Social Evolving Networks: Models and Information Spreading

Joint work of

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Outline

1. Motivation and models overview

(P. Santi)

2. Information spreading in social evolving networks

(F. Pasquale)

3. Conductance and information spreading

(L. Becchetti)

Part I:
Motivation and models overview

Introduction

Goal:

Investigating the dynamics of information spreading in mobile social networks (**MSNs**)

What are MSNs?

MSNs are a specific type of opportunistic (or delay-tolerant) network in which mobile nodes are individuals (hence, ***social entities***) carrying smart phone/PDA or similar devices. Nodes in an MSN can establish direct wireless communication links and exchange msgs when close to each other

Features of MSN:

The network is ***very sparse*** and ***always disconnected***; small "connectivity islands" – communication opportunities – arise thanks to node mobility; mobility is essentially the only communication means within the network

State-of-the-art

Where we are:

- Some recent results on information spreading in Markovian Evolving Graphs (MEG) – ***discrete time model***: Given any two nodes *u*,*v* in the network, existence of edge (*u*,*v*) is modeled as a two-state Markov chain, with state 0 = **“No link”**, state 1 = **“Link”**, and transition probabilities *p* (link birth rate) and *q* (link death rate)

[CMMPS08] A. Clementi, C. Macci, A. Monti, F. Pasquale, R. Silvestri, *“Flooding Time in Edge-Markovian Dynamic Graphs”*, Proc. ACM PODC, 2008.

…

- Some recent results on bounding unicast delivery time in opportunistic networks – ***continuous time model***: Given any two nodes *u*,*v* in the network, the inter-meeting time between nodes *u*,*v* is modeled as an exponential r.v. with a certain, fixed parameter λ

[GNK05] R. Groenvelt, P. Nain, G. Koole, *“The Message Delay in Mobile Ad Hoc Networks”*, Performance Evaluation, 2005.

…

What about "social structure"?

Shortcoming of existing approaches:

"Social structure" of the collection of individuals forming an MSN is completely ignored: the *"connectivity properties"* (probability of having a communication opportunity) between two network nodes *u*,*v* are statistically equivalent to those between any other pair of nodes *w*, *z*. ***This is very distant from reality!!***

How can we take social structure into account in the analysis?

First attempt in a recent manuscript: analysis of unicast performance in MSNs in the continuous-time model, where meeting rate λ_{uv} depends on the degree of **"interest similarity"** between *u* and *v*

[DMMSS11] J. Diaz, A. Marchetti-Spaccamela, D. Mitsche, P. Santi, J. Stefa, *"Social-Aware Forwarding Improves Routing Performance in Pocket Switched Networks"*, submitted for publication, 2011.

Our goal

Our goal in this work is **gaining an understanding of the dynamics of information propagation in MSNs**

The following questions are of interest to us:

1. **What is the effect of "social structure" on information propagation speed?** Given the same "density of contacts", does a "social structure" ***increase*** or ***decrease*** information propagation speed? Intuition says: ***increase***, but formally proving this fact is not at all trivial
2. **What is the effect of "social structure" on the total number of messages (message complexity) to be sent to reach all nodes in the network?**

