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

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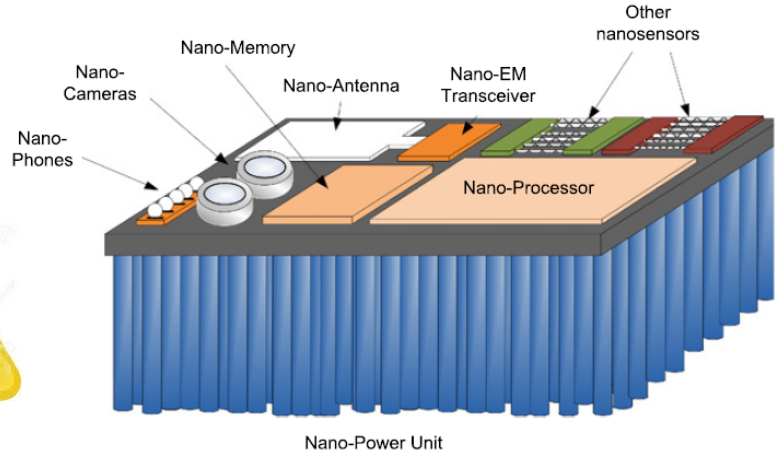
Outline

- Motivation
- Image Compression Method
- Simulation
- Conclusion

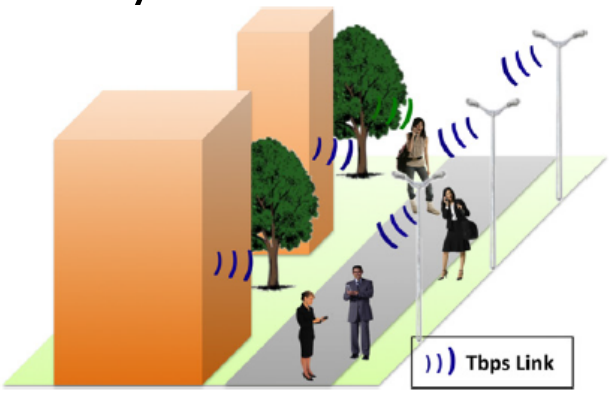
Introduction

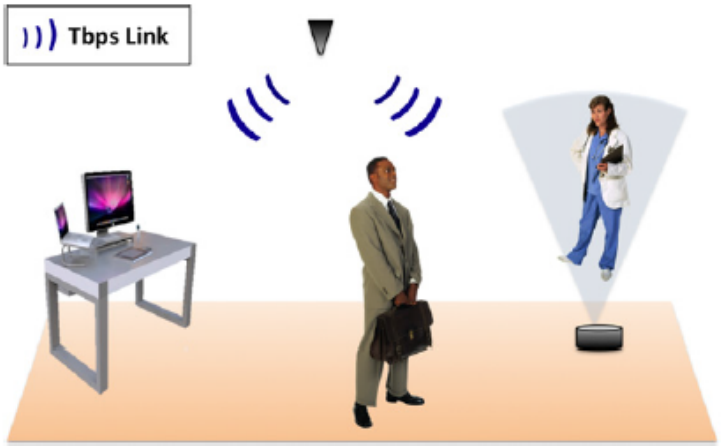
- Nanotechnology enables the development of nano-devices
- Nano-sensors and nano-devices can be used to detect the presence of infectious agents, e.g. virus, bacteria, cancer cells
- Nano-devices have tiny **size** and tiny **energy capacity** => we need **simple** algorithms with good **energy efficiency**
- 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



Introduction

- 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

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

THz Propagation Model

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

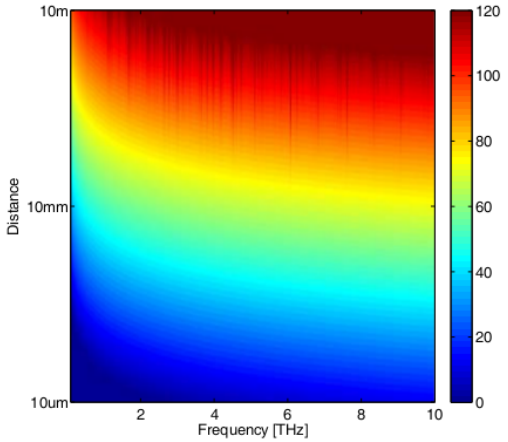
Path loss depends heavily on medium, distance and frequency

