Delay and Capacity Analysis of Structured P2P Overlay for IP Telephony

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Objectives

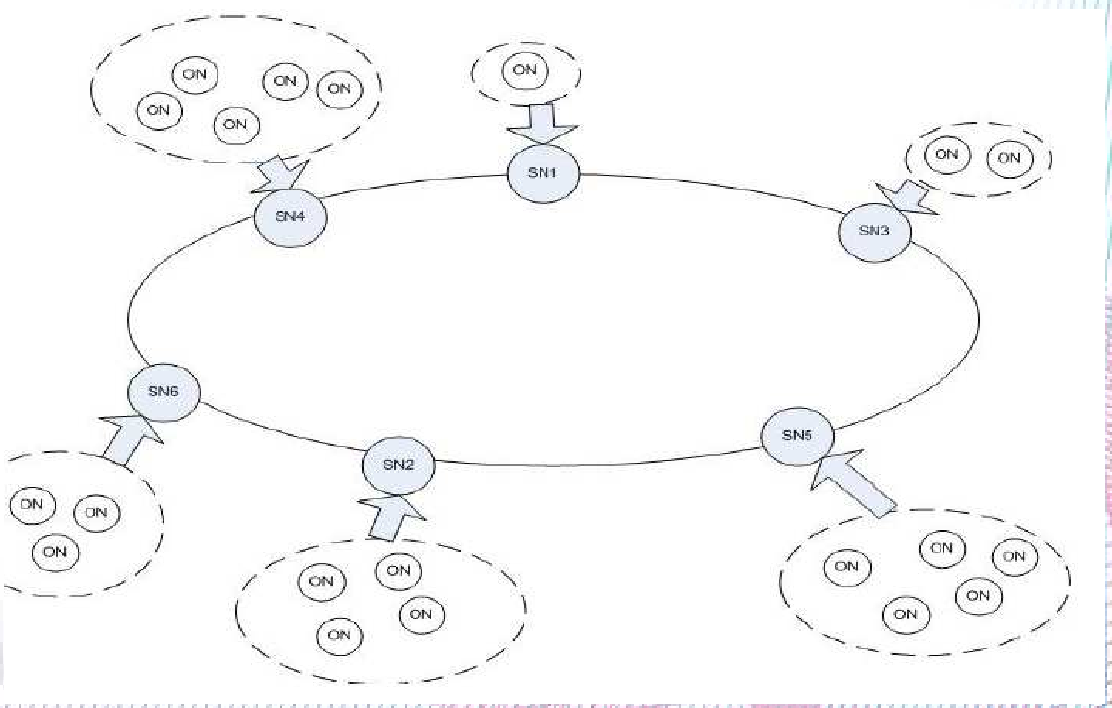
- Modeling P2P network used as a service control overlay for session-based applications like IP telephony
  - Obtaining the quantitative formulations for the effect of P2P network parameters on the performance parameters
    - Session setup delay (SSD)
      - Post-dialing delay
    - System capacity
      - Number of customers for a given resource and vice versa

P2P for lookup service

- A system with Super-nodes (SN) and client nodes (CN)

SN form a P2P overlay.
CN use this overlay for

- Lookup (who/where is alice)
- The actual voice communication is directly between bob and alice



Motivation

In a SN based P2P look-up service overlay, determining:

- how the average session set-up delay (SSD) might vary with varying the number of SNs can be very useful
- how the capacity (in terms of lookup processing rate) of the overlay scales with an increase in number of SN might also be equally useful.

