Two Hops or More:

On Hop Limited Search in Opportunistic Networks

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MSWiM 2015

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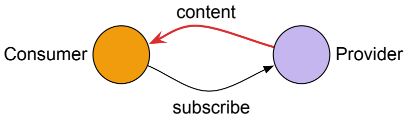

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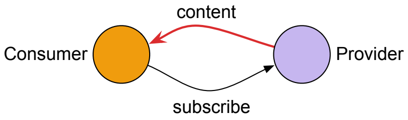
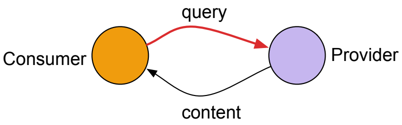


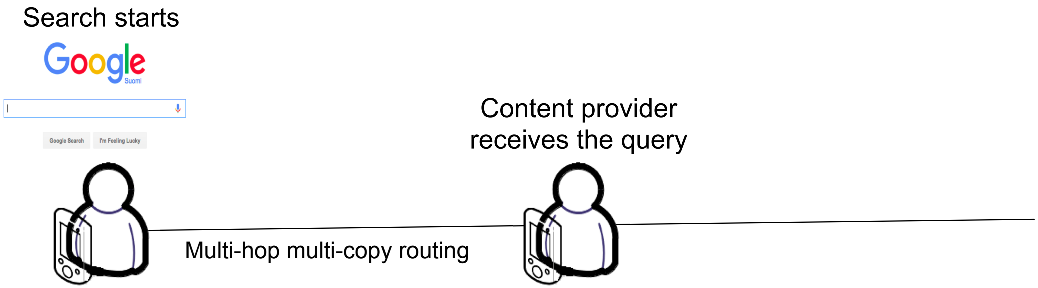
- Pull: more natural like desktop search, receiver driven



Hop-limited search

Search starts

Hop-limited search



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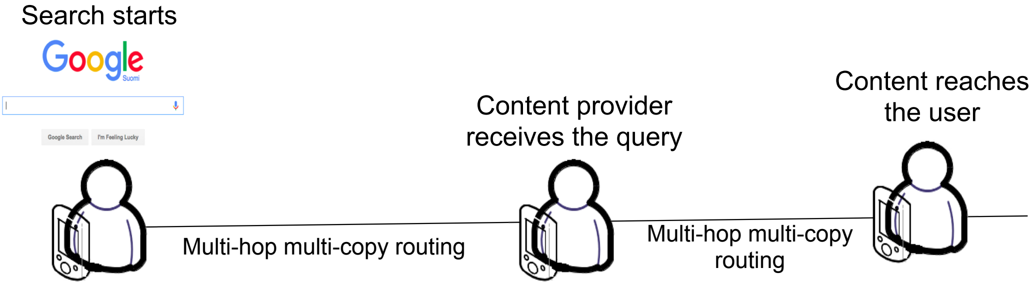

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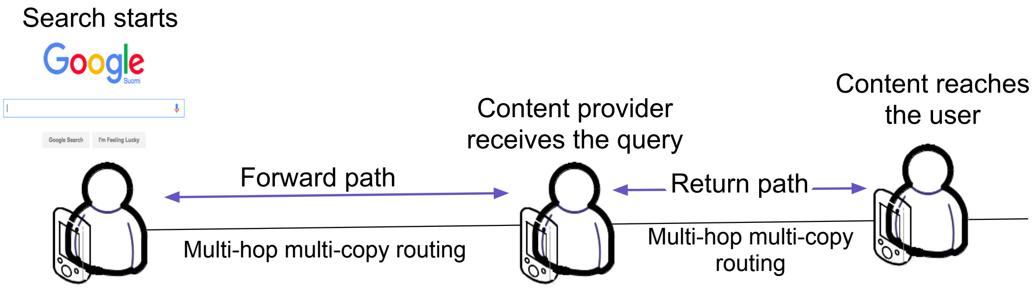

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- search success ratio, search completion time, search cost