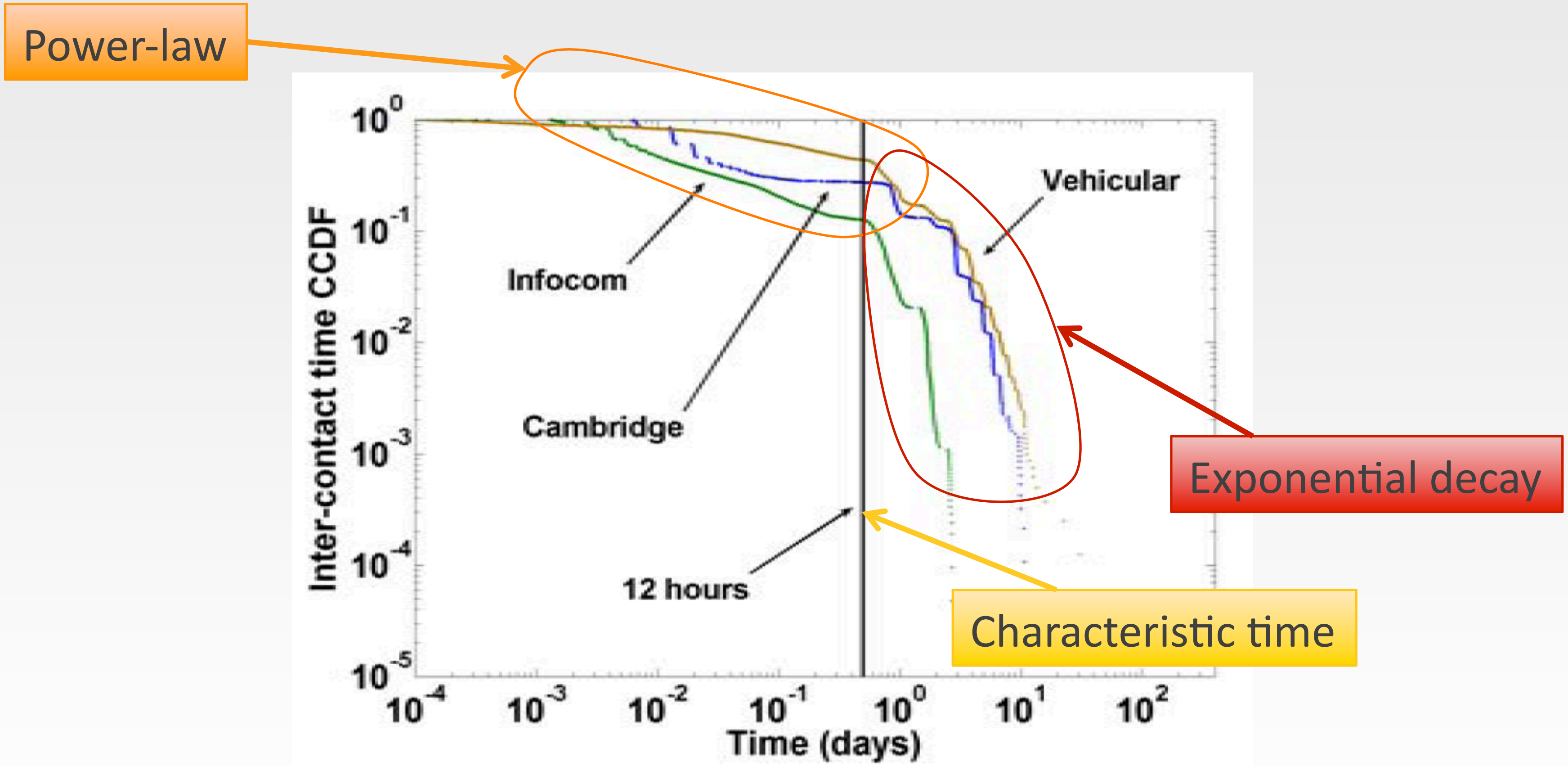
Modeling MSNs

A first challenge to address to tackle questions 1. and 2. is to define an ***analytically tractable model*** of MSN ***accounting for "social structure"***

Should we go for a continuous or discrete model?

Our choice is **discrete**, so that we can re-use the machinery of the recently proposed **MEG** approach

The dichotomy of inter-contact time distribution



Aggregated inter-contact time ccdf for three data sets
(taken from **[KLV07]**)

Inter-contact time distribution dichotomy (2)

Main finding of [KLV07]:

Inter-meeting time distribution displays a dichotomy:

There exists a *characteristic time* *T* (about 12 hours) such that inter-meeting time distribution behaves as a **power-law** before time *T*, and behaves as an **exponential distribution** after time *T*

Can the exponential tail of the distribution be ignored in analyzing opportunistic network performance?

No, because the **mean inter-meeting time** is often **larger than the characteristic time**, so the exponential tail cannot be ignored

[KLV07] T. Karagiannis, J.-Y. Le Boudec, M. Vojnovic, *"Power Law and Exponential Decay of Inter Contact Times between Mobile Devices"*, Proc. ACM Mobicom, 2007.

Modeling the ICT distribution dichotomy

Can we define a ***simple***, ***analytically tractable***, ***discrete-time*** model which is able to **reproduce the inter-contact time distribution dichotomy** observed in real world traces?

