Hierarchical routing for large networks

Research seminar on telecommunications software
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Clustering

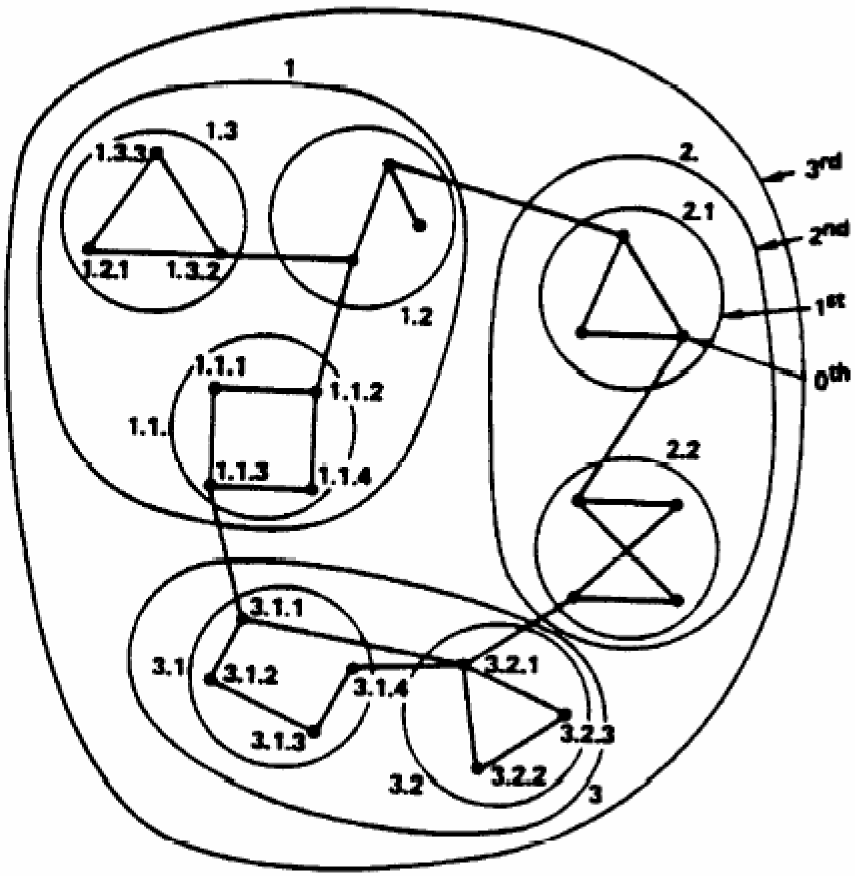
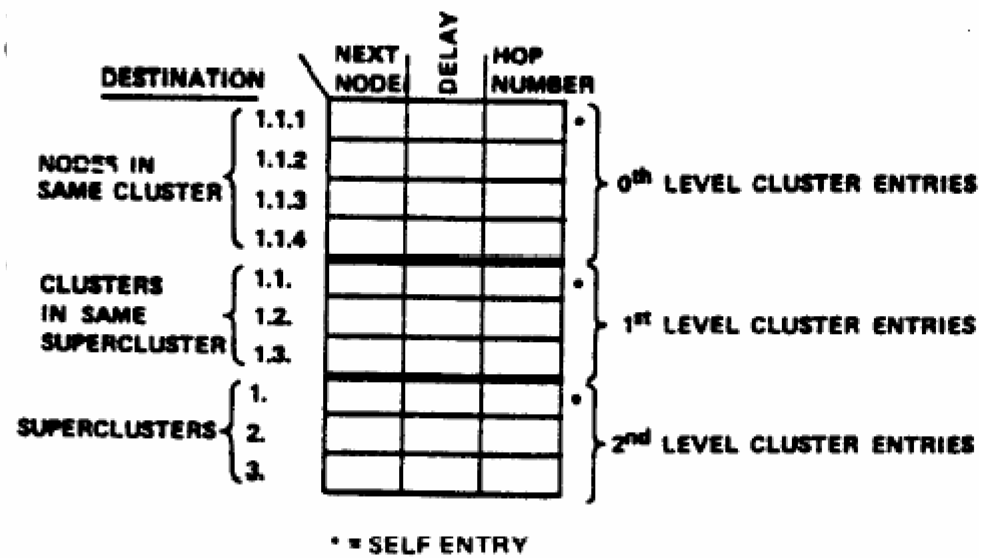


Fig. 1. A 3-level clustered 24-node network.

