Adaptive Routing Approach and Simulator for IEEE 802.16j WiMAX Mobile Multihop Relay Networks

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Outline

• Introduction
  – IEEE 802.16j issues
  – Related works
• Motivations + Goals
• Network model
• Cost-based Competitive On-Line Routing Algorithm
• Numerical Results
• Conclusions

Introduction

• A Wireless Metropolitan Access Network, defined by IEEE 802.16, has been extensively promoted recently.
  – Support high mobility (120 km/hr) and high data rate (40 Mb/s).
  – Metropolitan-scale wireless transmission range (5km).

• However, signal fading, attenuation, path loss caused by some hiding areas or near cell boundary.
  – Degrading transmission quality.
  – Possible solutions:
    • Deploying more BSs (-)
    • Deploying Repeaters (-)
    • Deploying Relay stations (v)

Issue

• Based on IEEE 802.16e standard, WiMAX proposed a relay-based approach, namely, the IEEE 802.16j standard.
  – To extend the service area of Base Stations (BSs).
  – To increase the transmission quality in the relay zone.

How to construct such WiMAX MMR networks?
How to determine an optimal routing path?

• According to the different features on mobility, Relay Station (RS) can be classified into three types:
  – Fixed RS (FRS)
  – Nomadic RS (NRS)
  – Mobile RS (MRS)
Motivations + Goals

Motivations

- To propose an IEEE 802.16j-confirmed relay-based adaptive cost-based routing approach that satisfies the IEEE 802.16j specifications.
  - Fully support for WiMAX MMR networks
    - Three types of RSs
    - Transmission path length
    - Adaptive Modulation and Coding (AMC)
    - Bandwidth allocation and utilization
  - To improve the transmission quality by deploying various types of RSs
  - To guarantee the path re-routing while RSs moving out of the existing areas

Goals

- To achieve some goals:
  - Low blocking rate and high utilization under various impact factors.
  - Lower end-to-end path delay.

Related works (Three categories)

- **High-reliability routing** [3-6] (06-08):
  - **Advantage**: Treat multi-metrics as the evaluation factors.
  - **Disadvantage**: Lack of systematic mechanism for computing optimal weight.

- **Load-balancing QoS routing** [7-8] (07):
  - **Advantage**: Considers average bandwidth utilization for multi-hop networks.
  - **Disadvantage**: Can not apply to the IEEE 802.16j Mobile Multi-hop Relay (MMR) networks because of without considering RS

- **IEEE 802.16j-based relay routing** [9-11, 22] (07-09):
  - **Advantage**: The routing path has the highest transmission rate.
  - **Disadvantage**: To use in centralized mode and not meet the nomadic/mobile RSs feature (mobility).

Network model (1/3)

Network model (2/3)
**Network model (3/3)**

<table>
<thead>
<tr>
<th>Transparent mode</th>
<th>Non-Transparent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage extension</td>
<td>NO</td>
</tr>
<tr>
<td>Number of hops</td>
<td>2</td>
</tr>
</tbody>
</table>

- **Scheduling**
  - Centralized
  - Centralized/Distributed

- **Performance**
  - Improve transmission quality
  - Improve transmission quality/Cover BS coverage

- **BS loading**
  - High
  - Light

**Impact factor 1 - High Reliability**

Example: IEEE 802.16j and MRS, moving signal

<table>
<thead>
<tr>
<th>Type weight</th>
<th>Fixed RS</th>
<th>Nomadic RS</th>
<th>Mobile RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS</td>
<td>12</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Fixed RS</td>
<td>2</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Nomadic RS</td>
<td>3</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Mobile RS</td>
<td>12</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

**Impact factor 2 - Low Path Delay**

- **The hop count** of a path significantly affects the end-to-end delay.
  - Less the hop count a path has, less the delay the path yields.

- Normalized, a nodal delay time consists of four parts:
  - Transmission delay
  - Propagation delay
  - Process delay
  - Queuing delay

**Impact factor 3 - Load Balancing**

- With limited network resources, the bandwidth resources of the MR-BS and RSs can not always satisfy the MS’s request.
  - Unbalanced bandwidth utilization
  - --> Higher Blocking & Dropping
In WiMAX, the physical layer’s OFDMA coding rate depends on the signal quality between the MR-BS and MS.

- Quadrature Amplitude Modulation (QAM)
- Quard Phase Shift Keying (QPSK)
- Binary Phase Shift Keying (BPSK)

The best channel condition can be chosen with RSs to MR-BS.

Cost-based Adaptive Routing Path

- Considering the residual bandwidth, path hop-count and AMC channel condition simultaneously.
  - Not required setting different weight values for individual impact factor.

- The proposed cost-based adaptive routing algorithm can be divided into two steps:
  - A. Cost-based Competitive On-Line Routing
  - B. An adaptive Max-Min AMC approach

    Choose the highest coding rate path.

    If there are several selected routing paths with the same least path cost,

A. Cost-based Competitive On-Line Routing (1/3)

- The COL cost function:
  - The competitive on-line access cost in terms of the residual bandwidth of nodes.

