Infostation overlays in cellular systems

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Outline

- Cellular systems
- Infostations
- Cell area vs Coverage area
- System model
- Performance measures
- Numerical example
Wireless Data over 2G Cellular

- **Cellular Voice:**
  - Anytime Anywhere
  - Slow: 10K bps
  - High cost/bit
    - \( \text{v cents/min voice} = 13v \quad \text{cents/MB} \)

- **Data over Cellular:**
  - Slow and Expensive:
    - \( 20 \text{ cents/min voice} = 2.60/\text{MB} \)
    - \( 100X \) too high
Wireless Data over 3G Cellular

- 2X or 3X increase in BW efficiency ⇒ reduced cost/bit
- Higher speed: 144K or 384K bps
- But voice is still 10K bps ⇒ v cents/min = 13v cents/MB
- $/MB still too high for anytime/anywhere data
DATA can tolerate delay!

- Messaging services: e-mail, voice mail, fax, maps, non-interactive web pages, ...
- We don’t need ubiquitous coverage

- Reduced coverage
  \[ \Rightarrow \text{Higher data rates} \]
- A little wait might be worthwhile!
Infostations

- Network of wireless ports
- Irregularly distributed
- Discontinuous coverage
- Asymmetric link
- High data rate transmission
- Messaging services
Infostation System

Download a map

Low bit-rate cellular

E-mail, voice mail, fax

Internet access
Isolated Infostation

Optimization Problem:
- With finite energy, how many bits can be delivered?

Solution: Use small coverage
Highway Infostations

- Distance attenuation
  → time varying channel
- Xmit power profile = Time Average Capacity
Cellular Infostations

- Infostations at cellular sites
Traditional Cellular

- Modulation and BER $\Rightarrow$ SIR threshold
- SIR $\Rightarrow$ Cluster size $N$
  (frequency reuse)
- For worst-case location!
For Infostations, there is no need to provide ubiquitous coverage
- Better SIR conditions
- Smaller cluster size
- More bandwidth available

HIGHER DATA RATE!
SIR in 2D Infostation system

\[ SIR = \frac{\sum_{i=1}^{6} P \left( \frac{d}{r} \right)^n}{P \left( \frac{d}{D_i} \right)^n} \]

\[ SIR \approx \frac{1}{6} \left( \frac{\sqrt{3NR}}{r} \right)^n \]
SIR with respect to $r/R$ and $N$
Which system is better?

- 2M bps
- 6M bps
Every Infostation is modeled as an $M/M/1$ queue with reneging.
Parameters for 2D

- User density, \( u \)
- Cell radius, \( R \)
- Mobile speed, \( v \), \( f_V(v) \)
- Coverage radius, \( r \)
- Data rate, \( c \)
- Messages per user per second, \( \lambda_u \)
- Message size, \( m \)

\[
\begin{align*}
\lambda &= (2\pi r)(u/2) E[V] \\
1/ \mu &= E[X] = \\
&= \lambda_u t_c (m/c) \\
v &= 2E[V]/\pi r
\end{align*}
\]
Bias: \( f_\Theta(\theta) = \cos(\theta)/2 \), \( 0 < |\theta| < \pi/2 \)

\[ \text{Prob(}-\phi < \theta < \phi\text{)} = r/R \]

\[ t_c = (\pi R^2)/(2r E[V]) \]
Between Infostation visits, messages accumulate in mailbox.

After successful visit, ready for next.

After unsuccessful visit, either
  - the residual contents of a mailbox are discarded, or
  - the mailbox will not accept new messages until it is emptied.
2D Performance

- **Throughput**
  \[ c (1-p_0) \]

- **Delay**
  \[ t_c / (1-P_{out}) + t_Q \]

\[ t_c = (\pi R^2 / 2r E[V]) \]
\[ 1-P_{out} = (\mu / \lambda)(1-p_0) \]
\[ t_Q \text{ calculated for } M/M/1 \text{ FCFS with reneging} \]
### 2D Numerical Example

<table>
<thead>
<tr>
<th>Modulation</th>
<th>N</th>
<th>c</th>
<th>r/ R</th>
<th>E[X]</th>
<th>λ</th>
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<tr>
<td>BPSK</td>
<td>1</td>
<td>1</td>
<td>0.66</td>
<td>9.52</td>
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<td>2</td>
<td>0.56</td>
<td>5.61</td>
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<tr>
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<td>4</td>
<td>0.37</td>
<td>4.25</td>
<td>0.15</td>
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<tr>
<td>16 QAM</td>
<td>3</td>
<td>1.33</td>
<td>0.64</td>
<td>7.36</td>
<td>0.25</td>
</tr>
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<td>0.74</td>
<td>8.49</td>
<td>0.29</td>
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<tr>
<td></td>
<td>7</td>
<td>0.57</td>
<td>0.99</td>
<td>11.11</td>
<td>0.39</td>
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<tr>
<td>64 QAM</td>
<td>1</td>
<td>6</td>
<td>0.25</td>
<td>4.19</td>
<td>0.10</td>
</tr>
<tr>
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<td>2</td>
<td>0.42</td>
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<td>11.28</td>
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<tr>
<td></td>
<td>12</td>
<td>0.5</td>
<td>0.85</td>
<td>14.78</td>
<td>0.33</td>
</tr>
</tbody>
</table>

\[ u=(0..0.0004), \ R=500, \ E[V]=2.5, \ m=2e6, \ \lambda_u=0.01 \]
2D Throughput: 64QAM

Efficiency vs. User Density graph with various modulation schemes and their efficiency levels:
- 64QAM / 1: 6.25%
- 16QAM / 1: 17.6%
- QPSK / 1: 24.0%
- 64QAM / 3: 42.2%
- 64QAM / 4: 72.2%

The graph illustrates the efficiency of different modulation schemes under varying user densities.
2D Reneging probability: 64QAM
2D Delay: 64QAM \( t_c / (1-P\text{_{out}}) + t_Q \)
2D Throughput: $N=1$

\[ (r/R)^2 \]
\[ 6.25\% \]
\[ 13.7\% \]
\[ 31.4\% \]
\[ 43.6\% \]
2D Reneging probability: N=1

![Graph showing the relationship between user density and reneging probability for different modulation schemes (BPSK, QPSK, 16QAM, 64QAM).]
2D Delay: $N=1$  \[ t_c / (1-P_{\text{out}}) + t_Q \]
Conclusions

- **Reduced coverage**, allowing higher level modulations and smaller cluster sizes, provides **increased throughput**.
- For 1D, **delay is also better** (see WPMC'99)
- For 2D, as user density (offered load) increases, delay performance gets relatively better.