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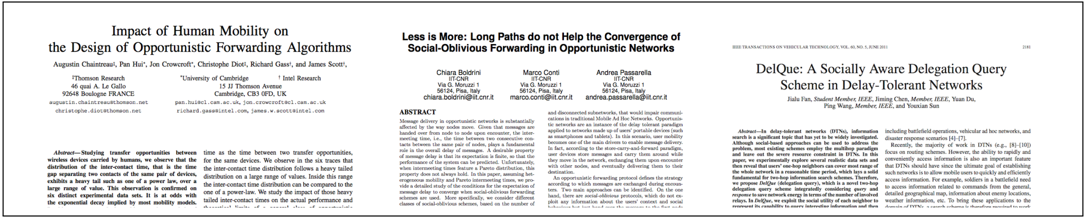

Impact of Human Mobility on the Design of Opportunistic Forwarding Algorithms

Augustin Chaintreau‡, Pan Hui*, Jon Crowcroft*, Christophe Diot‡, Richard Gass†, and James Scott†,
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Abstract—**Studying transfer opportunities between wireless devices carried by humans, we observe that the distribution of the inter-contact time, that is the time gap separating two contacts of the same pair of devices, exhibits a heavy tail such as one of a power law, over a large range of value. This observation is confirmed on six distinct experimental data sets. It is at odds with the exponential decay implied by most mobility models.** ... time as the time between two transfer opportunities, for the same devices. We observe in the six traces that the inter-contact time distribution follows a heavy tailed distribution on a large range of values. Inside this range the inter-contact time distribution can be compared to the one of a power-law. We study the impact of those heavy tailed inter-contact times on the actual performance and ...

Less is More: Long Paths do not Help the Convergence of Social-Oblivious Forwarding in Opportunistic Networks

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Marco Conti, IIT-CNR, Via G. Moruzzi 1, 56124, Pisa, Italy, marco.conti@iit.cnr.it
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ABSTRACT
Message delivery in opportunistic networks is substantially affected by the way nodes move. Given that messages are handed over from node to node upon encounter, the intermeeting time, i.e., the time between two consecutive contacts between the same pair of nodes, plays a fundamental role in the overall delay of messages. A desirable property of message delay is that its expectation is finite, so that the performance of the system can be predicted. Unfortunately, when intermeeting times feature a Pareto distribution, this property does not always hold. In this paper, assuming heterogeneous mobility and Pareto intermeeting times, we provide a detailed study of the conditions for the expectation of message delay to converge when social-oblivious forwarding schemes are used. More specifically, we consider different classes of social-oblivious schemes, based on the number of ...

and disconnected subnetworks, that would impair communications in traditional Mobile Ad Hoc Networks. Opportunistic networks are an instance of the delay tolerant paradigm applied to networks made up of users' portable devices (such as smartphones and tablets). In this scenario, user mobility becomes one of the main drivers to enable message delivery. In fact, according to the store-carry-and-forward paradigm, user devices store messages and carry them around while they move in the network, exchanging them upon encounter with other nodes, and eventually delivering them to their destination.

An opportunistic forwarding protocol defines the strategy according to which messages are exchanged during encounters. Two main approaches can be identified. On the one hand, there are *social-oblivious* protocols, which do not exploit any information about the users' context and social ...

IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 60, NO. 5, JUNE 2011 2181

DelQue: A Socially Aware Delegation Query Scheme in Delay-Tolerant Networks

Jialu Fan, *Student Member, IEEE*, Jiming Chen, *Member, IEEE*, Yuan Du, Ping Wang, *Member, IEEE*, and Youxian Sun

Abstract—**In delay-tolerant networks (DTNs), information search is a significant topic that has yet to be widely investigated. Although social-based approaches can be used to address the problem, most existing schemes employ the multihop paradigm and leave out the severe resource constraint in DTNs. In this paper, we experimentally explore several realistic data sets and then reveal that users' one-hop neighbors can cover most range of the whole network in a reasonable time period, which lays a solid fundamental for two-hop information search schemes. Therefore, we propose *DelQue* (delegation query), which is a novel two-hop delegation query scheme integratedly considering *query* and *response* to save network energy in terms of the number of involved relays. In *DelQue*, we exploit the social utility of each neighbor to ...**

including battlefield operations, vehicular ad hoc networks, and disaster response scenarios [4]–[7].

