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Abstract: THz-wireless systems, due to their ability to transmit high data rates, appear to be an ideal approach to invest fiber-based networks with an unprecedented degree of flexibility. The key for this seamless interconnection is an analog baseband interface. In this presentation, we summarize our efforts to combine fiber-optics and THz-wireless in order to achieve >100Gb/s systems; first, by introducing a real-time optical modem for a purely THz-electrical setup, and second, by introducing an optic/THz baseband interface to construct a combined transmission link: a THz-wireless fiber extender.

Purpose: Information of the Technical Advisory Group THz

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INTEGRATION OF HIGH-DATA RATE THZ-WIRELESS SYSTEMS INTO FIBER-OPTICAL NETWORKS

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ICT-09-2017 – Networking research beyond 5G
Duration: 7/2017 – 12/2019
OUTLINE

- Motivation

- 100 Gb/s real-time experiments
  - THz-wireless system
  - Optic/THz-wireless system

- Conclusions and future work
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Motivation
THz transmission and the future of high-speed flexible wireless networks

- THz wireless data transmission at carrier frequencies in the 100 – 1000 GHz range
  - Large bandwidth, compatible with state-of-the-art fibre-optical transmission systems
  - This allows to design **flexible Terabit/s Wireless Systems** capable of being directly integrated into fiber-based network architectures
Motivation
THz transmission and the future of high-speed flexible wireless networks

- Possible applications can be grouped into 3 particular scenarios:
  - Omnidirectional
  - Point-to-Multipoint
  - Point-to-Point
Motivation
THz transmission and the future of high-speed flexible wireless networks

- Seamless interconnection between fiber networks and THz-wireless links
- Joint impairment mitigation of the combined optic/THz-wireless link
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100 Gb/s real-time experiments – THz-wireless system

Experimental real-time THz-wireless system using a digital-coherent optical modem

- ~34 GBd PDM-QPSK modulation
- 2x2 polarization MIMO
- CFP2-ACO pluggable interface
- QSFP28 client side interface

- InP MMIC technology
- BW: 25 GHz (Tx)
  50 GHz (Rx)
- 23 dBi antennas
- ~300 GHz carrier

- Length: 50 cm
- Height: 20 cm above the metal ground plate
- Separation: 12.5 cm lateral displacement
100 Gb/s real-time experiments – THz-wireless system

DSP chain used for the 100 Gb/s THz-wireless link

- Reference case: Offline DSP commonly used in fiber-optical experiments
- Similar algorithms implemented in real-time modem
100 Gb/s real-time experiments – THz-wireless system
Physical layer performance using a digital-coherent real-time optical modem

- Long-term stable (4 days of continuous operation) pre-FEC BER below SD-FEC threshold
- Comparison to offline DSP: Pre-FEC BER better due to optimized DSP

100 Gb/s real-time experiments – THz-wireless system
Ethernet tests using an IXIA XGS12 100 GbE traffic platform – Frame loss rate

- The traffic platform defines the number of lost frames as follows:
  
  \[ \text{lost frames} = \text{Tx frames} - \text{Rx frames} \]

- ‘In transit’ is therefore an actual condition

\[
8.545 \mu s / \left( 794 \frac{B}{\text{frames}} \cdot 8 \frac{b}{B} / 100 \frac{\text{Gb}}{s} \right) = 135 \text{ frames}
\]

- Frame loss rate: \textbf{0.03 fps} (1.85 fpm)
- Frame size: random (70 – 1518 Bytes)
100 Gb/s real-time experiments – THz-wireless system
Ethernet tests using an IXIA XGS12 100 GbE traffic platform – Throughput

- Payload type **does not** influence the overall throughput of the system
- Frame size **does** affect the overall throughput of the system
  - 12-Byte long ‘interframe gap’ between frames
  - More frames → more idle time → less actual transmitted data
- Max. measured data rate was **98.07 Gb/s**
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100 Gb/s real-time experiments – Optic/THz-wireless system

Link configurations for a THz-Wireless Fiber Extender

- The goal was to construct a short-range real-time implementation of a high-speed THz-wireless fiber extender as a proof-of-concept

- Fiber – THz Wireless – Fiber
- Fiber – THz Wireless
- THz Wireless – Fiber

Real-time digital coherent optical modem

Optic-THz baseband interface

PC: phase conjugation. Inversion of in-phase components of both polarizations at the optic-THz BB interface

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100 Gb/s real-time experiments – Optic/THz-wireless system
Physical layer performance of an optic/THz-wireless transmission system

- BER performance vs. total fiber distance for different link configurations

- Neither the fiber configuration nor the optical link distance seems to affect the overall performance
  - High OSNR: > 35 dB
  - THz-wireless link is the limiting factor
100 Gb/s real-time experiments – Optic/THz-wireless system
Physical layer performance of an optic/THz-wireless transmission system

- Comparison to simulation results

- Performance of a combined link is determined by the link with the worse SNR condition

- Assuming there’s a large SNR difference between them

- Evidence shows that the THz link operates in a low SNR condition
100 Gb/s real-time experiments – Optic/THz-wireless system

DSP techniques and their application to optic/THz-wireless links –

Estimated total accumulated chromatic dispersion

- Chromatic dispersion is estimated as a function of the fiber distance
- The THz fiber extender is transparent to CD
  - A slope of ~17 ps/km·nm can be extracted (SSMF)
- Phase conjugator by inverting in-phase components at optic-THz interface
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Conclusions and future work
Towards integrated optic/THz-wireless connectivity for Beyond 5G

- Experimental demonstration: 100-Gb/s THz Wireless Transmission over 0.5 m
  - Stable BER performance over 96 hours of continuous operation
  - Validation of 100 Gb/s throughput (98.08 Gb/s)

- Experimental demonstration: Seamless interconnection between optical transmission links and THz-wireless technologies
  - Real-time 100 Gb/s transmission over fiber + THz-wireless link
  - Demonstrated the linearity and transparency of the THz-wireless fiber extender

- Next steps: Increase range, capacity and flexibility
  - Extend range by using high-gain antennas (1 km-long THz-wireless transmission)
    - 28 GBd QPSK transmission over 1 km
  - Improve linearity and output power of electronic front-ends (high-order modulation formats)
  - Adaptive PHY DSP to cope with channel dynamics (better suited DSP techniques)
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WE PUT SCIENCE INTO ACTION.

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