The intermediate density scaling regime

FLoWS

STATUS QUO

Previous work on the scaling behavior of capacity of ad hoc networks studied two regimes: the dense regime*, where an increasing number of nodes is placed in a fixed area; and the* extended *regime, where area and the number of nodes scale identically.*

We aim to study a regime where the scaling of area is treated as a free parameter.

This is joint work with ***A. Ozgur and O. Leveque (EPFL) and D. Tse (Berkeley).***

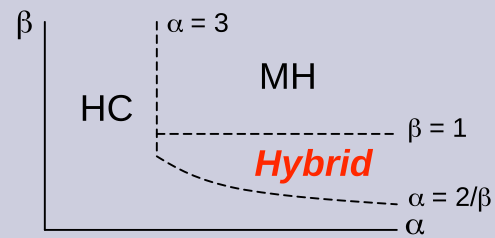
NEW INSIGHTS

We characterize the capacity of a random ad hoc network model when area scales independently of the number of nodes.

The scaling regime we consider reveals optimal communication strategies as we vary the area scaling and the path loss.

FLOWS ACHIEVEMENT(S)

MAIN RESULT: ***Depending on path loss and the scaling of area relative to number of nodes, a novel hybrid scheme is required to achieve capacity, where multihop transmission (MH) is used between "clusters" that employ hierarchical cooperation (HC) via MIMO to realize each hop.***



HOW IT WORKS: We study a scaling regime where:

n = # of nodes

n^{β} = area

α = path loss exponent

Nodes are paired randomly into source-destination pairs. What is the max throughput?

In contrast to prior work, area is not constant (the dense regime) or linear (the extended regime) in n.

We characterize the capacity of the system in terms of α and β. When $\alpha > \max\{3, 2/\beta\}$ and $\beta < 1$we need the scheme described above.

For fixed α, the scheme smoothly changes from pure HC to pure MH as β increases.

ASSUMPTIONS AND LIMITATIONS:

Our model uses a path loss model analogous to those used in the other work in this line

Of course it also employs a similar far field assumption.

END-OF-PHASE GOAL

Although we have developed capacity expressions, we do not yet have complete intuition for why the various parameters interact as described—in particular, does there exist a single description that captures the range of schemes employed?

Once the analytical development is complete, our goal is to submit the results to ISIT.

COMMUNITY CHALLENGE

Develop scaling regimes to obtain insights into better schemes.

Determine robustness of scaling results to channel model definition.

Physical area is a fundamentally distinct parameter from network size, and should be allowed to scale independently

Motivating philosophy

We are interested in developing a parsimonious characterization of the various *operating regimes* for wireless networks,
and how these operating regimes depend on engineering parameters such as:

- Number of nodes
- Power
- Area
- Path loss characteristics

Joint work with A. Ozgur, O. Leveque, D. Tse.

Prior results on scaling

Two main network models:

- *Dense networks:*
  Area held constant, and number of nodes $\rightarrow 1$
- *Extended networks:*
  Area increases proportional to number of nodes

Starting with Gupta and Kumar (2000),
where the dense network model was studied
under a multihop transmission strategy,
various works studied performance in these regimes.

Most recently Ozgur et al. (2007) characterized scaling laws
for capacity in both dense and extended networks.

Intermediate density model formulation

Our approach here: area should be a distinct parameter!

- We consider a random network model where
  n nodes are located uniformly at random
  in an area A.

  As we only consider scaling behavior of capacity,
  we assume $A = n^{\beta}$, where β ¸ 0.

- Nodes are grouped into random source-destination pairs,
  with uniform traffic matrix.

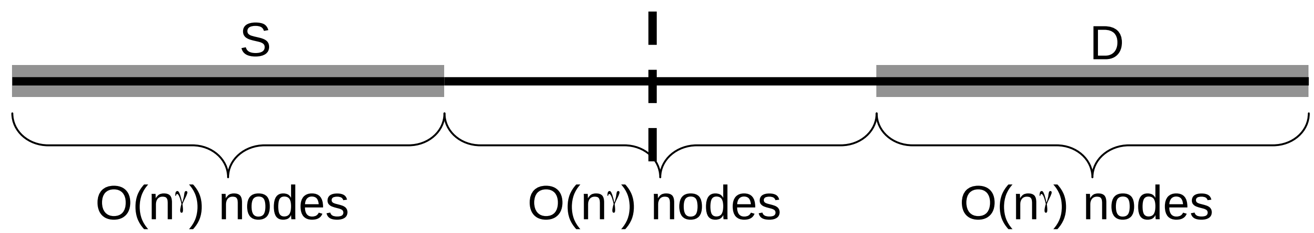
- We assume that each node has a transmit power
  constraint P that does not scale with n, and that
  the path loss exponent is α.

Upper bound on capacity

We employ a cutset bound.

For presentation simplicity, consider 1-D.

Start by considering n^γ sources transmitting to n^γ destinations, separated by n^γ nodes:



Using an analog of the argument in Ozgur et al., we can show that the capacity of this system is exactly the cutset bound for the full 1-D network.

Upper bound on capacity

By showing that independent transmissions give the upper bound, then adding together received power from all transmit nodes, we obtain:

$C(S, D) \cdot n^{\gamma}$ ¢ $O(\min\{ n^{(1-\beta)\alpha + \gamma(1 - \alpha)}, 1\})$.

Thus the best exponent is:

$\max_{0 \cdot \gamma \cdot 1} \min \{(2 - \alpha)\gamma + (1 - \beta)\alpha, \gamma\}$

We refer to the optimizing value γ^* as the *optimal cluster size.*

Achievability

- When $\beta > 1$:
  The network is “overextended”, but
  capacity achieving schemes are identical
  to extended network (cf. Ozgur et al.):
  hierarchical cooperation with MIMO if $\alpha < 2$,
  multihop if $\alpha > 2$.

- When $\beta < 1$:
  If $\alpha < 1/\beta$ or $\alpha < 2$,
  then hierarchical cooperation is optimal.

  If $\alpha > 1/\beta$ and $\alpha > 2$:
  Neither hierarchical cooperation nor multihop is optimal!

Achievability

We consider a scheme that uses multihop transmission at the level of clusters; each hop is realized using hierarchical cooperation via MIMO.

Suppose we use the optimal cluster size, and consider two adjacent clusters of size $n^{\gamma *}$.

These two clusters can be equivalently viewed as a dense network with $O(n^{\gamma *})$ nodes and per node power constraint P¢ $(A\, n^{\gamma *}/n)^{-\alpha}$.

Our key insight is that this per node power constraint is equal to $P/n^{\gamma *}$*, which is exactly the power threshold needed to execute the hierarchical cooperation scheme of Ozgur et al. in dense networks.*

Thus between adjacent clusters, hierarchical cooperation suffices to achieve throughput $O(n^{\gamma *})$.

Summary

Treating area as a free parameter leads to a new, "intermediate density" operating regime with a new transmission scheme:
Multihop transmission between clusters,
with hierarchical cooperation via MIMO to achieve cluster-to-cluster hops.

The diagram on the first slide is the generalization to 2-D, and demonstrates how the optimal scheme depends on the area scaling and the path loss exponent.

However, this is still not a complete story:
we are still investigating whether there is a unifying perspective that resolves the different schemes present in that diagram.