Recently, the majority of work in DTNs (e.g., [8]–[10]) focus on routing schemes. However, the ability to rapidly and conveniently access information is also an important feature that DTNs should have since the ultimate goal of establishing such networks is to allow mobile users to quickly and efficiently access information. For example, soldiers in a battlefield need to access information related to commands from the general, detailed geographical map, information about enemy locations, weather information, etc. To bring these applications to the ...

- Decision on hop count is not clear in the literature: two hops or more?

Three components of search

1. Content: scarce item or densely available item?
2. User's tolerated waiting time: low patience or tolerant to delay?
3. Search cost: avoid bandwidth waste and battery consumption

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   - Content availability: α
2. User's tolerated waiting time: low patience or tolerant to delay?
   - TTL of the message: T
3. Search cost: avoid bandwidth waste and battery consumption
   - hop-limit: h

Modeling of hop-limited search

- Total N nodes in the network
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$$\boxed{P_s = 1 - (1 - \alpha\gamma)^K \text{ where } \gamma = \frac{K}{N-1}}$$

Search success

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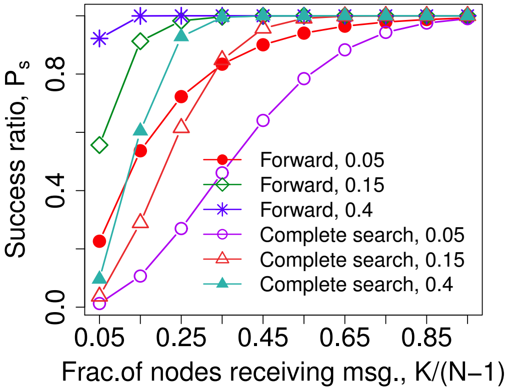

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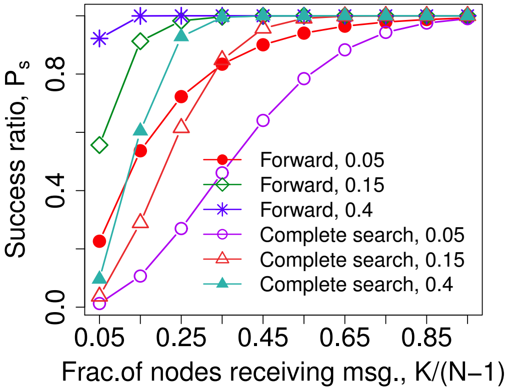

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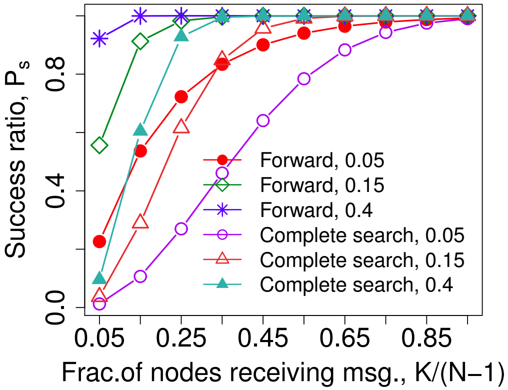

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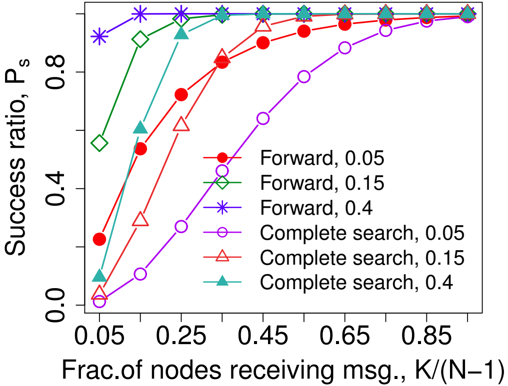

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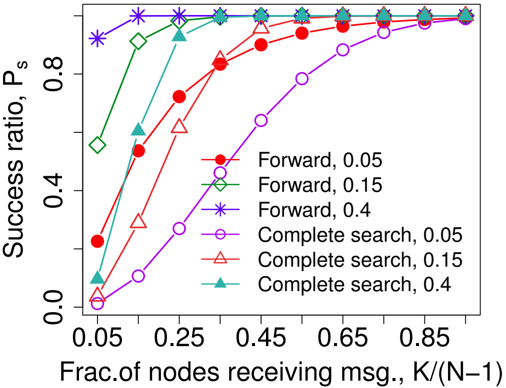