“The basic question of **HOW MANY SUPERNODES**”

Contributions

- Queuing network based model for modeling the look-up process and the delay of Chord-based structured P2P routing.
  - Closed form expression for: lookup hops, lookup delay and “absorption probability”
  - Formulation of the relevant parameters in terms of so-called “absorption probability” allows the model to be extended to other P2P structures.
  - Closed-form expression for the capacity of the overlay as a function of the number of SN.
  - The expression for optimum number of SN for minimum SSDs
  - A trade-off relationship between capacity and delay

Analysis of Chord Routing

- The chord [1] routing is well known but very complex to analyze.
- We idealize chord routing considering a deterministic placement of nodes and modeling the routing process as a tree
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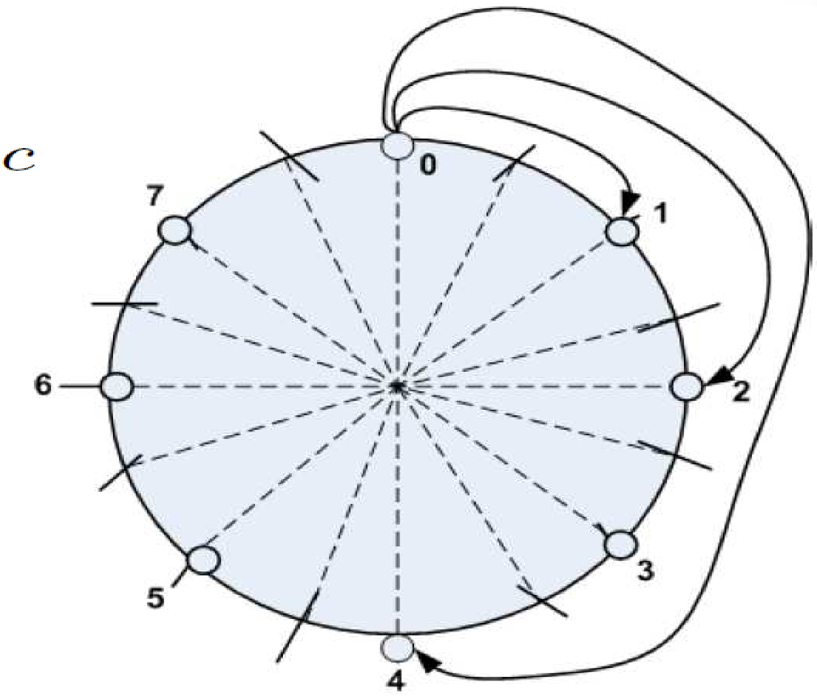
Model assumptions

- Keyspace $K = 2^k$
- Number of Nodes $N = 2^c$
- Each SN is assigned to serve $2^{(k-c)}$ keys
- No consideration to Churn for simplifying the model.
  - Up time of a typical skype SN is about 2 hours [2] and lookup ends up in a matter of few seconds