- 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

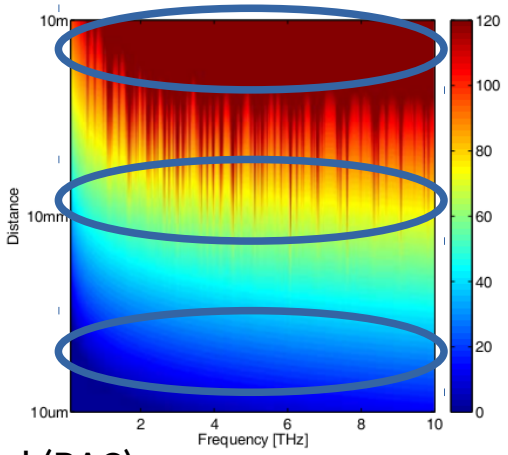
Noise depends on temperature and waves

Terahertz band is binary asymmetric channel (BAC)

Path loss

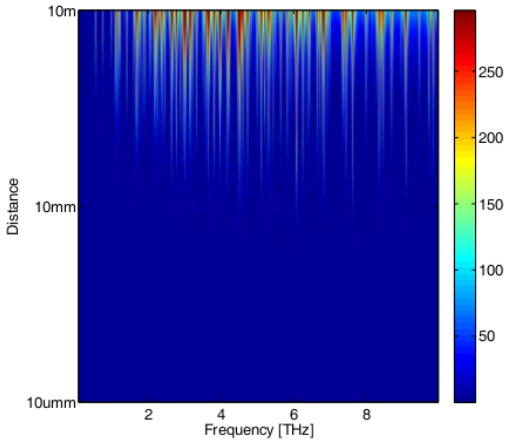


(a) 0.1% H_2O

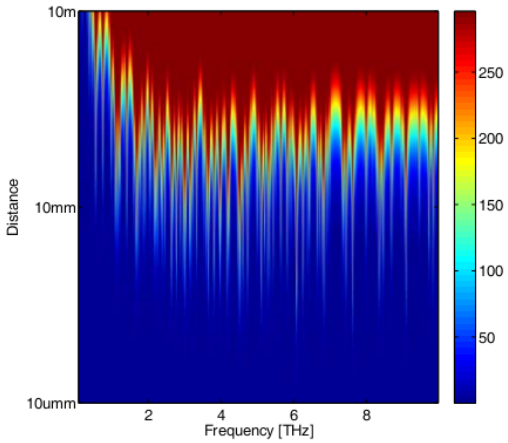


(b) 10% H_2O

Noise



(a) 0.1% H_2O



(b) 10% H_2O

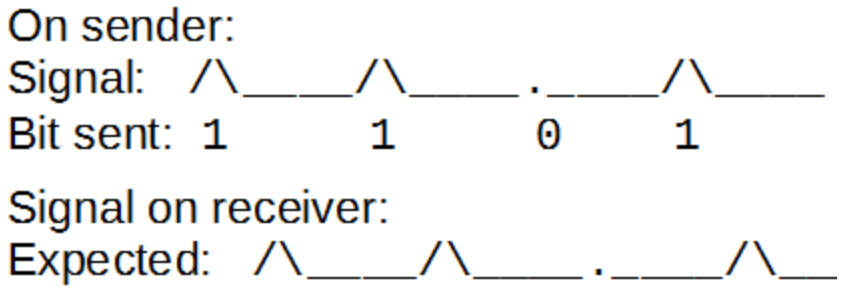
Introduction

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 β :

