Compressive Data Gathering for Large-Scale Wireless Sensor Networks

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Outline

• Motivation
• Related Work
• Compressive Data Gathering (CDG)
• Data Recovery
• NS-2 Simulation
• Conclusion
• Discussion
Problems in Data Gathering

• More close to the sink, power failure more sooner
Problems in Data Gathering (continue)

- Data is redundant (sparse)
Related Work

• Transform-based Compression
  – Joint entropy coding
  – Wavelet transform

• Problems
  – In order to achieve the highest compression ratio, compression and routing algorithms need to jointly optimized
  – Computational and communication overheads
Related Work (cont.)

• Distributed Source Coding
  – Slepian-Wolf coding theory
    • Decouples routing from compression

• Problems
  – When correlation pattern changes or abnormal events show up, the decoding accuracy will be greatly effected.
From Compressive Sensing to Compressive Data Gathering

• The asymmetrical property makes CS a perfect match for wireless sensor networks
Basic Idea

• A simple chain topology

<table>
<thead>
<tr>
<th>Baseline transmission</th>
<th>Global comm. cost</th>
<th>Bottleneck load</th>
</tr>
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<tr>
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<td>$N(N+1)/2$</td>
<td>$N$</td>
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Basic Idea

- A simple chain topology

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<td>Baseline transmission</td>
<td>N(N+1)/2</td>
<td>N</td>
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<tr>
<td>Compressive Data Gathering</td>
<td>N*M</td>
<td>M</td>
</tr>
</tbody>
</table>
Is Reconstruction Possible?

- The encoding and decoding flow chart

\[
\begin{align*}
\text{K-sparse signal} & \rightarrow \text{Sparse Transform} \quad \Theta = \Psi^T X \\
\text{M measurements} & \quad Y = \Phi \Theta \\
\text{Transmission} & \rightarrow \text{Reconstruct signal} \\
& \quad \text{min} \| \Psi^T X \|_1 \text{ s.t. } Y = A^{CS} X
\end{align*}
\]
Is Reconstruction Possible? (continue)

\[
\begin{pmatrix}
  y_1 \\
  y_2 \\
  \vdots \\
  y_M
\end{pmatrix} = \begin{pmatrix}
  \phi_{11} & \phi_{12} & \cdots & \phi_{1N} \\
  \phi_{21} & \phi_{22} & \cdots & \phi_{2N} \\
  \vdots & \vdots & \ddots & \vdots \\
  \phi_{M1} & \phi_{M2} & \cdots & \phi_{MN}
\end{pmatrix} \begin{pmatrix}
  d_1 \\
  d_2 \\
  \vdots \\
  d_N
\end{pmatrix}
\]

\[M << N\]

- **Facts**
  - Sensor reading is sparse and change slowly

- **According to CS theory**

\[
\min_{x \in \mathbb{R}^N} \|x\|_1 \quad s.t. \quad \|y - \Phi d\|_2 < \epsilon, \quad d = \Psi x
\]
Practical Problem 1

- Abnormal reading compromise data sparsity
Practical Problem 1 (continue)

- Solution:

\[ d = d_0 + d_s \quad d = \Psi x_0 + I x_s \]

\[ \Psi' = [\Psi \ I] \]

\[ d = \Psi' x, \quad x = [x_0^T x_s^T]^T \]

2 sparse

7 sparse

5 sparse

overcomplete basis
Practical Problem 2

• If a signal is not sparse in any intuitively known domain
Practical Problem 2 (continue)

• Solution: Re-ranking the value position to a smooth curve
Example 1

- Temperature data from the Pacific sea with deepness

\[ N = 1000 \quad K = 40 \quad M = [1, 4]^*K \]
Example 2

- Temperature data from data center
  - Temperature do not change violently with time

\[ N = 498 \]
\[ M = 0.5N \]
\[ M = 0.3N \]
NS-2 Simulation

• Chain Topology
  • N = 1000

• Grid Topology
  • N = 1089

Table 1: Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC protocol</td>
<td>802.11</td>
</tr>
<tr>
<td>Physical data rate</td>
<td>2Mbps</td>
</tr>
<tr>
<td>Transmission range</td>
<td>15 meters</td>
</tr>
<tr>
<td>Interference range</td>
<td>25 meters</td>
</tr>
<tr>
<td>Payload size</td>
<td>20 Bytes</td>
</tr>
<tr>
<td>RTS/CTS status</td>
<td>OFF</td>
</tr>
<tr>
<td>Retry limit</td>
<td>7</td>
</tr>
<tr>
<td>IFQ length</td>
<td>200</td>
</tr>
<tr>
<td>K/N (data sparsity)</td>
<td>0.05</td>
</tr>
<tr>
<td>$c_1 = M/K$</td>
<td>4</td>
</tr>
</tbody>
</table>
Chain Topology

N = 1000 \quad M = 200

Figure 8: Output-input interval in chain topology
Grid Topology

Figure 9: A typical routing tree in grid topology
Grid Topology (cont.)

N = 1089  M = 55

Figure 10: Output-input interval in grid topology

Figure 11: Packet loss ratio in grid topology
Conclusion

• Compressive sensing is a emerging field which may bring fundamental changes to networking and data communications research

• Contributions
  - The first complete design to apply CS theory to sensor data gathering
  - Convert the traditional compress-then-transmit process into a compressive gathering (compress-with-transmission)
  - Achieve a capacity gain of $\frac{N}{M}$ over baseline transmission
Discussion

• If sensor reading are not sparse in any known domain and in any proper order, can CDG achieve capacity gain?
• If sensing data are sparse in the original domain, which method is more efficient?
• Is CDG suitable for small scale sensor networks?
• Is CDG suitable for mobile wireless sensor networks?