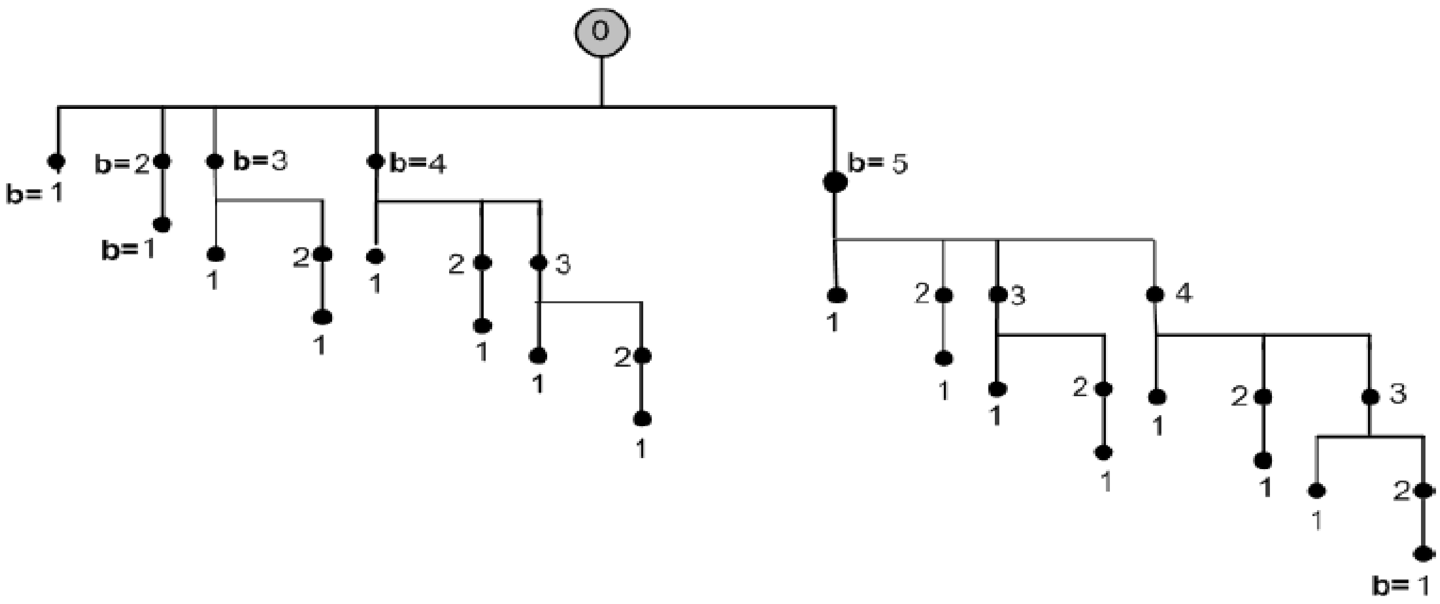
Key Results

- Lemma 1
  - For $N \leq K$ the peer out degree is c.
- Lookup routing path tree (LRPT): the probable routing path of a lookup messages originating at a given SN as a tree.

- **Absorption:** When a look-up message is received by a SN i, if the lookup is destined to it or its CN, then the lookup is no more forwarded and considered to be absorbed.
- **E*b*-NRSN** (Effective *b*-neighbor reachable SN): For a given SN *i*, an Eb-NRSN is a SN in the LRPT of SN *i* that, apart from absorption possibility, have *(b-1)* possible forwarding branches.

LRPT

- Lemma 2: The lookup message forwarded to *i*th neighbor can either be terminated instantly or can be forwarded to one of the first *(i - 1)* neighbors of the ith neighbor.



LRPT: E*b*-NRSN

- Lemma 3: Each E*b*-NRSN is referred to it by its predecessor for $(2^{b-c-1}K)$ keys
- The probability that an Eb-NRSN is eventually referred by the originator SN is given as

$$\pi_b = \frac{1}{2^{c-(b-1)}}$$

- $Number\ of\ Eb\text{-}NRSN\ (n_b) = 2^{(c-b)}$

$Number\ of\ SNs\ for\ which\ a\ SN\ is\ Eb\text{-}NRSN = 2^{(c-b)}$

Absorption probability and lookup hops

Definition 1. *Absorption Probability ($P(N)$) of a SN is defined as the probability with which an incoming lookup is terminated at this SN. An incoming lookup message can be a new lookup request generated by the CN associated with the given SN; or it could have been forwarded to the SN by its predecessor(s).*

Lemma 4. *In the given Chord Overlay Model, the absorption probability ($P(N)$) is given as follows*