- A relaxation on the energy harvesting process
- A channel relaxation



Introduction

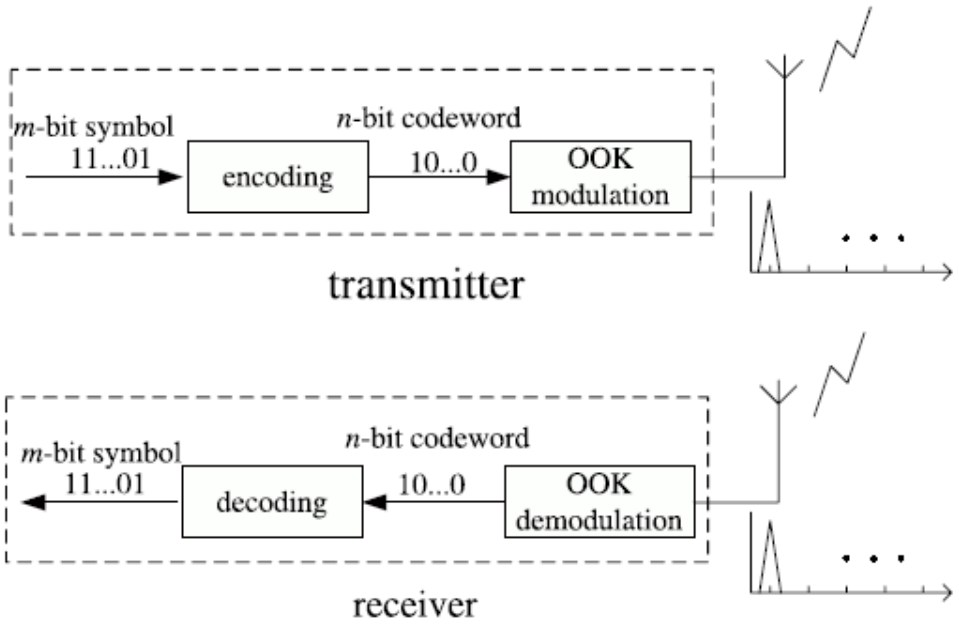
Nanonetwork Minimum Energy (NME)

Nanonetworks..., IEEE UIC, 2015

- 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.

Input symbol	Symbol frequency	NME
111	80	000
110	70	010
101	60	001
100	50	100
011	40	101
010	30	011
001	20	110
000	10	111



The framework of using OOK modulation and the low-weight coding.

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Image Compression Method

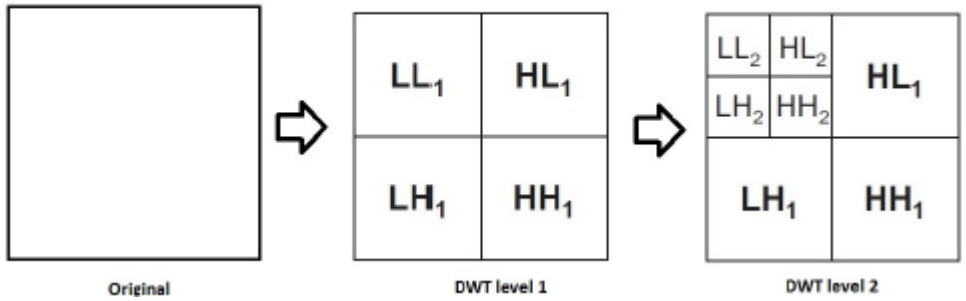
SEIC Method

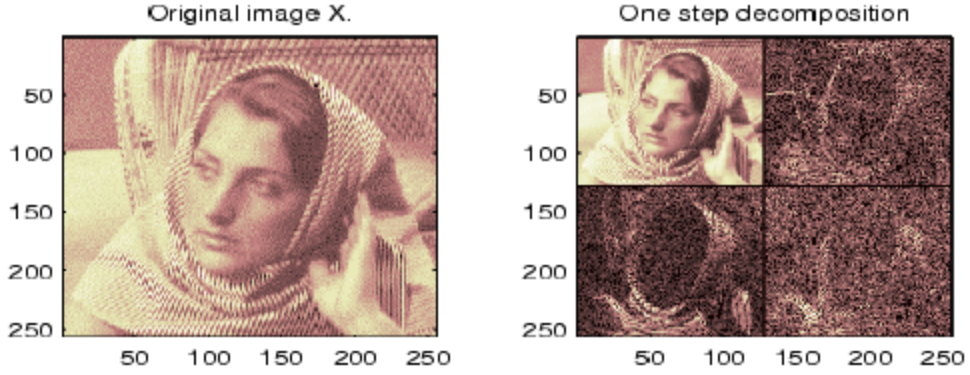
- Simple and energy efficient image compression (**SEIC**) is based on **transform coding**, i.e. discrete wavelet transform (DWT), followed by **low-weight code**
  - In transform domain, SEIC simply reduces the number of used coefficients
  - NME is used to reduce the number of bits 1 in used coefficients
- 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)