OPEN PROBLEM IN THE LITERATURE

To address the above question, let's go back to [KLV07]. The authors give a possible explanation of the observed inter-contact time distribution dichotomy

Dichotomy: possible explanation

Which could be a possible explanation of the observed inter-contact time distribution dichotomy?

In [KLV07], the authors attempt to answer this question by analyzing the relationship between the **return time** and the **inter-contact time** distribution

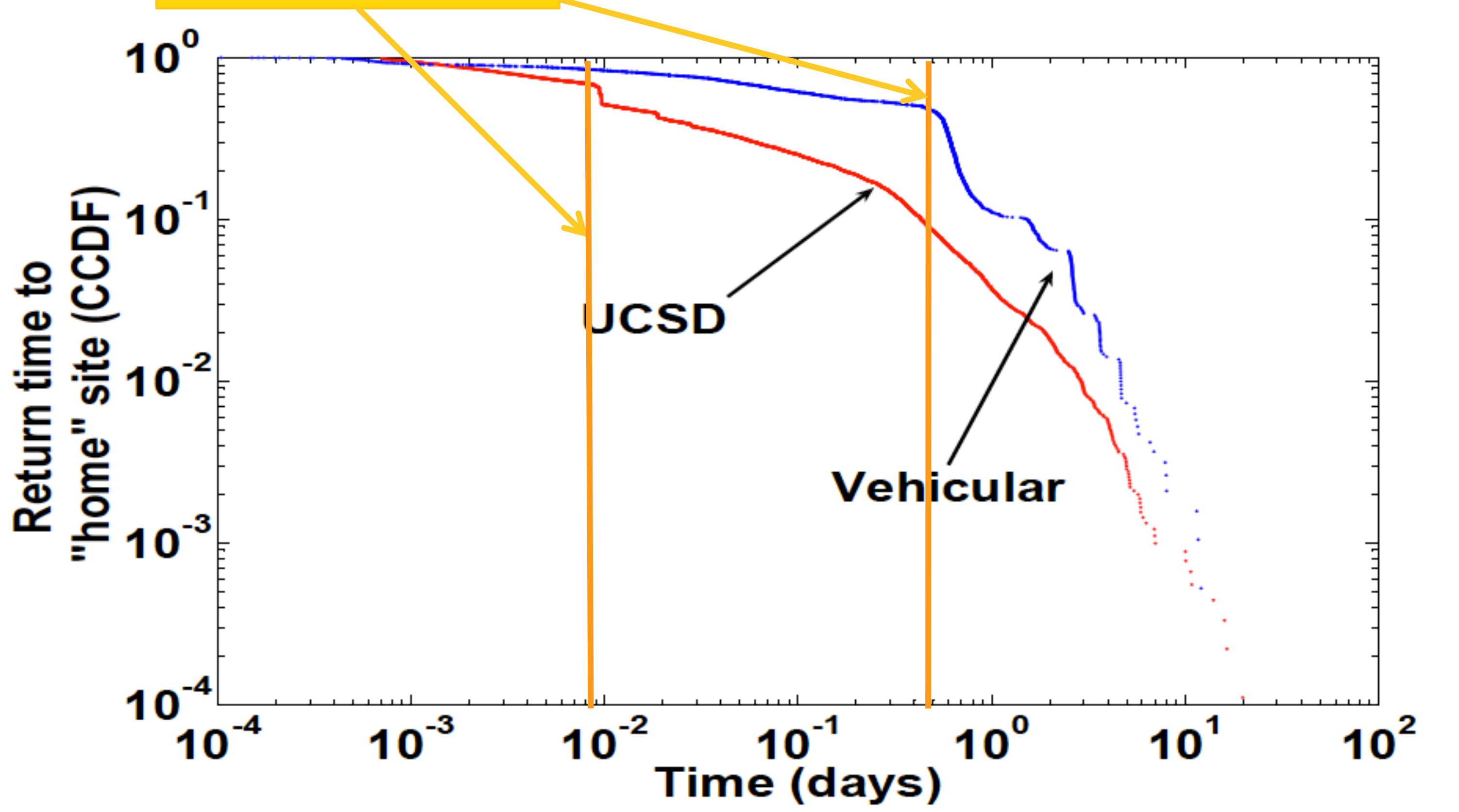
Return time: time for a node to return to its **"home site"**

"Home site": location where the node spends most of the time

In real-world traces, **"home site"** is defined as the most visited AP/cell, or geographical region (for vehicular traces)

Return time distribution

Characteristic time



Return time distribution for two real-world traces
(taken from **[KLV07]**)

Return vs. inter-contact time

Why are return and inter-meeting time related?