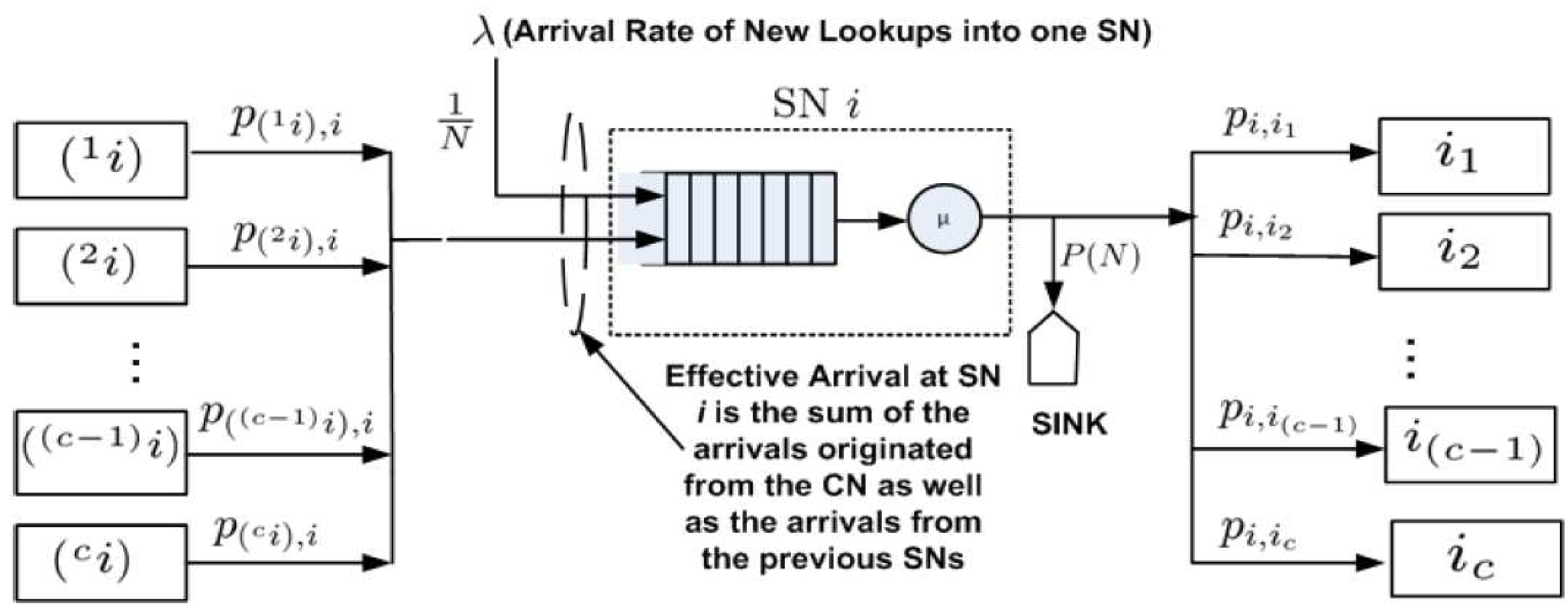
$$P(N) = \frac{1}{(1+\frac{c}{2})} \text{ for } N = 2^c \text{ and } N <= K \quad (4)$$

Lemma 5. *In the given Chord Overlay Model, the average number of SNs visited per lookup ($\overline{S}$) is given as follows*

$$\overline{S} = 1 + \frac{c}{2} \quad (11)$$

Queuing Network Model

- Open Queuing Network (Markovian assumption for Product Form Formulation)



Node Model for an SN

Queuing Network Parameters

- Notations following well-known parameters (e.g. [4])

Parameter	Description
λ_{total}	mean total arrival rate
μ	SN service rate
$({}^k i)$	the SN whose k^{th} finger is SN i
i_k	the k^{th} finger of SN i
$p_{({}^k i),i}$	the routing probability from the SN $({}^k i)$ to SN i
p_{i,i_k}	the routing probability from SN i to SN i_k
$p_{0,i}$	the probability of a lookup message to originate at SN i
$p_{i,0}$	the absorption probability
λ_i	Effective arrival rate in SN_i
e_i	Visit ratio of SN_i
ρ_i	Utilization factor of SN_i

Assumptions on Traffic Model

- Total lookup message arrival process in the system is a Poisson process with λ_{total} mean arrival rate.
- All SNs gets exactly same rate of lookup message requests from their associated CNs
- The destination of a lookup is selected uniformly among all the participating CNs such that for any lookup, the probability of a SN being the destination SN is equiprobable.
- All SNs in the system have an exponentially distributed service time with mean $\frac{1}{\mu}$
- All SNs have an infinite buffer for lookup message

