Analysis of
Simple Infrastructure Multihop Relay Wireless System

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Base Document:

Purpose:
Information for discussions on the future work areas for multi-hop relay support for 802.16

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Simple Infrastructure Multihop
Relay Wireless System

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Variations of Infrastructure Multihop

- Forwarding links in different dedicated spectrum/Radio
  - Becomes Economic and deployment engineering problems.
    - Enhancements on Conventional wireless backhaul
  - Dedicated spectrum cannot be used flexibly
    - Thus, cheaper spectrum at high frequencies are often used for backhaul.

- Same spectrum for backhaul and user links
  - Same type of radio technology (e.g., all WiFi meshes)
  - Most flexible: Dynamically used in time/frequency/code/tone, etc..
  - Concerns on Capacity Hit compared to conventional systems with same amount of spectrum
    - Must control resource consumption for backhaul
      - Number of hops, modulation efficiency, etc..

- Analyze a simple system to identify basic features needed in standards
Backhaul vs. Tower leasing

- The cost of electronics goes down but the cost of civil engineering, site acquisition & laying fiber remains very high.
- Non MMR:
  - High Backhaul cost & High or Low Tower Cost (depends on cell radius)
- MMR( 6 to 1 cell aggregation):
  - Backhaul (Aggregation) & Low Tower cost (cell radius small)
- Tower related cost become more important as backhaul cost go down
  1 → Tower Leasing
  2 → Backhaul facility
  3 → Customer Acquisition and CPE Subsidy
  4 → Maintenance

OpEx Breakdown for NonMesh-1 mile (year 1)

OpEx Breakdown for Non Mesh-1mile

Opex breakdown for Mesh 1:6 1 mile/year 1)

Opex breakdown for Mesh 1:6 (Year 1)
Assumptions

• Time-shared “centralized MAC” packet radio system
  ▪ 802.16/WiMAX OFDM(A)
  ▪ CDMA EV-DO, UMTS HSDPA

• Equal time per SS under uniform infinite offered traffic
  ▪ Scheduling considerations later, perhaps outside of 16
    • Except measurements to assist scheduling decisions

• Two-hop infrastructure system
  ▪ For now.. Lower complexity and cost
  ▪ Most gain achieved by the first additional hop
    • due to exponential nature of propagation

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Assumptions

• “Low complexity” RS
  ▪ Smaller and lower height than BS, but higher than SS
    • Infrastructure RS
  ▪ Single radio communicating with both SS and BS
  ▪ Omni directional antenna to serve SS
  ▪ Similar complexity as SS except
    • May use Directional antenna for RS-BS link
    • Alternate between antennas using simple switch

• Capacity Limited system
  ▪ Coverage advantage is obvious and previously studied
  ▪ Examine the hit on user traffic capacity due to multihop relaying
**Mesh Sector**

- Place RS near Sector boundary
  - Omni for RS
  - Symmetric, Simple, Shorter range.
    - Maximum benefit in terms of path gain
  - With smallest number of RS with Omni antenna
- Red RS using the same RF channel as the supporting red BS
  - Same reuse pattern as conventional systems
- Green RS belongs to the facing sector
  - Can switch sectors depending on load
Simple Analysis

- Resource reuse feasible?
- If so, Sector throughput gain?
- Analytical formulation for worst case multi-cell arrangement indicates “Yes” to both questions.
Intra-Sector Scheduling Approach

- Compatible with 802.16 PMP frame structure
  - One possible frame structure

Time

- Backhaul
- Dedicated Scheduling
- Simultaneous Scheduling
  - BS to RS
  - BS to SS
  - RS to SS
Mesh Sector Analyzed

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## Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency reuse</td>
<td>(1,6,6) &amp; (1,3,6)</td>
</tr>
<tr>
<td>Cell radius</td>
<td>1000 m</td>
</tr>
<tr>
<td>BS gain</td>
<td>20 dB</td>
</tr>
<tr>
<td>RS gain</td>
<td>0 dB</td>
</tr>
<tr>
<td>BS height</td>
<td>30 m</td>
</tr>
<tr>
<td>RS height</td>
<td>15 m</td>
</tr>
<tr>
<td>SS height</td>
<td>2 m</td>
</tr>
<tr>
<td>Transmit power</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Power control</td>
<td>No, for now</td>
</tr>
<tr>
<td>Path loss model</td>
<td>Erceg-Greenstein (aka. 802.16 model)</td>
</tr>
</tbody>
</table>
Simulation Parameters - Rates