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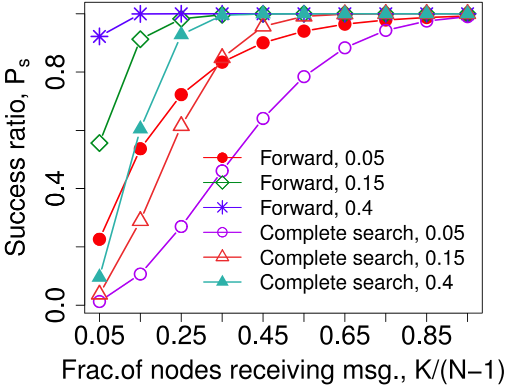

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Our approach: find $N_h(T)$ from real traces and plug into P_s

Search success ratio: simulations

- Infocom06 (98 nodes, conference)
- Cabspotting (around 500 nodes, San Francisco cabs)
- Helsinki City Scenario (synthetic)

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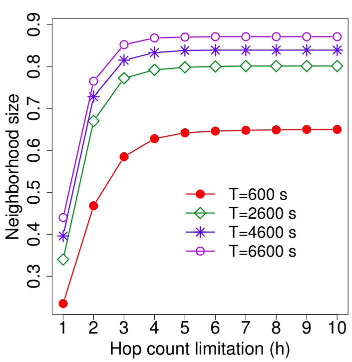
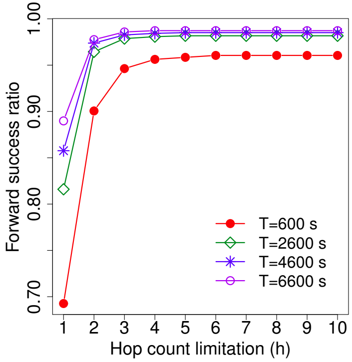
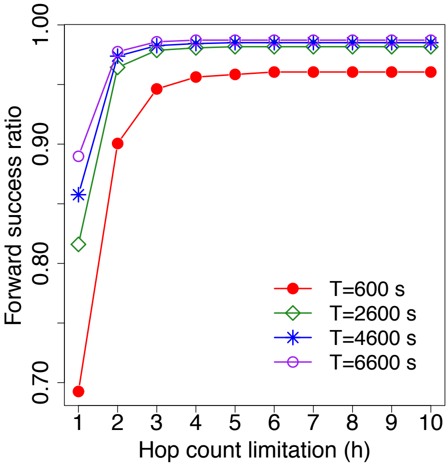




Search success ratio: simulations

Key take-away:

- Second hop brings the highest benefits for content discovery
- But still improvements for $h \leqslant 4$
- Minimal improvement $\rightarrow$ not significant increase in user satisfaction

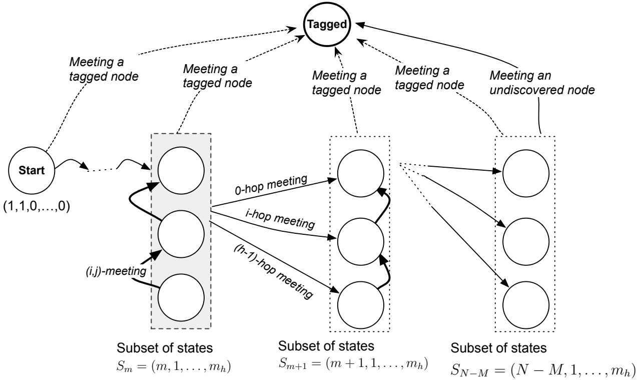


Search completion time

Continuous Time Markov Chain modeling of the forward path: T_h

- Return path = forward path with $\alpha = \frac{1}{N-1}$
- $\tilde{T}_h$: an approximation for T_h, meeting rate λ, details in the paper!