Hypothesis:

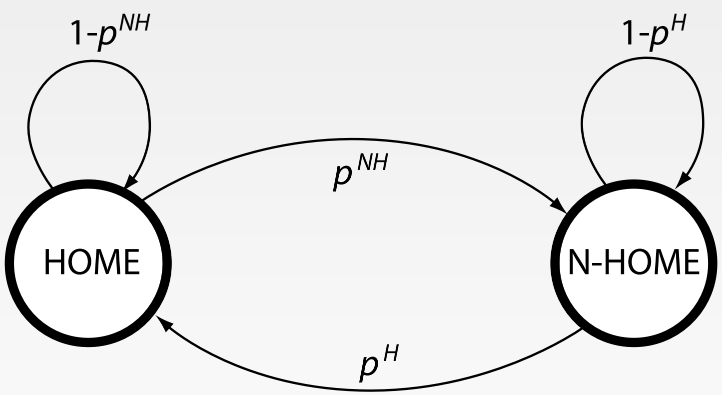
Two mobile nodes always meet at a particular site – **"meeting site"**

Under the above hypothesis, **inter-contact time** is *stochastically larger* than **return time** of any of the two nodes to the **"meeting site"**

If the two devices are *time-synchronized*, then **return time to "meeting site"** would closely characterize **inter-contact time** between the two nodes

The Home-MEG model

The **Home-MEG** model builds upon the intuition that ***nodes tend to meet in a single place*** (Home location). Thus, the probability of having a contact opportunity between nodes *u*,*v* is p_{high} if the two nodes are at home, and p_{low} if one of the two nodes (or both) are in the outside world



The **Home-MEG** model for a node pair *u*,*v* is thus a simple two-state Markov chain, where state is HOME when both *u*,*v* are at home location, and NotHOME otherwise

Home-MEG model for a network of *n* nodes: *n*(*n*-1)/2 replicas of statistically identical Home-MEGs

The Home-MEG model (2)

The **Home-MEG** model thus has four parameters:

1. p_{NH} = probability of transition to state NH
2. p_H = probability of transition to state H
3. p_{high} = probability of having a (***instantaneous***) contact opportunity when in state H
4. p_{low} = probability of having a (***instantaneous***) contact opportunity when in state NH

Can we set the values of (p_{NH} ,p_H, p_{high}, p_{low}) so to resemble inter-contact time distribution of real-world traces?

