Cost/Revenue Trade-off in the Optimization of Fixed WiMAX Deployment with Relays

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1. Global Information Multimedia Communication Village (GIMCV) and its environments
2. Evolution towards Wireless Broadband Systems
3. Fixed/mobile WiMAX spectrum
4. Fixed/mobile WiMAX demonstrators in Portugal
5. Formulation for the supported cell/sector throughput
6. A glimpse on cost/revenue optimization and cellular planning tools
Evolution of Wireless towards Wireless Broadband Systems

Radio access Technologies
- TDMA
- QPSK
- Adaptive
- QAM
- OFDM/QAM
- Adaptive coding
- MIMO
- Adaptive array

Spectral Efficiency
- TDMA
- QPSK
- Adaptive
- QAM
- OFDM/QAM
- Adaptive coding
- MIMO
- Adaptive array

Data Rate
- ~40k
- 2M
- 14M
- 54M
- 100M
- 1G

Mobility
- Stationary
- Pedestrian
- Vehicular

Data Rate (b/s)
- 2.4GHz
- 5GHz
- 802.11n

Spectral Efficiency (b/s/Hz)
- 0.4
- 0.4
- 2.8
- 2.7
- 5
- 10

Radio access Technologies
- TDMA
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Wireless Broadband Systems
- 1G (Analog)
- 2G (Digital)
- 3G (IMT2000)
- B3G/LTE (System Beyond IMT2000)

Evolution of Wireless towards Wireless Broadband Systems

- AMPS
- ETACS
- NTT
- PDC/GSM/IS-95
- W-CDMA/HSDPA
- CDMA2000 EV-DO/DV
- Bluetooth
- ZigBee
- UWB
- 802.15.1
- 802.15.4
- 802.15.3a
- 802.16-2004
- 802.16e
- 802.16 Mobile
- 802.16-2004 Fixed
- 802.11b
- 5GHz
- 802.11a/g
- 802.11n
- 2.4GHz
- 802.11a/g

Timeline
- 1995
- 2000
- 2010
Fixed (IEEE 802.16-2004) and Mobile (IEEE 802.16-e) Operation

- Broadband Access for Enterprise
  - 802.16-2004
  - 802.16-e

- Broadband Access for Public hotspots and Mesh Networks
  - 802.16-2004

- Nomadic Broadband complementary to 3G, EDGE & WiFi
  - 802.16-e

- Broadband Access @ Home complementary to DSL & Cable
  - 802.16-2004

- WiFi
2-6 GHz band available for WiMAX

Unlicensed Band

- ISM: 2.4 – 2.48 GHz
- US WCS: 2.305 – 2.320 GHz, 2.345 – 2.360 GHz
- MMDS: 2.5 – 2.69 GHz
- 3.3 – 3.4 GHz
- 3.4 – 3.6 GHz
- WRC: 5.47 – 5.725 GHz
- UNII: 5.15 – 5.35 GHz
- UNII/ISM: 5.7255 – 5.85 GHz

Licensed Band

ISM: Industrial, Scientific & Medical Band
UNII: Unlicensed National Information Infrastructure band
Point-to-multipoint demonstrator at 3.5 GHz, Health Science Faculty
Signal-to-noise ratio, SNR, measurements
Detailed measurements of SNR in DL

Frequency license bands:
3543-3567.5 MHz
3443-3467.5 MHz

Throughput\text{max} = 230 \text{ kB/s} = 1840 \text{ kb/s} \text{ (per SU)}

16-QAM with several coding rates; however it increased to \sim 6 \text{ Mb/s} after QoS classes were configured
Measured SNR - distances in the interval [275, 475] m

\[ y = -32.72 \log(x) + 15.86 \]
The frequency reuse problem ...

- $I$ - interference power
- $N$ - noise power
- $C$ - power of the received carrier
Step distances for CNIR vs supported Physical throughput

- There are $J$ different coverage rings in a cell, each supporting a different MCS (for instance, $J = 4$ in Figure).
- The distances that correspond to the steps between consecutive MCS are represented by $d_j$, $j = 1, 2, \ldots, J$. Here we denote the order of the MCS as $MCS_j$.
- The supported throughput is obtained as

$$R_{b_{\text{sup}}} = \frac{\int\int R_b(d, R, K)dx\,dy}{\frac{3\sqrt{3}}{2} \cdot R^2} \sum_{j=1}^{J} \left( \frac{3\sqrt{3}}{2} \cdot (d_j^2 - d_{j-1}^2) \cdot (R_{b_{MCS_{1st}} + 1}) \right)$$

where $(R_b)_{MCS_{1st}+1-j}$ is the throughput for the $j^{th}$ coverage ring.
Rings vs supported PHY throughput

\[ \text{MCS}_j(CNIR_{dB}) = \begin{cases} 
0, & \text{CNIR} < 3.3 \\
1, & 3.3 \leq \text{CNIR} < 5.5 \\
2, & 5.5 \leq \text{CNIR} < 6.5 \\
3, & 6.5 \leq \text{CNIR} < 8.9 \\
4, & 8.9 \leq \text{CNIR} < 12.2 \\
5, & 12.2 \leq \text{CNIR} < 15.0 \\
6, & 15.0 \leq \text{CNIR} < 19.8 \\
7, & 19.8 \leq \text{CNIR} < 21.0 \\
8, & \text{CNIR} > 21.0 
\end{cases} \]