- The cost of carrying a call on a node $\text{1}$ with occupancy $i$ can be expressed as

$$W_1(i) = \frac{i}{C_1}$$

$\mu$: selected constant parameter

$C$: capacity of link

Residual BW

$$W_1(i) = \frac{i}{C_1}$$

Since $0 \leq i \leq C_1$, we have $0 \leq W_1(i) \leq 1$

To simplify:

$$\mu \frac{i}{C_1}$$

Max

Min

COST

A. Cost-based Competitive On-Line Routing (2/3)

- Equivalent to setting the admission threshold to one and the cost of a node with occupancy $i$ to

$$W_1(i) = \mu \frac{i}{C_1}$$

Since $0 \leq i \leq C_1$, we have $0 \leq W_1(i) \leq 1$
A. Cost-based Competitive On-Line Routing (3/3)

- The **link cost** for class \( k \) call, \( p_k^l(i) \), are defined herein by
  \[
  p_k^l(i) = \begin{cases} 
  \sum_{j=1}^{i-1} \mu j^k & \text{if } \ i + b_k \leq C_r; \\
  \infty & \text{otherwise}. 
  \end{cases}
  \]
  \( b_k \): the required bandwidth of class \( k \).

- The **path cost** is defined by
  \[
  \Gamma_k(r) = \sum_{i=1}^{\Gamma(r)} p_k^l(i)
  \]
  \( \Gamma(r) \): the cost of carrying a class \( k \) call on a multi-hop path \( r \).

B. An adaptive Max-Min AMC approach

- To satisfy the **AMC coding rate** in MMR networks:
  - **AMC Zone**
  - **Adaptive modulation and coding rate**
  - **QoSK**

<table>
<thead>
<tr>
<th>AMC Zone</th>
<th>Adaptive modulation and coding rate</th>
<th>QoSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>QPSK1,2</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>QPSK1,2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>OfDM</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>OfDM</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>OfDM</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>OfDM</td>
<td>0</td>
</tr>
</tbody>
</table>

Three important performance metrics

- **Fractional Reward Loss (FRL):**
  \[
  FRL = \frac{\sum_{k=1}^{K} RW_k \lambda_k B_k}{\sum_{k=1}^{K} RW_k \lambda_k}
  \]
  \( k \): the service class with the different priority.
  \( \lambda_k \): the arrival rate of \( k \) class services flow.
  \( RW_k \): the reward of the \( k \) class service flow.
  \( B_k \): the blocking rate of the \( k \) class service flow.

- **Average bandwidth utilization (UT):**
  \[
  \text{Utilization} = \frac{\text{Allocated} - \text{BW}(W)}{MR - BS_{CAP}}
  \]

- **Average path delay time:**
  \[
  \sum_{i=1}^{\Gamma} d_{\text{node}} = \sum (d_{\text{process}} + d_{\text{queue}} + d_{\text{transmission}} + d_{\text{propagation}})
  \]

Numerical Results

- Several **compared approaches** for multi-hop relay networks.
  - **Hop Count (HOP)**
    - To select the shortest path
  - **RS Type (TYPE)**
    - To select higher reliability routing path
  - **Bandwidth (BW)**
    - To select higher bandwidth resource routing path
  - **Normalize dynamic weighting approach (NDWA)**
    - To include multi-metrics and adjust specific weight dynamically.
**Simulations parameters**

<table>
<thead>
<tr>
<th>Simulation parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of MSs (NBS)</td>
<td>10–70</td>
</tr>
<tr>
<td>Network Size</td>
<td>2000 m</td>
</tr>
<tr>
<td>BS bandwidth</td>
<td>35 Mbps</td>
</tr>
</tbody>
</table>

**Network model**

- Bandwidth for LBS (CBR): 64 Kbps
- Bandwidth for rPS: 16 Kbps
- Bandwidth for nPS: 64 Kbps
- Packet size: 1,900 bytes
- Arrival rate of Poisson distribution, \( \lambda \) (Kps): 2–12
- Average holding time of exponential distribution, \( \mu \) (Kps): 1
- Parameters of Pareto distribution: \( \alpha = 2 \), \( \alpha = 0.5 \), and \( \beta = 0.8 \)

**Traffic model**

**Different MR-BS utilizations in OFDMA system under various arrival rates**

**Utilization under various arrival rates**
FRLs under various numbers of NDS

Utilization under various NDS

Average end-to-end path delay time under various number of NRSs/MRSs

To assist the Numerical Results

• To show MS-RS-BS transmission procedure with GUI
Conclusions

• By the hint of determine an optimal routing algorithm in MMR networks, we proposed an adaptive path determination for IEEE 802.16j MMR networks in the non-transparent mode with the distributed scheme.
  – To improve the MR-BS utilization enhancement.
  – To reduce End-to-end path delay of WiMAX MMR networks.

• The adaptive COL cost-based approach with AMC scheme consider the residual bandwidth, path hop count, load balancing and AMC coding rate, the determined optimal routing path to achieve:
  – Highly Reliable
  – Data Transmission Rate
  – Satisfying Real-time Streaming Transmission

Q&A

Thank You!