Multi-level DWT transform





Visual result of Barbara using SEIC-DWT

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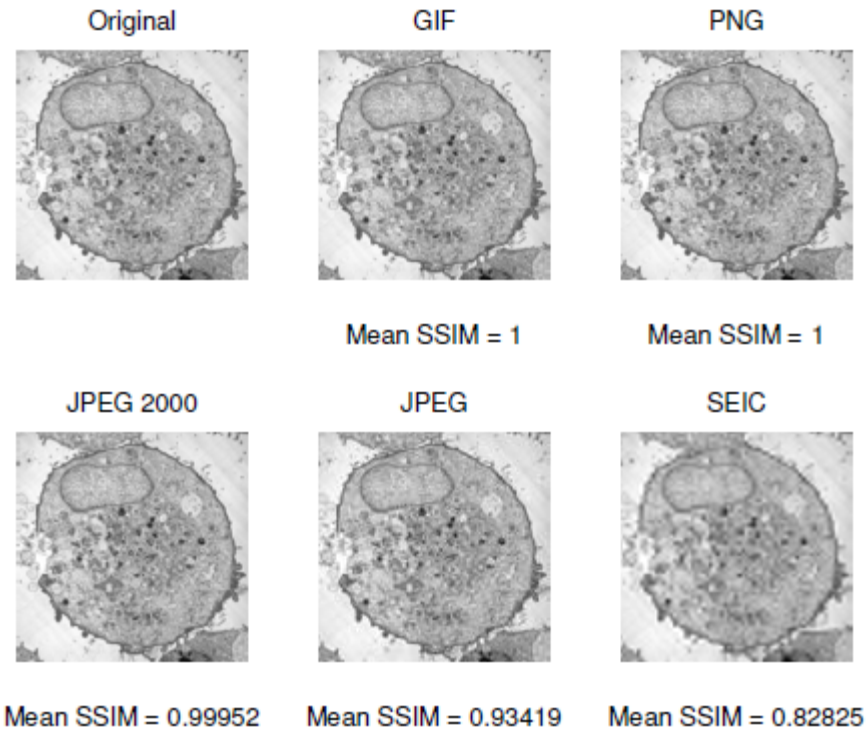
Simulation

- Simulation using MATLAB
- TS-OOK modulation with pulse energy E_{tx} = 1 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



ENERGY EFFICIENCY FOR ALL USED METHODS (DWT APPROX MEANS DWT WITH ONLY APPROXIMATION COEFFICIENTS).