\[ d_j = \text{cnir}^{-1}\left(\min\left(CNIR\left(R_{b_{d,\text{MCS}_j +1-j}}\right)\right)ight), \quad j = 1, \ldots, J. \]

\[ (R_b)_l = \begin{cases} 
0, & l = 0 \\
1.41, & l = 1 \\
2.12, & l = 2 \\
2.82, & l = 3 \\
4.23, & l = 4 \\
5.64, & l = 5 \\
8.47, & l = 6 \\
11.23, & l = 7 \\
12.27, & l = 8 
\end{cases} \]
Supported Cell/Sector Throughput
for $K = 7$
## Fixed WiMAX Assumptions for Cost/Revenue Optimization

### Costs without relays

*(Hypothesis “B” is the for the future, when prices will go down)*

<table>
<thead>
<tr>
<th>Costs</th>
<th>Omnidirectional without relays</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{fi}[\text{€/km}^2]$</td>
<td>K=1</td>
</tr>
<tr>
<td></td>
<td>K=3</td>
</tr>
<tr>
<td>$C_{BS}[\text{€}]$</td>
<td>18 000 (A) -&gt; 9000 (B)</td>
</tr>
<tr>
<td>$C_{Inst}[\text{€}]$</td>
<td>10 000 (A) -&gt; 1 000 (B)</td>
</tr>
<tr>
<td>$C_{bh}[\text{€}]$</td>
<td>5000 (A) -&gt; 2500 (B)</td>
</tr>
<tr>
<td>$C_{M&amp;O}[\text{€/year}]$</td>
<td>4000 (A) -&gt; 1000 (B)</td>
</tr>
</tbody>
</table>

### Costs with relays for omnidirectional and tri-sectored BS antennas

<table>
<thead>
<tr>
<th>Costs</th>
<th>Omnidirectional</th>
<th>Tri-sectored</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{fi}[\text{€/km}^2]$</td>
<td>47.14</td>
<td>47.14</td>
</tr>
<tr>
<td>$C_{BS}[\text{€}]$</td>
<td>4800</td>
<td>6800</td>
</tr>
<tr>
<td>$C_{Inst}[\text{€}]$</td>
<td>1333.33</td>
<td>2000</td>
</tr>
<tr>
<td>$C_{bh}[\text{€}]$</td>
<td>833.33</td>
<td>833.33</td>
</tr>
<tr>
<td>$C_{M&amp;O}[\text{€/year}]$</td>
<td>833.33</td>
<td>833.33</td>
</tr>
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</table>

### Revenues

A given price for 1 MB of information is assumed, e.g. 0.0025 €/MB or 0.005 €/MB
Challenge: Coverage Scenario with Relays

- DL Scenario and 240° sector coverage in Relay Station (RS) coverage area
- The central coverage area BS may have omnidirectional or tri-sectorial antenna

\[ D = 3\sqrt{k \cdot R} \]

\[ \frac{C}{I} = \frac{R^{-\gamma}}{2(D - 0.8372R)^{-\gamma} + (D + 0.09535R)^{-\gamma} + (D + 0.8866R)^{-\gamma}} \]
Profit: comparison

The graph compares different pricing models for Sect. & RSs (Sections & Remote Stations) and RSs only. The cost per MB is indicated as 0.005€/MB for Sect. & RSs, leading to a higher profit margin compared to RSs only. The profit is shown as a percentage of the cost, with the x-axis representing the distance in meters (R[m]) and the y-axis representing the profit percentage.
Over the region of Beira Interior, with an area of 550km², the number of cells necessary to cover the area under study is 14 and 24 cells, approximately, for coverage distances $R=4$ and $R=3$ km, respectively.
(a) QPSK $\frac{1}{2}$  
(b) QPSK $\frac{3}{4}$  

c) 16-QAM $\frac{1}{2}$  
(d) 16-QAM $\frac{3}{4}$  

e) 64-QAM $\frac{2}{3}$  
(f) 64-QAM $\frac{3}{4}$
Conclusions

• By weighting the physical throughput in each concentric cell coverage ring by the size of the ring, the contribution from each transmission mode (or MCS) is included in a formulation to obtain the average supported throughput.
• The use of sectorization is clearly advantageous.
• Improvements are achieved for the longest coverage distances with the use of sub-channelisation in UL.
• Relays are cheaper than full-functionality BSs.
• With Relays, the need of resources for BS-to-RS communications causes a decrease in throughput (only partially compensated by sectorization).
Conclusions (cont.)

- Results show that the use of relays with sectorization (an example is presented for $K = 3$) enables to achieve higher profit.
- The optimum (maximum) values occur for coverage distances up to 1000-1500 m.
- Future broadband wireless access technologies will certainly be based on multi-hop networks with relays.
New Mobile WiMAX BS at 5.4 GHz
http://future4g.dcti.iscte.pt/eng/