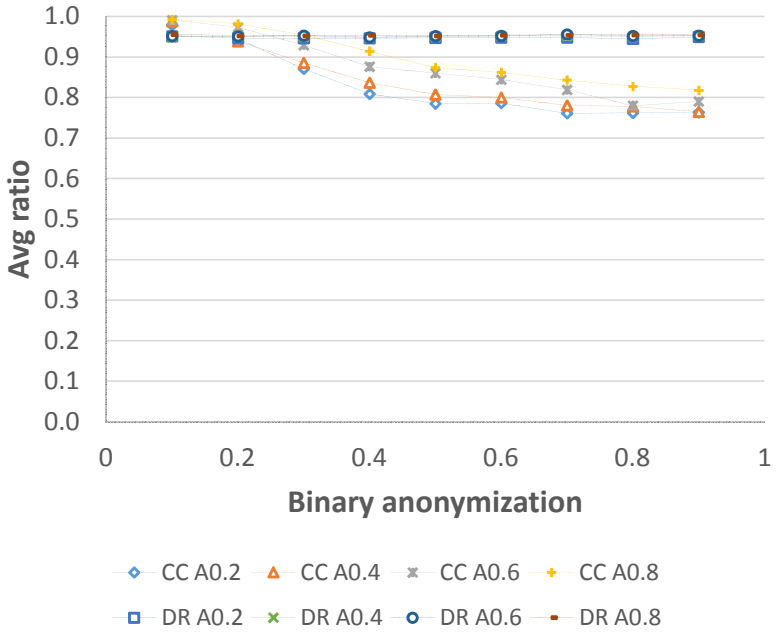
5.3 Cryptographic costs (2/2)

- PRIVO's performance with Paillier
  - Average delivery ratio losses (+) and gains (-) using the Paillier cryptosystem (%)

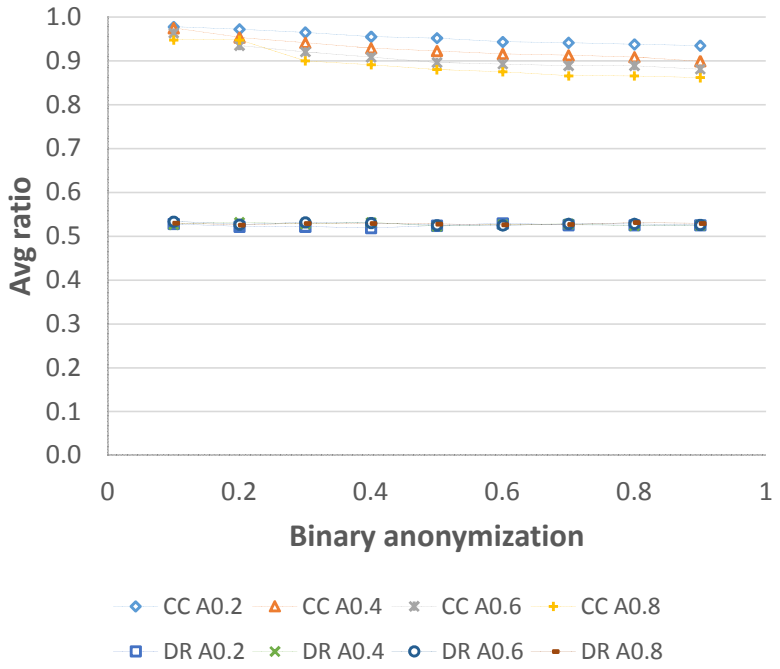
	512 bits	1024 bits	2048 bits
SPMBM	-0.08	-0.01	1.01
WDM	1.11	4.77	21.73
INFO5	0.00	-0.21	-0.09
TR	-0.11	-0.06	-0.88

5.4 Information loss

SPMBM



TR



CC: Correlation coefficient; DR: Delivery Ratio; A: Total Anonymization

6. Conclusions

- This paper proposed PRIVO, a PRIvacy-preserVing Opportunistic routing protocol for DTNs.
- PRIVO ensures
  - *Link privacy* by means of binary anonymization and neighborhood randomization
  - *Attribute privacy* by means of the Paillier homomorphic encryption scheme.
- PRIVO presents on average cryptographic costs below 1% in most scenarios
- If there are some repetitive movement patterns then PrivoSDBC is the best choice, otherwise it is PrivoMTTE

E-Poster Gains Table

Scenarios/Mobility		Key Sizes		
		512 bits	1024 bits	2048 bits
	Shortest-path Map-Based Movement	-0.08	-0.01	1.01
	Working Day Movement	1.11	4.77	21.73
	CRAWDAD Haggle-one-infocom2005	0.00	-0.21	-0.09
	CRAWDAD Taxicabs in Rome	-0.11	-0.06	-0.88