Traffic Parameters in terms of Absorption Probability

Lemma 6. *The visit ratio (e_i), effective arrival rate (λ_i) and the utilization (ρ_i) of a given SN i in the load-balanced chord overlay model is*

$$e_i = \frac{1}{N \cdot P(N)} \qquad \lambda_i = \frac{\lambda_{total}}{N \cdot P(N)} \qquad \rho_i = \frac{\lambda_{total}}{\mu \cdot N \cdot P(N)} \tag{14}$$

$$e_i = \frac{\lambda_i}{\lambda_{total}}, \quad e_i = p_{0,i} + \sum_{j=1}^{N} p_{j,i} \cdot e_j, \quad e_i = e_j$$

$$p_{i,0} = 1 - \sum_{j=1}^{N} p_{i,i_j}, \qquad p_{i,0} = P(N)$$

$$e_i = p_{0,i} + e_i \sum_{k=1}^{c} p_{(^k i),i}, \qquad p_{(^k i),i} = p_{i,i_k}$$

Delay and Capacity

Theorem 1. *The total mean lookup delay (session setup delay) ($\overline{D}$) in the load-balanced chord overlay model is*

$$\overline{D} = \frac{1}{\mu(1-\rho_i)}\left(1+\frac{c}{2}\right) \tag{18}$$

Considering a Jackson formulation (PFQN), delay at a node is given as $\overline{D_i} = \frac{1}{\mu(1-\rho_i)}$

Theorem 2. *The capacity of the load-balanced chord overlay for IP telephony (λ_{max}) can be expressed as follows:*

$$\lambda_{\max} = N \times P(N) \times \mu = \frac{N}{1+\frac{c}{2}}\mu \tag{21}$$

Capacity is bounded by the maximum utilization of 1

Comparison with Simulation

- Simulation carried out in ns-2 (a DES)