$$\tilde{T}_h = \sum_{i=0}^{\infty} \frac{(1-\alpha/\lambda)^i}{\lambda(1+i(1-h^{-1}))}.$$



Search completion time: CTMC model

α	Time	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$
Low	T_h	1	0.21	0.13	0.12	0.11
	$\tilde{T}_h$	1	0.14	0.12	0.11	0.11
	Error	0	-0.32	-0.08	-0.03	-0.03
Medium	T_h	1	0.40	0.33	0.31	0.31
	$\tilde{T}_h$	1	0.39	0.35	0.33	0.33
	Error	0	-0.01	0.07	0.06	0.05
High	T_h	1	0.51	0.46	0.45	0.45
	$\tilde{T}_h$	1	0.54	0.49	0.47	0.46
	Error	0	0.05	0.08	0.06	0.04

- Notice the drastic decrease at $h = 2$

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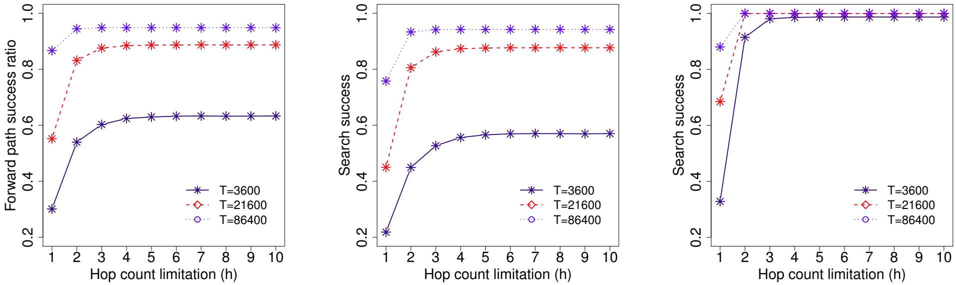
- $\tilde{T}_h$ provides pretty accurate approximation of T_h

How about in the wild?

Complete search: Simulations

- Realism included: simulations using ONE simulator
- We want to understand:
  - validity of our conclusions from the model (second hop!)
  - average (temporal and hop) distance to content provider
  - average (temporal and hop) distance to the searching node
  - forward path vs. return path
  - search cost

Search success: low content availability ($\alpha = 0.05$)



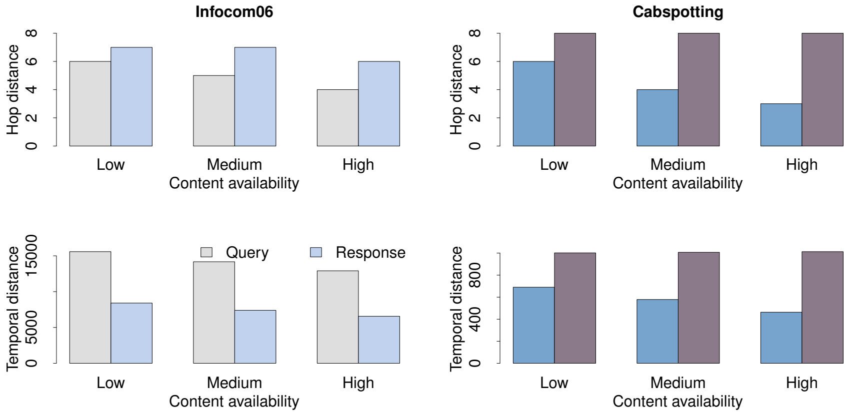
(a) Infocom06 (b) Infocom06 SF cabs

- Second hop!
- High tolerated waiting time: wait till meeting the content provider!
- SF cabs have higher contact opportunities

Where is the content?