Routing table reduction:
from 24 to 10



Increase in path length:
3.2.1 -> 3.1.4 by two hops

Notation

- m – number of cluster levels
- N – number of nodes in the network
- l – routing table length
- C_k – kth cluster
- i_m – (m-1)th cluster to which Ck belong
- $n_k = \{n_k(i_{k+1})\}$ degree vector of kth cluster
- $n = (n_1, n_2, \ldots , n_m)$ degree vector
- h – path length in hops
- d – diameter of the network

Minimizing the routing table length

- Real-value solution for fixed m
  - $n_k(i_{k+1})=n_k=N^{1/m}$, $l = mN^{1/m}$
- Global optimal clustering
  - $m = \ln N$, $n_k=e=2.718\ldots$, $l = e \ln N$
- Integer solution
  - Most two clusters of length 2, others 3
- No self-entries
  - $l=mN^{1/m}-m$; $n_k=2$, $m=\mathrm{ceil}(\ln N/\ln 2)$

Reduction of the routing table length

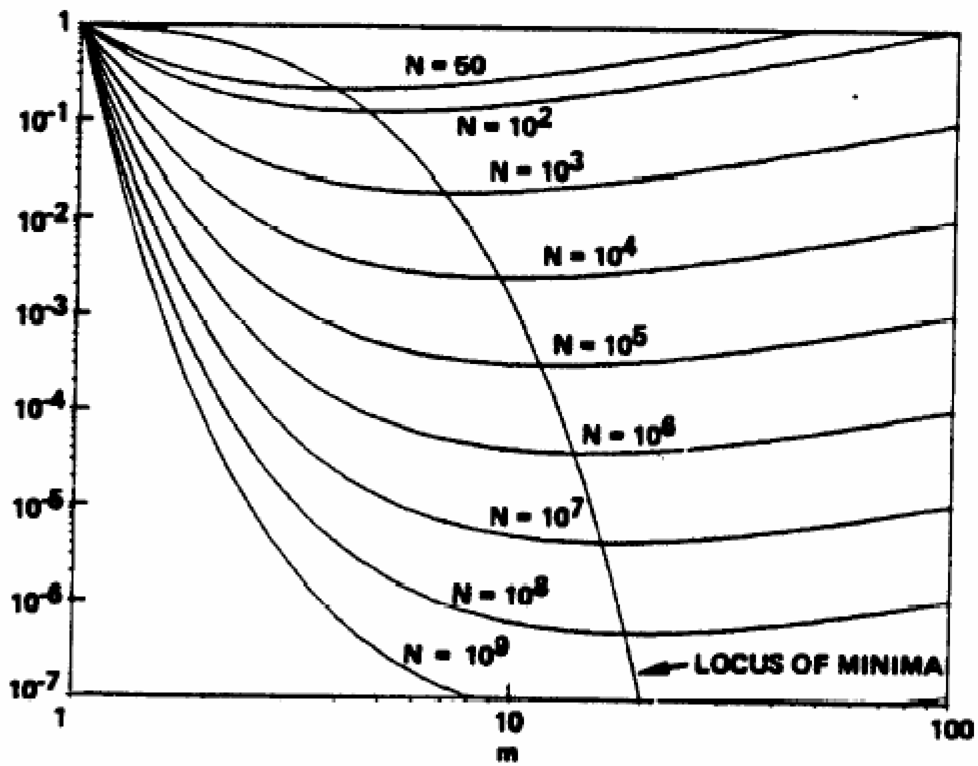


Fig. 4. Minimum relative table length, l/N, given m.