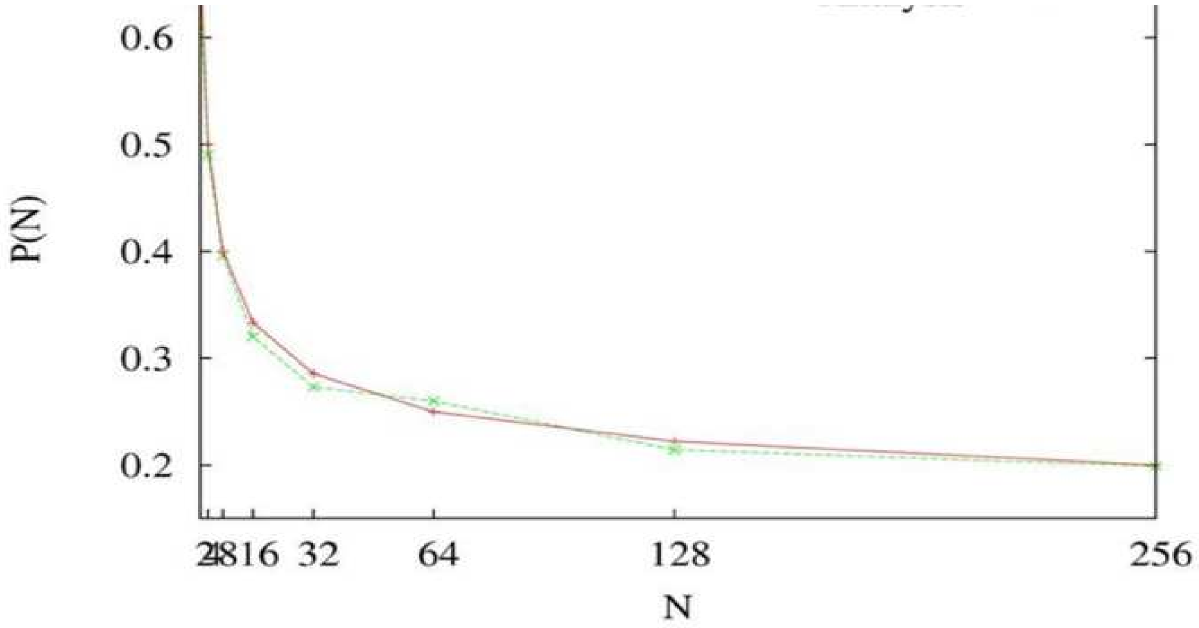


Fig. 5. Absorption Probability versus Different number of SN(N) for Chord-topology overlay scheme with $\mu = 4$ call requests/sec and Call Rate Per node=1 call/2 Mins , $n = 700$

Result (2)