- 6 MHz channel
- Representative values for 802.16/WiMAX
  - Continuous capacity analysis tends to be optimistic
  - Lower yet more robust rates are available but not simulated.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Code Rate</th>
<th>Required SINR (dB)</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>6.6</td>
<td>6.0</td>
</tr>
<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>10.5</td>
<td>12.0</td>
</tr>
<tr>
<td>64-QAM</td>
<td>2/3</td>
<td>15.3</td>
<td>24.0</td>
</tr>
<tr>
<td>64-QAM</td>
<td>3/4</td>
<td>20.8</td>
<td>27.0</td>
</tr>
</tbody>
</table>
Directional Antenna Pattern

Beamwidth = 60 degrees; Gain at 30 degrees = -12 dB

Antenna gain (dB)

Angle of departure (degrees)
Multi-Cell Scenario without RS
Reuse pattern (1,6,6)
Multi-Cell Scenario without RS

- No log normal fading
Multi-Cell Scenario without RS

- With log normal fading
Multi-Cell Scenario with RS Reuse pattern (1,6,6)
Multi-Cell Scenario with RS

- No log-normal fading
  - For illustration
- Simultaneous scheduling regions
Multi-Cell Scenario with RS

- No log-normal fading
  - For illustration
- Dedicated scheduling regions
Throughput Comparison: (1,6,6)

User traffic Throughput Per sector (Mbps)

Terrain A
Terrain C

Excluding forwarding throughput

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QPSK _ Outage Comparison (1,6,6)

Percentage of SS below QPSK _

Obviously, Capacity and Coverage interplay, but the conventional system needs larger reuse distances to match the RS system. Thus, the capacity gain in the previous slide is in fact higher.

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SS Data Rate Comparison

[CDF graph showing data rate comparison between Without mBS and With mBS]
Throughput Comparison: (1,3,6)

User traffic
Throughput
Per sector
(Mbps)

Excluding forwarding throughput

Terrain A  Terrain C

<table>
<thead>
<tr>
<th></th>
<th>Without RS</th>
<th>With RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain A</td>
<td>11.53</td>
<td>11.92</td>
</tr>
<tr>
<td>Terrain C</td>
<td>11.06</td>
<td>11.92</td>
</tr>
</tbody>
</table>

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QPSK _ Outage Comparison (1,3,6)

Percentage of SS below QPSK _

Terrain A
- Without RS: 40.4%
- With RS: 22.8%

Terrain C
- Without RS: 40.0%
- With RS: 23.7%
Conclusions

• (1,6,6) system with 6 mBS per cell shows:
  ▪ QPSK _ Outage improvement around 80 %
  ▪ Overall sector throughput improves from 16 Mbps to 21 Mbps

• Less Gains under more severe interference situations: e.g., (1,3,6)

• Capacity improvement in multihop forwarding system more than compensates for radio resources diverted towards RS - BS Link
  ▪ If simultaneous scheduling is supported.
  ▪ Without sophisticated interference management
Implications on PAR/5C & Future Work

• Smaller Scope is more realistic for quick standardization
  ▪ Basic well-understood toolkit for multiple scenarios and solutions
  ▪ Limit to infrastructure fixed/nomadic RS?
    • Less impact on SS, but don’t impose “don’t touch SS” requirement
    • Provides large and immediate benefits in coverage and economics
      ▪ General solution for arbitrary number of hops is harder than 1 or 2 additional hops? Too restrictive?
      ▪ Additional PARs for further scenarios as current draft solidifies
        • Perhaps 2 or 3 PARs needed in staggered time schedule
  ▪ Mechanisms to support intra-sector spatial reuse
    ▪ Channel/Interference measurement mechanisms: Examine existing methods and extend
    ▪ Scheduling/Identification mechanisms
Implications on PAR/5C & Future Work

- Layer 2 routing remains transparent to SS Host OS.
  - Consider (M)RSTP from 802.1, though may not be optimal
    - Request extensions to 802.1?
  - Channel condition assisted routing decisions
    - e.g., “is RS-BS link fast enough to bother?”

- Multihop CID management
  - More compatible to 802.16, but scope, uniqueness, conflict, aggregation, assignment

- or MAC address inside BS-RS links?
  - Simpler routing and identity management, but overhead.

- Scheduling coordination among RS and BS?
  - Fragmentation and buffering btw two hops

- BS and RS may appear as BS to SS
  - If BS MAP controls all, coverage extension limited, but simpler?
  - ARQ independence for RS: Quicker turnaround
  - Better backward compatibility
  - Implications on the complexity of RS
Spellings suggested by PowerPoint

- Multihop ➔ Ultimo
- Saha ➔ Saga
- Erceg ➔ Erect (Erect-Greenstein model)
- dBm ➔ dam
- Shankar ➔ Shaker
- WiFi ➔ Wife