THz Communication is Emerging

- THz communications promise Terahertz/speed data rates
- Recent advancements in electronic, photonic, and plasmonic technologies are closing the gap in THz transceiver design
- THz signal generation, modulation, and radiation methods are converging
- Channel model, noise, and hardware-impairment notions are emerging
- This paves the way to well-grounded research directions on THz-specific signal processing techniques for wireless communications

Advances in THz Transceiver Design

Electronic
- Silicon-germanium (Si-Ge) generators
- Gallium-nitride (GaN) power amplifiers

Photonic
- Quantum cascade lasers (QCLs)
- Photonic digital-to-analog (D/A) and A/D converters

Plasmonic
- Graphene-based HEMT transistors
- Plasmonic waveguides and phase controllers

THz Signal Processing Research Directions

- Ultra-massive multiple-input multiple-output (UM-MIMO) systems that extend the communication range
- Multicarrier waveform designs that take advantage of available spectral windows (other than orthogonal frequency-division multiplexing (OFDM))
- Pulse-based transmission (short femtosecond ON/OFF signals) versus carrier-based transmission (spectrally efficient continuous signals)
- Accurate beamforming and beamsteering criteria that take advantage of channel sparsity through compressed sensing techniques
- Optimal precoding and combining methods that make best use of resources
- Low-cost channel estimation schemes via fast channel tracking
- Near-optimal data detection in large symmetric UM-MIMO
- Perturbation-based regularization for equalization with near singular channels

THz Channel Conditions

- Quasi-optical behavior with line-of-sight (LoS) dominance
- Severe propagation losses and power limitations
- Path loss α has frequency (f) and distance (D) dependent molecular absorption spikes (c: speed of light)
  \[
  \alpha = \frac{\lambda^2}{4\pi f D}
  \]
  where \(\lambda\) is the wavelength in the medium.
- Sparse channel with beamforming
- Ill-conditioned correlated channel with spatial multiplexing
- Largest spatial degrees of freedom are achieved by M-antenna arrays with antenna separations \(\Delta\)
  \[
  \Delta = \sqrt{\frac{\lambda D}{2\pi}}
  \]
- Colored noise over frequency

Graphene-Based Antennas (Arrays of Sub-Arrays)

- High electron mobility and tunability \(\rightarrow\) flexible multicarrier designs
- Surface plasmon polariton wavelengths \(\lambda_{pp} \ll c/f \rightarrow\) compact designs
- Multiplexing at the level of sub-arrays (SAs) and beamforming at the level of antenna elements (AEs) \((Q \times P)\) AE s in each SA

Recent Results on THz Spatial Modulation

- Region 1 has large \(\Delta \rightarrow\) large footprint
- Region 2 has small \(\Delta \rightarrow\) compact design
- Region 2 optimized \(\rightarrow\) flexible/compact
- Total number of bits \(N_b\) per channel use given constellation \(X\) is
  \[
  N_b = \log_2 \left( |\mathcal{X}| \right) + \log_2 \left( \frac{|\mathcal{X}|}{|\mathcal{X}|} \right)
  \]
- Higher capacities with generalized spatial and index modulation solutions

References

I. F. Akyildiz, J. M. Jornet, “Realizing ultra-massive MIMO (1024x1024) communication in the (0.06–10)