Decrease in table length vs. increase in path length

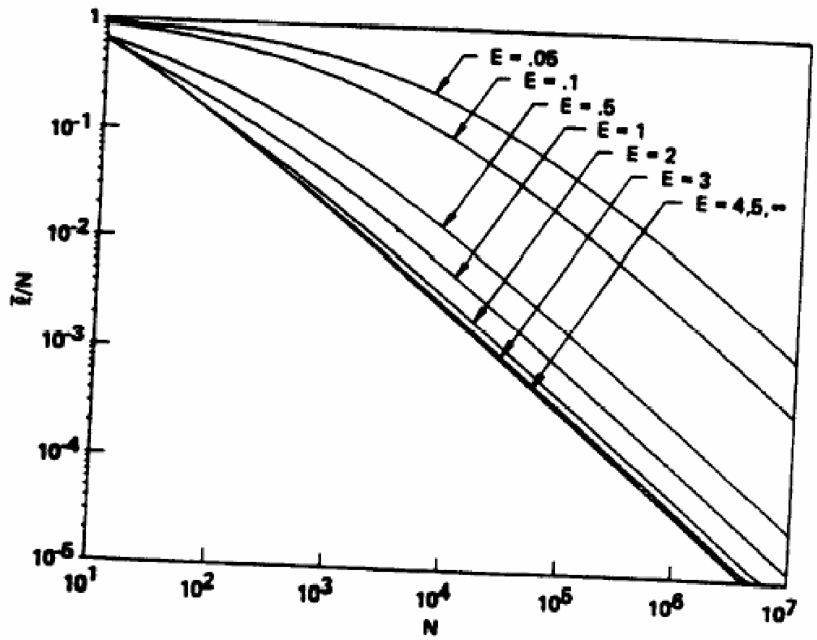


Fig. 10. Decrease in table length for a given maximum increase in path length.

number of nodes, goes to infinity, the "static" performance of the mHR schemes approaches that of a non-clustered routing scheme, while the relative table length approaches zero; i.e.,

$$N \to \infty \Rightarrow \begin{cases} h_c/h \to 1, \\ l/N \to 0. \end{cases}$$

Increase in path length

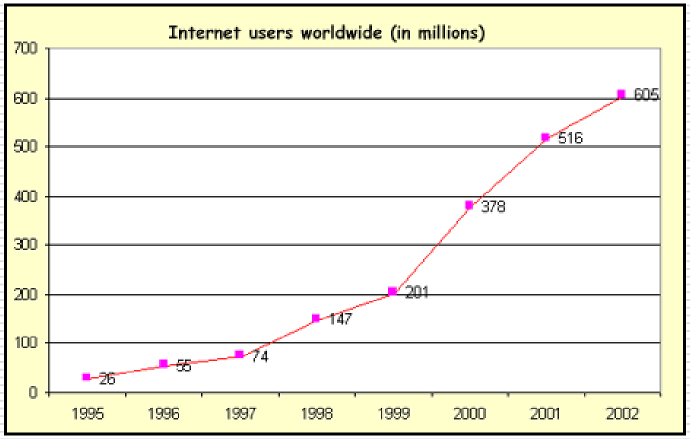
- Closest Entry Routing (CER)
  - no data on intra-cluster routing to outside
- Overall Best Routing (OBR)
  - intra-cluster path lengths to outside
- Non-Cluster Routing (NCR)
  - degenerate case when clusters' length=1

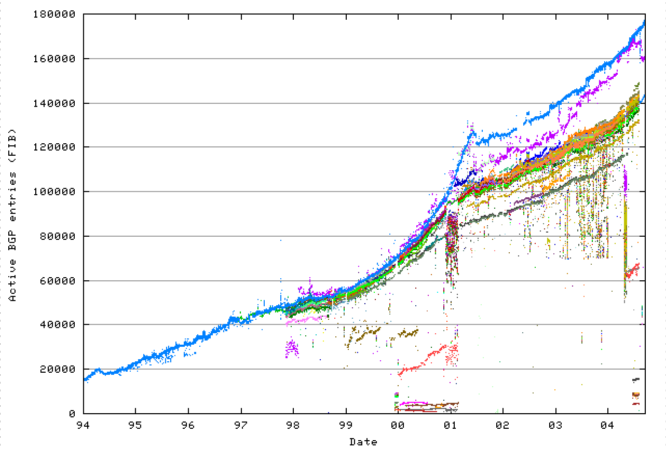
Proposition 9. *Under the conditions above and Assumption 3, the increase in the average path length in the network due to the reduction of routing information is such that*

$$h_c - h \leqslant \sum_{k=1}^{m-1} \left[1 - \frac{n_1 n_2 \ldots n_k - 1}{N - 1} \right] d_k \,. \qquad (27)$$

Internet

- Three-level clustering
- Routing tables 200000 entries
- About 600 000 000 hosts
- Optimal 20 clusters, table length 50





Conclusions

- Hierarchical routing significantly reduces routing table size
- The side effect is increase of routing path
- Optimal clustering provides table length reduction from N to e ln N
- For large networks, the increase of path length is insignificant
- These ideas are applied in DHT design, and to some extent in the Internet