The ICT distribution in the Home-MEG model

Prob($ICT=k$) = Prob ($H|Contact$) P_{kH} + Prob ($NH|Contact$) P_{kN}

where

$P_{iH} = p^{NH} (1-p_{low})P_{(i-1)N}+(1- p^{NH})(1-p_{high})\ P_{(i-1)H}$

$P_{iN} = (1- p^{H})\ (1-p_{low})P_{(i-1)N}+ p^{H} (1-p_{high})\ P_{(i-1)H}$

for $i = 2,\ldots,k$ ***and***

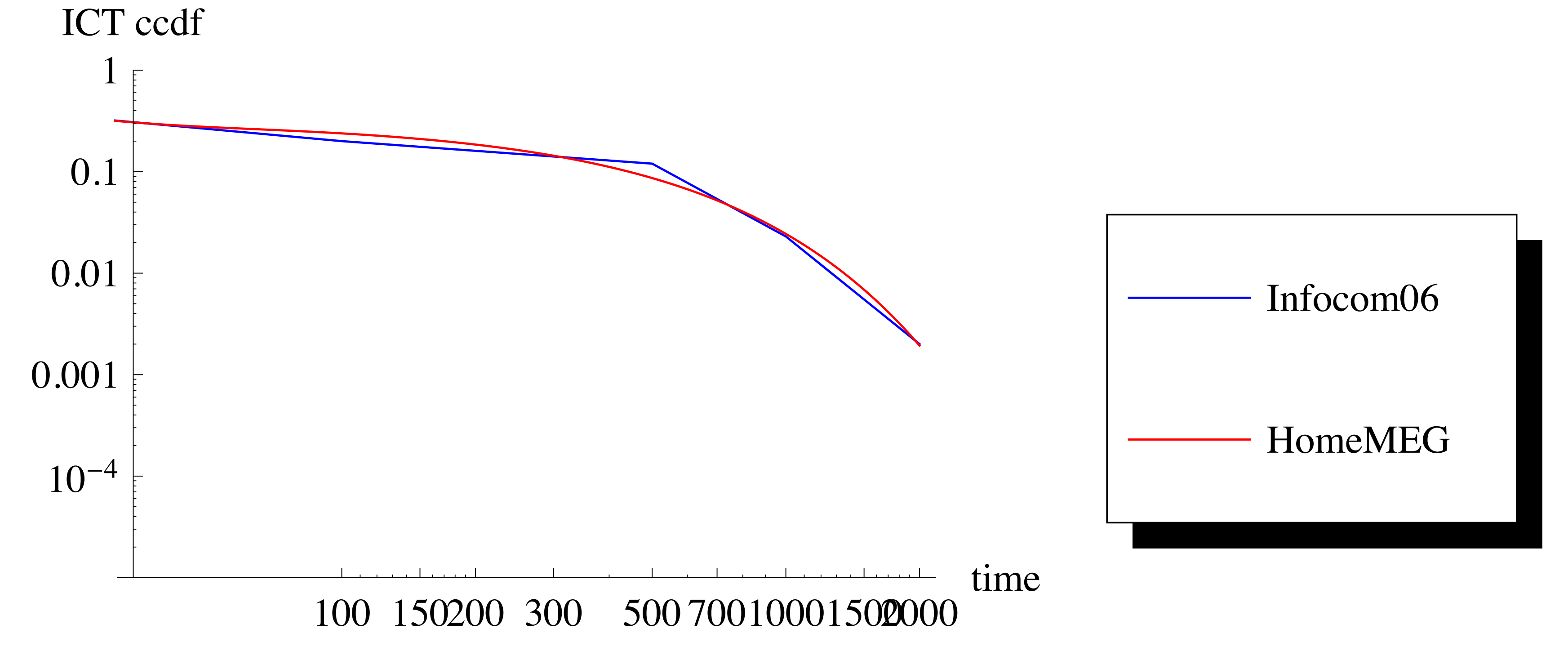
$P_{1H} = p^{NH}\ p_{low} + (1- p^{NH})p_{high}$