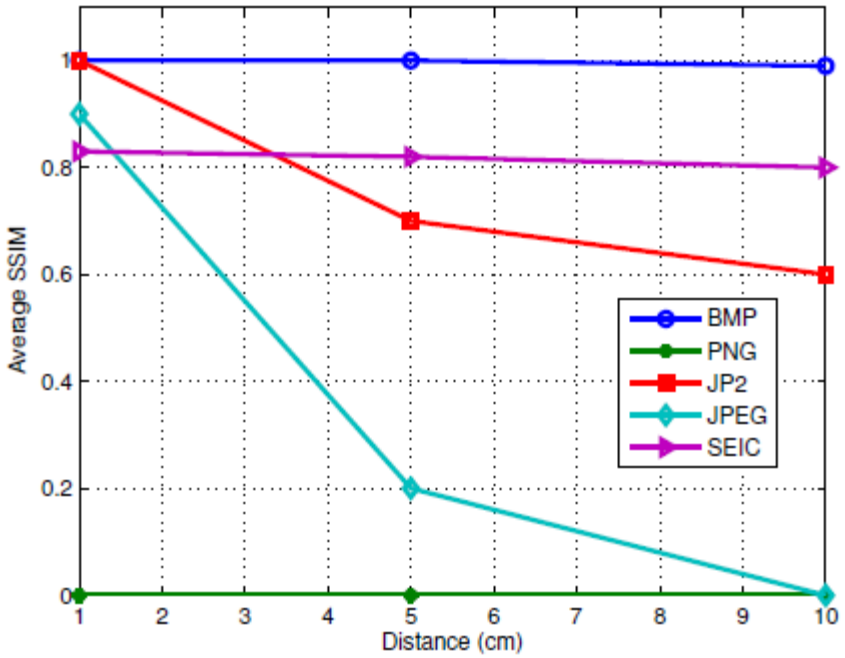
Image	Method	Energy cons. (fJ) Transmitter	Energy cons. (fJ) Receiver	Energy eff. (%)	PSNR (dB)	SSIM
Cancer	BMP	76 223	139 696	–	–	–
Cancer	GIF	64 339	153 024	15.6	∞	1
Cancer	PNG	51 080	99 584	33.0	∞	1
Cancer	JPEG 2000	47 895	96 520	37.2	62.0	0.99
Cancer	JPEG	17 852	36 024	76.6	38.1	0.93
Cancer	DWT approx	16 229	36 992	78.7	33.1	0.83
Cancer	SEIC	7 198	36 992	90.6	33.1	0.83
Lena	BMP	65 594	139 696	–	–	–
Lena	GIF	57 797	146 640	11.9	∞	1
Lena	PNG	42 842	84 752	34.7	∞	1
Lena	JPEG 2000	37 267	75 344	45.5	60.8	0.99
Lena	JPEG	14 781	29 256	78.3	40.4	0.95
Lena	DWT approx	13 581	36 992	79.3	35.1	0.90
Lena	SEIC	7 765	36 992	88.2	35.1	0.90
Barbara	BMP	66 303	139 696	–	–	–
Barbara	GIF	59 109	149 936	10.9	∞	1
Barbara	PNG	42 196	83 280	36.4	∞	1
Barbara	JPEG 2000	36 110	72 472	42.9	60.9	0.99
Barbara	JPEG	14 410	28 552	77.2	42.4	0.97
Barbara	DWT approx	13 301	36 992	79.9	37.2	0.94
Barbara	SEIC	7 742	36 992	88.3	37.2	0.94
Baboon	BMP	69 411	139 696	–	–	–
Baboon	GIF	61 582	155 152	11.3	∞	1
Baboon	PNG	47 778	95 104	31.2	∞	1
Baboon	JPEG 2000	44 939	90 680	35.5	62.0	0.99
Baboon	JPEG	15 530	31 784	77.6	39.1	0.93
Baboon	DWT approx	14 076	36 992	79.7	35.3	0.84
Baboon	SEIC	7 082	36 992	89.8	35.3	0.84

Simulation

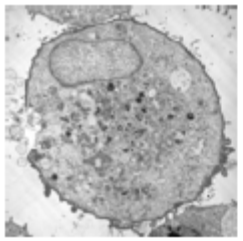
Robustness Against Transmission Error

- 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.



Uncoded



Mean SSIM = 0.996

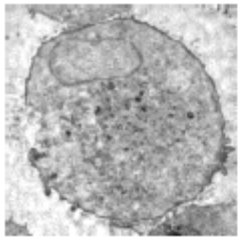
GIF

File error

PNG

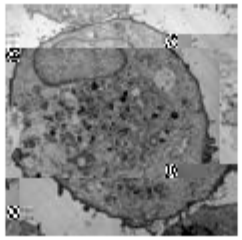
File error

JPEG 2000



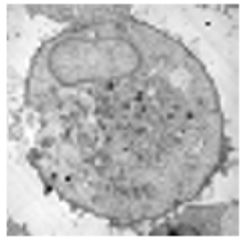
Mean SSIM = 0.69237

JPEG



Mean SSIM = 0.19514

SEIC



Mean SSIM = 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