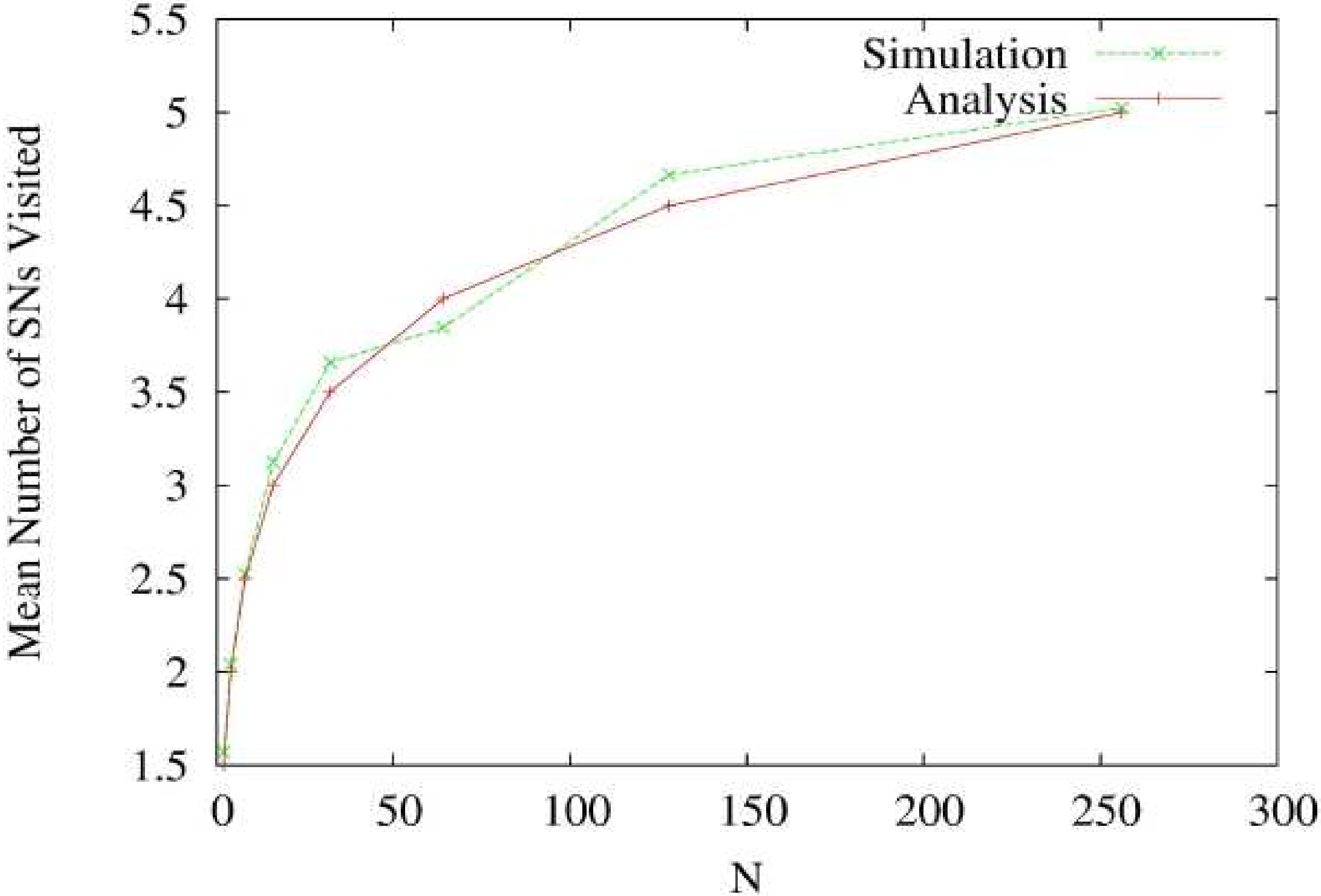


Fig. 4. Average SN visited per Lookup versus N for idealized version of Chord

Result(3)

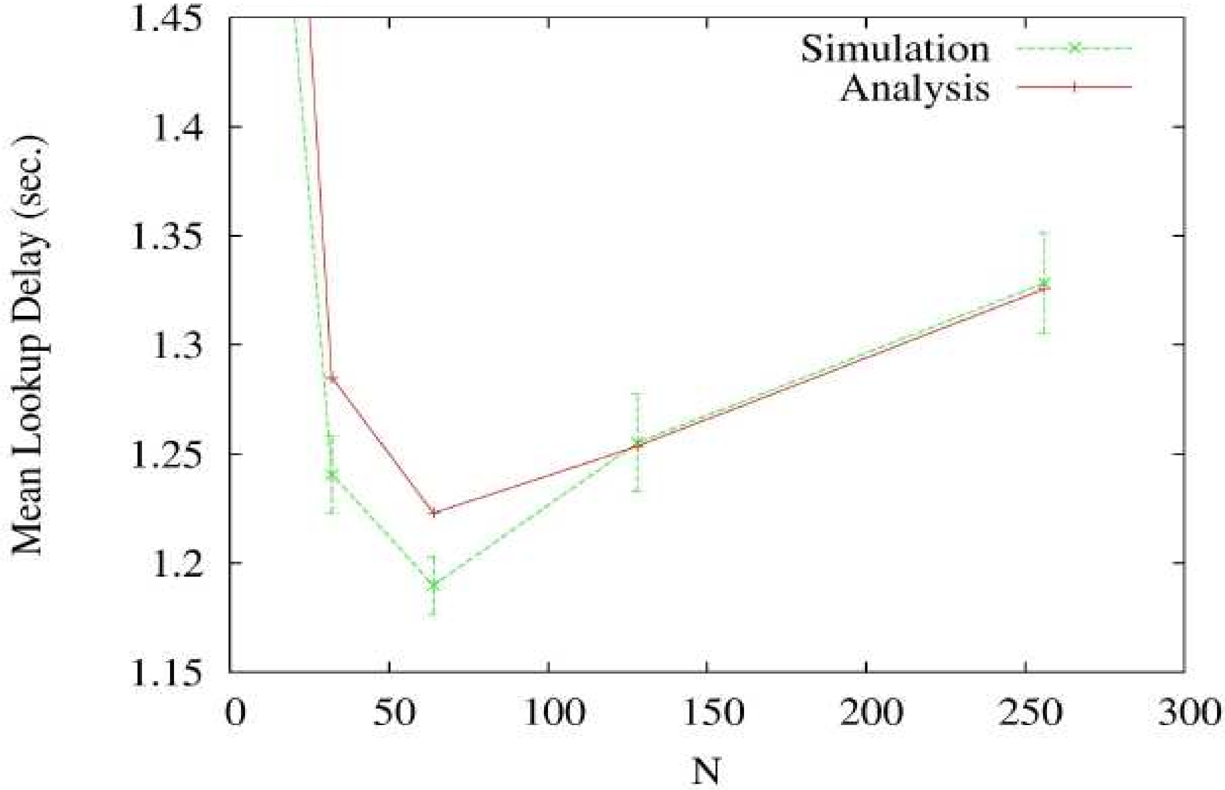


Fig. 7. average Lookup delay in overlay versus number of SN(N) for idealized chord scheme with $\mu = 4$ call requests/sec and Call Rate Per node=1 call/ Mins , $n = 700$