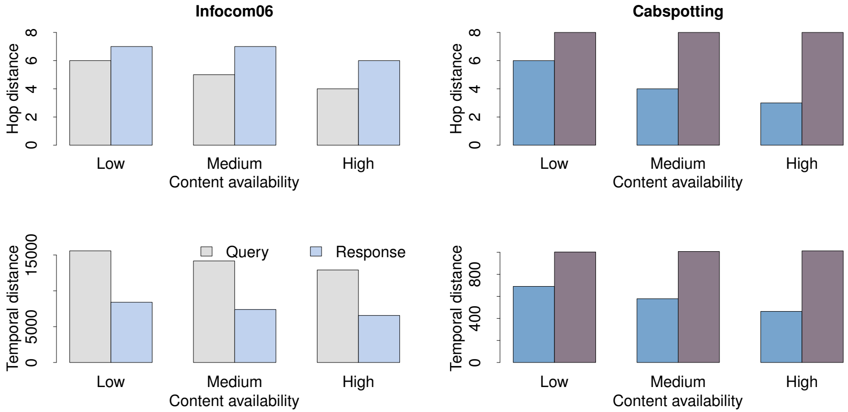
No hop or time restriction, epidemic search

Where is the content?



Left bars: query, right bars: response

- Content's location depends on content availability: forward path
- Distance to searching node: independent of content availability



Forward and return paths: are they correlated?

- ρ: Pearson correlation coefficient of forward and return paths
- γ: Difficulty of return path compared to forward path (i.e., ratio)

T	α	ρ_{hop}	ρ_{temp}	γ_{hop}	γ_{temp}	P_h	P_s
600	Low	0.30	0.36	1.47	2.23	0.35	0.30
	Med.	0.29	0.34	1.72	3.09	0.42	0.34
	High	0.27	0.32	1.97	4.02	0.48	0.38
3600	Low	0.35	0.43	1.4	2.18	0.63	0.57
	Med.	0.35	0.38	1.61	2.98	0.67	0.61
	High	0.33	0.32	1.85	4.13	0.70	0.65
86400	Low	0.33	0.13	1.39	2.60	0.95	0.94
	Med.	0.35	0.13	1.62	3.52	0.95	0.94
	High	0.35	0.12	1.86	4.50	0.95	0.95

No strong correlation (effect of restricted tolerated time)

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Return path is more challenging

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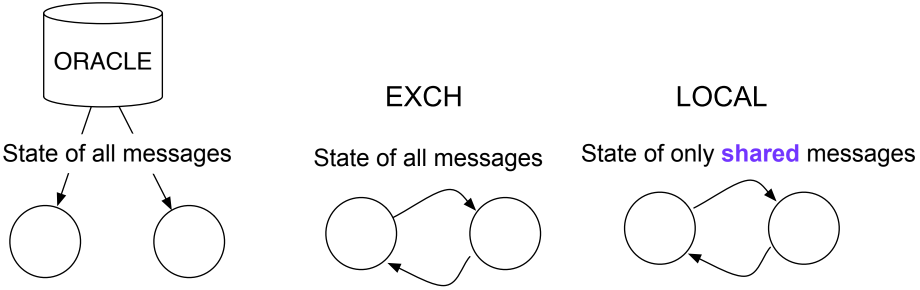
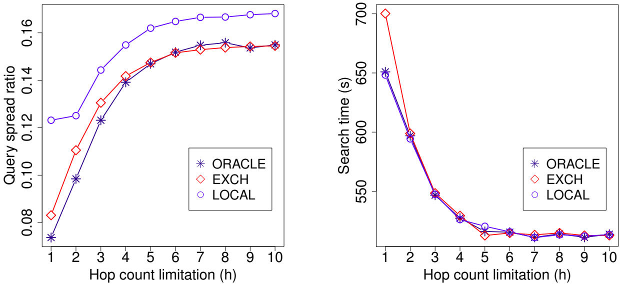


Search cost with increasing hop count



- Even local knowledge is sufficient, thanks to the small network diameter!
- Two-hops improves a lot, but further hops help decreasing search completion time.

Take aways from our paper

- Hop-limited search:
  - content availability and mobility
  - tolerated waiting time
- Second hop brings the highest benefits but further hops still improve search performance
- Small world networks, i.e., no benefit after 4-5 hops
- Return path is more challenging

Thanks!

http://www.netlab.tkk.fi/tutkimus/pdp/

supported by Finnish Academy of Science

Related Works

- Optimal hop count: MsWiM 2014
  Esa Hyytiä, Suzan Bayhan, Jörg Ott, Jussi Kangasharju
- Availability estimation: ComCom 2015
  Esa Hyytiä, Suzan Bayhan, Jörg Ott, Jussi Kangasharju