$P_{1N} = (1- p^{H})\ p_{low}+ p^{H}\ p_{high}$

Prob ($H|Contact$) = $(p^{H}\ p_{high})/(p^{H}\ p_{high} + p^{NH}\ p_{low})$

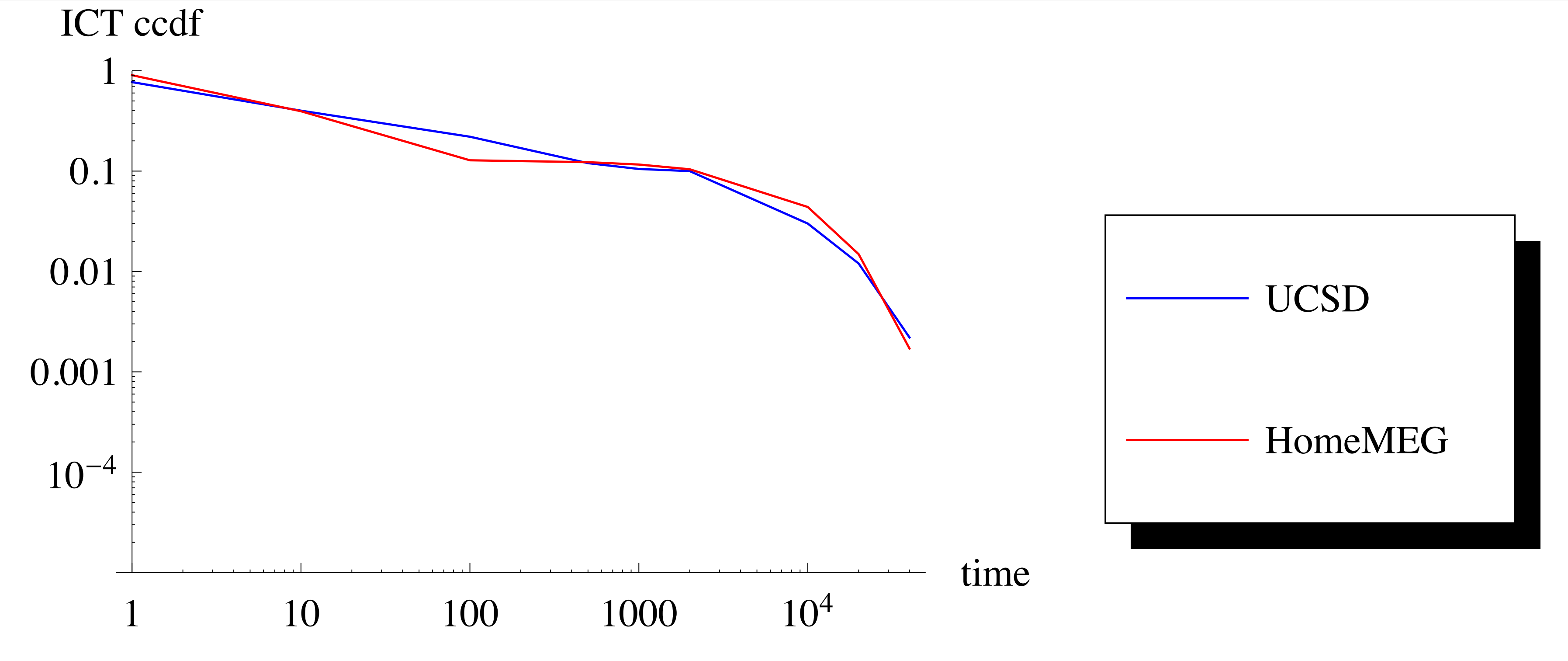
Prob ($NH|Contact$) = $(p^{NH}\ p_{low})/(p^{H}\ p_{high} + p^{NH}\ p_{low})$

Home-MEG model: validation



HomeMEG model (p_{NH} = 0.025, p_H = 0.003, p_{high} = 0.07, p_{low} =0.0003) vs. Infocom06 trace

Home-MEG model: validation (2)



HomeMEG model (*p_{NH}* = 0.0133,*p_H* = 0.00011, *p_{high}* = 0.1, *p_{low}* =0.00001) vs. UCSD trace

Looking at parameters

Let us give a look to the values of parameters of best fit Home-MEG model for Infocom06 and UCSD trace

Parameter	Infocom 06	UCSD
p^{H}	3×10^{-3}	1.1×10^{-4}
p^{NH}	25×10^{-3}	13.3×10^{-3}
p_{high}	7×10^{-2}	10×10^{-2}
p_{low}	3×10^{-4}	1×10^{-5}
p_{HOME}	0.107	0.008
P_{high}/p_{low}	233.33	10000

Useful assumptions in the analysis: $p_{HOME} << p_{NHOME} = 1 - p_{HOME}$, and $p_{low} << p_{high}$

To do list and open problems

1. Can we ***formally prove*** the power law/exponential tail dichotomy in the Home-MEG model?

   A formal proof of the above mentioned dichotomy seems complex: the generic term Prob(*ICT*=*k*) is a high order polynomial with a number of terms exponential in *k*