Result (4)

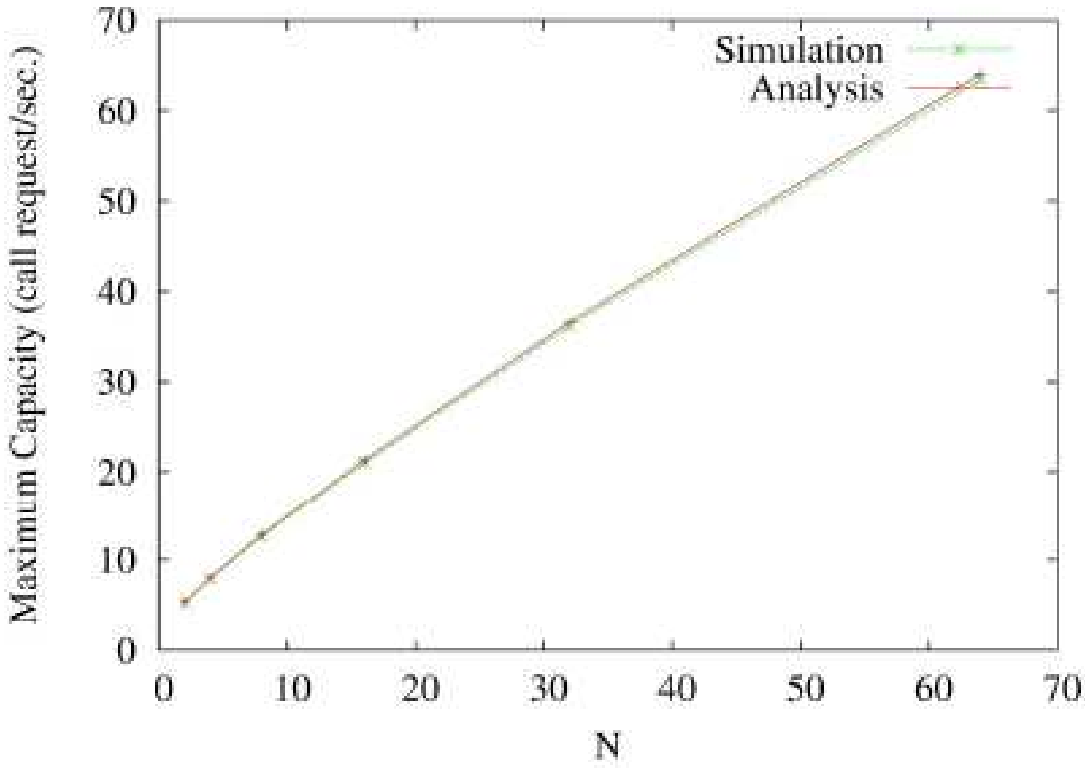


Fig. 8. Maximum lookup rate vs N

Discussion

- Delay: an increase in the number of supernodes (more lookup resources) does not necessarily increase (or decrease)
  - At first, when the load is high, the delay decreases with an increase in N
  - After a certain point, the delay however starts to increase with an increase in the SN resources.
  - An optimum can be easily calculated. This guarantees minimum delay for the given traffic load condition

Discussion(2)

- By adding more SN, the capacity of the network can be increased
  - (even if this happened for chord, this might not be the case, for example we have shown that in ring, a capacity limit is observed.)
- The formulation can be used to dimension such systems (or additionally adding more SN if capacity is exceeded)

Discussion(3)

- After the point of minimum SSD, more SN increases SSD whereas increase system capacity. So, a trade-off relationship exists between the delay performance and the system capacity.

Future work

- Use this model for other P2P networks
  - See our work [4]
- Enhance the model for non-balanced cases

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Thank you

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