Throughput Improvements in Micro-Cellular Multi-Hop Networks

IEEE 802.16 Presentation Submission Template (Rev. 8.3)

Document Number:
IEEE C802.16mmr-05/022

Date Submitted:
2005-11-11

Source:
Ozgur Oyman, Sumeet Sandhu
Intel Corporation
2200 Mission College Blvd.
Santa Clara, CA 95054 USA

Voice: +1 (408) 653-5789
Fax: +1 (408) 765-0524
E-mail: {ozgur.oyman, sumeet.sandhu}@intel.com

Venue:
IEEE 802.16 Session #40 Vancouver, CANADA
Mobile Multihop Relay (MMR) Study Group Meeting

Base Document:
None

Purpose:
Information

Notice:
This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release:
The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE’s name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE’s sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.

IEEE 802.16 Patent Policy:
The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, including the statement “IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard.” Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.
Throughput Improvements in Micro-Cellular Multi-Hop Networks

Ozgur Oyman and Sumeet Sandhu

Intel Corporate Technology Group

IEEE 802.16 MMR Study Group Meeting

November 14-18, 2005
Does breaking up the link L0 into two links M0 and L1 result in a net performance increase?
Objective: Performance analysis of multi-hop wireless
1D-TD Model Assumptions:

- Message of Node 1 hops through all intermediate nodes until it reaches Node N + 1.
- Time-division (TD) based communication model
- Node k only receives from Node k – 1 and transmits to Node k+1
Basic Throughput Analysis

- Only assume path loss:

Received Power: \( P_{\text{rec}} \left( \frac{D}{N} \right) \)

- Consider the AWGN channel:

\[
C \frac{1}{N} \log 1 \quad P_0 \quad D / N
\]

Low SNR regime

\[
C \quad \frac{N}{D} \quad \frac{1}{N}
\]

High SNR regime

\[
C \quad \frac{N}{N} \log \frac{N}{D}
\]

There exists an optimal number of hops to maximize throughput!
Optimizing Mesh Throughput

Spectral efficiency (bps/Hz) vs. Number of hops for different path loss and shadowing scenarios.

- Channel type = 1
- Path loss & shadowing only

- $d = 0.5\ km$
- $d = 1\ km$
- $d = 2\ km$
- $d = 3\ km$
Channel Model

- Path loss (exponent 2-6)
  \[ PL = A + 10 \gamma \log_{10} \left( \frac{d}{d_0} \right) + s \quad \text{for } d > d_0, \]

- Lognormal Shadowing (std = 4-8 dB)
- Rayleigh Fading
- Macro BS Power = 41.76 dBm (15 W)
- Micro BS Power = 34.77 dBm (3 W)
- Macro BS Height = 34 m
- Micro BS Height = 12.5 m
Network Capacity

- Let $C(i)$ denote the maximum achievable rate per unit bandwidth during hop $i$.
- Let $\lambda_i$ be the fractional time channel $i$ is used.
- Capacity under time-division

$$C \left( \max_{i} \min_{N} \ i \ C_i \right) \xrightarrow{\text{max}} C \left( \frac{1}{N} \sum_{i=1}^{N} \frac{1}{C(i)} \right)$$
Per-link adaptation is better than worst link adaptation

![Graph showing the relationship between number of hops and spectral efficiency for different transmission modes. The graph includes lines for Decode-and-Forward with Optimal time-sharing, Decode-and-Forward with Equal time-sharing, and Amplify-and-Forward with Equal time-sharing. The x-axis represents the number of hops, and the y-axis represents the outage (10%) spectral efficiency (b/s/Hz).]
Throughput at Different Ranges

- Channel type = 1
- Path loss, shadowing, fading included

Number of hops vs. Mean spectral efficiency (bps/Hz) for different distances:
- d = 0.5 km
- d = 1 km
- d = 2 km
- d = 4 km
Hop More at Outage - I

CDF

Spectral efficiency (bps/Hz)

Increasing number of hops (1-6)

channel type = 1
path loss, shadowing, fading
range = 2 km
Hop More at Outage - II

![Graph showing spectral efficiency vs. number of hops]

- Spectral efficiency (bps/Hz)
- Number of hops
- Ergodic (mean)
- Outage (10%)

range = 2 km
Throughput Results Summary

• We observed that for any given range there exists an optimal number of hops to maximize end-to-end throughput.

• Optimal number of hops increases for longer range

  There exists an optimal hop distance.

• Under fading, we showed that hopping can be an additional source of diversity over other forms of diversity (space, time or frequency).

• Multi-hop diversity is especially useful at low outage levels.
Channel Sensitivity

- **Next step:** Verification of channel models
- Current models: COST, ITU, Erceg-Greenstein
- How sensitive are the multihop gains to different propagation environments?
- **Key variables:** Antenna heights, carrier frequency, hop distance, shadowing std, LOS / NLOS path loss exponent
Optimal hop distance varies drastically with carrier frequency!
Optimal hop distance varies drastically with different path loss exponents!
Conclusions

• We characterized the end-to-end throughput performance of multihop relaying and showed significant gains over direct transmissions.

• Throughput-optimal design of multihop networks is very sensitive to the channel behavior.

• One necessary step into MMR design is to decide on appropriate channel models.

• The performance improvements of multihop relaying also allows better range extension.