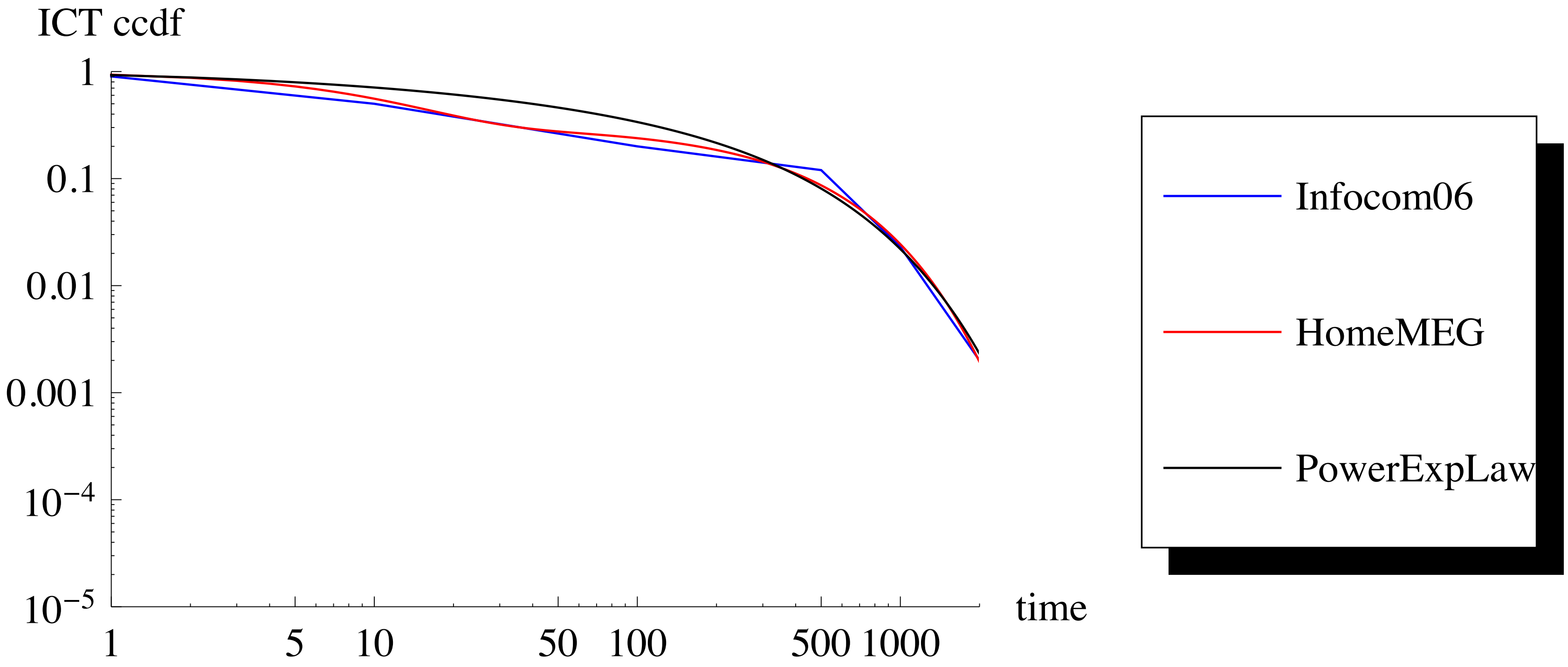
   We have empirically proven that Prob(*ICT*=*k*) can be approximated by an **power law distribution** with **exponential cutoff**:

   $\mathrm{Prob}(ICT=k) \approx (k-1)^{-\alpha} e^{-\beta(k-1)} / E_\alpha(\beta)$ and $\mathrm{Prob}(ICT > k) \approx (k-1)^{1-\alpha} E_\alpha(\beta(k-1)) / E_\alpha(\beta)$

   where $E_\alpha(\beta)$ is the exponential integral function defined as:

   $$E_\alpha(\beta) = \int_1^\infty \frac{e^{-\beta t}}{t^\alpha} dt$$

Home-MEG model: validating dichotomy



HomeMEG model vs. Infocom06 trace vs. Power law with Exponential cutoff (α = 0.829, β = 0.0018)

To do list and open problems

2. Study the dynamics of **information propagation** in Home-MEG networks

3. The **"social structure"** is only ***implicitly*** accounted for in the Home-MEG model. Can we generalize the Home-MEG model ***explicitly*** taking into account **"social structure"**?

To do list and open problems (2)

Possible Social-HMEG model:

- ✓ A network of n nodes is modeled through m_1 Home-MEGs of **type 1**, and $n(n\text{-}1)/2 - m_1$ Home-MEGs of **type 2**
- ✓ **type 1** Home-MEG: models contacts between nodes in the same **"community"** → $p_{high} >> p_{low}$
- ✓ **type 2** Home-MEG: models contacts between nodes in different **"communities"** → $p_{high} \approx p_{low} \approx 0$

Open question:

Does the (aggregate) ICT distribution in the Social-HMEG model display the power-law+exponential tail dichotomy?