Simple and Energy Efficient Image Compression for Pulse-Based Communication in THz Band

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Outline

• Motivation
• Image Compression Method
• Simulation
• Conclusion
Introduction

- Nanotechnology enables the development of nano-devices
- Nano-sensors and nano-devices can be used to detect the presence of infectious agents, e.g. virus, bacteria, cancer cells
- Nano-devices have tiny size and tiny energy capacity => we need simple algorithms with good energy efficiency
- As in macro world, in micro world compression consumes much less energy than computation
- => Compression can be used to obtain energy efficiency in transmitting them
Nanocommunication operates in THz band

THz band provides a very large bandwidth, which allows very high transmission rate

In macro scale, Teranets, i.e. Terabit per-second networks at THz band, will enable 5G cellular network, ultra-high definition video conference, etc.

Compression techniques can be used to obtain bandwidth efficiency
**Introduction**

**THz Propagation Model**

**Path loss** (spreading loss + absorption loss) and **noise** greatly affect transmission quality.

**Path loss** depends heavily on medium, distance and frequency:
- limited transmission above 10 m; we will need very directional antennas!
- several windows which are tens of GHz wide each for distances between 1 to 10 meters
- almost 10 THz wide transmission window for distances much below 1 m

**Noise** depends on temperature and waves.

Terahertz band is binary asymmetric channel (BAC)

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Information and figures from 2011 Jornet et al., Channel modeling and capacity analysis...
Introduction

**TS-OOK Modulation**

- Time-Spread On-Off keying (TS-OOK) modulation based on a 100 femtosecond-long Gaussian pulse; such pulses have been used in nanoscale imaging and sensing
- Binary transmission: bit 1 as a pulse transmission and bit 0 as a silence (no transmission)
- Pulse duration: $T_p$  
- Pulse period: $T_s$  
- Spreading ratio $\beta = T_s / T_p$

The advantages of large $\beta$:
- A relaxation on the energy harvesting process
- A channel relaxation

On sender:
Signal: \[
\wedge\wedge\wedge\wedge . \wedge\wedge\wedge\wedge
\]
Bit sent: 1 1 0 1

Signal on receiver:
Expected: \[
\wedge\wedge\wedge\wedge . \wedge\wedge\wedge\wedge
\]
Introduction

Nanonetwork Minimum Energy (NME)

- Reducing the number of bits 1 in TS-OOK yields energy efficiency
- NME uses source statistic to reduce the number of bits 1
- Symbols with higher occurrence are mapped to symbols with smaller codeword weight (number of bits 1)

The example mapping table for NME code.

<table>
<thead>
<tr>
<th>Input symbol</th>
<th>Symbol frequency</th>
<th>NME</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>80</td>
<td>000</td>
</tr>
<tr>
<td>110</td>
<td>70</td>
<td>010</td>
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<tr>
<td>101</td>
<td>60</td>
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<td>100</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>011</td>
<td>40</td>
<td>101</td>
</tr>
<tr>
<td>010</td>
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<td>011</td>
</tr>
<tr>
<td>001</td>
<td>20</td>
<td>110</td>
</tr>
<tr>
<td>000</td>
<td>10</td>
<td>111</td>
</tr>
</tbody>
</table>

The framework of using OOK modulation and the low-weight coding.
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Simple and energy efficient image compression (SEIC) is based on transform coding, i.e. discrete wavelet transform (DWT), followed by low-weight code.

- In transform domain, SEIC simply reduces the number of used coefficients.
- NME is used to reduce the number of bits 1 in used coefficients.

SEIC is both simple and energy efficient:

- Use less circuit than JPEG 2000.
- Does not have negative coefficients.
- Fixed codeword size provides less complexity in symbol detection and is more robust in the presence of errors.
Image Compression Method

SEIC uses only the first decomposition $LL_1$ (approximation and detail coefficients)
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Simulation

• Simulation using MATLAB
• TS-OOK modulation with pulse energy $E_{tx} = 1 \text{ fJ}$
• Transmission at THz band with distance up to 10 cm
• Used images:
  – Cancer cell image (cancer128.bmp) to represent an image with micro scale content (a cell)
  – Lena image (lena128.bmp) to represent images with high correlation between adjacent pixels
  – Barbara image (barbara128.bmp) to represent images with moderate correlation between adjacent pixels
  – Baboon image (baboon128.bmp) to represent images with low correlation between adjacent pixels
Simulation

SEIC has the largest energy efficiency, with a trade off in image quality.

![Image of comparison between different formats: Original, GIF, PNG, JPEG 2000, JPEG, SEIC with mean SSIM values: Original 1, GIF 1, PNG 1, JPEG 2000 0.99952, JPEG 0.93419, SEIC 0.82825.]

<table>
<thead>
<tr>
<th>Image</th>
<th>Method</th>
<th>Energy cons. (fJ) Transmitter</th>
<th>Energy cons. (fJ) Receiver</th>
<th>Energy eff. (%)</th>
<th>PSNR (dB)</th>
<th>SSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancer</td>
<td>BMP</td>
<td>76223</td>
<td>139696</td>
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</tr>
</tbody>
</table>
Robustness Against Transmission Error

- A compressed image is vulnerable to transmission error
- SEIC is more robust to transmission error compared to other image compressions

The average SSIM of received compressed Cancer image for various methods.

- **BMP**
- **PNG**
- **JP2**
- **JPEG**
- **SEIC**

**Mean SSIMs**:
- **Uncoded**: 0.996
- **GIF**: 0.69237
- **PNG**: 0.19514
- **JPEG 2000**: 0.81806
- **JPEG**: 0.19514
- **SEIC**: 0.81806
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Conclusion

- SEIC is less complex (< 25%) than DWT-based image compression, e.g. JPEG 2000
- SEIC yields the largest energy efficiency (up to 91%)
- Future work include testing other transform codings, e.g. DCT and video transmission