Aalto University
School of Electrical
Engineering

Department of Communications
and Networking (Comnet)

Sustainable Zero-Energy Machine Type Communications for 6G and beyond

Prof. Riku Jäntti
riku.jantti@aalto.fi

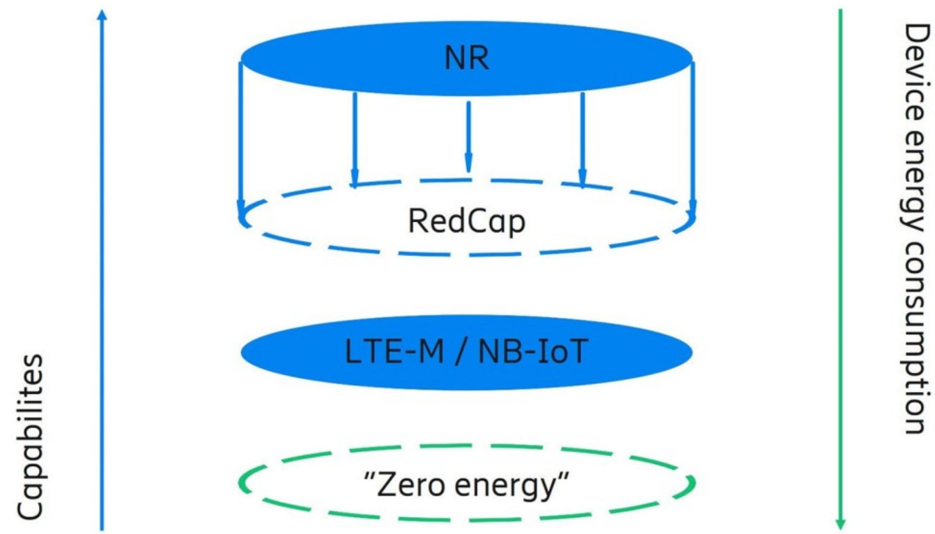
Aalto University
School of Electrical
Engineering

Sustainable Zero-Energy Machine Type Communications for 6G…

Zero-energy devices for 6G MTC

- Zero-energy devices, of course, consume energy, but their energy supply is extremely limited
  - Energy harvesting from ambient sources
  - Energy storage in supercapacitators

=> Device power consumption needs to be minimized

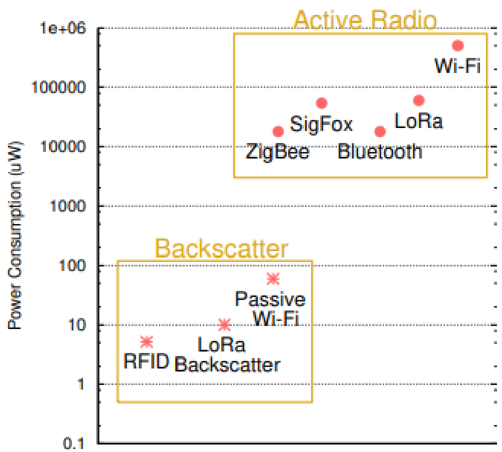


Zero-energy devices and their relation to 4G/5G technologies
https://www.ericsson.com/en/blog/2021/9/zero-energy-devices-opportunity-6g

Zero-energy devices for 6G MTC

ZED transmitters

- Ultra-low-power backscatter modulators

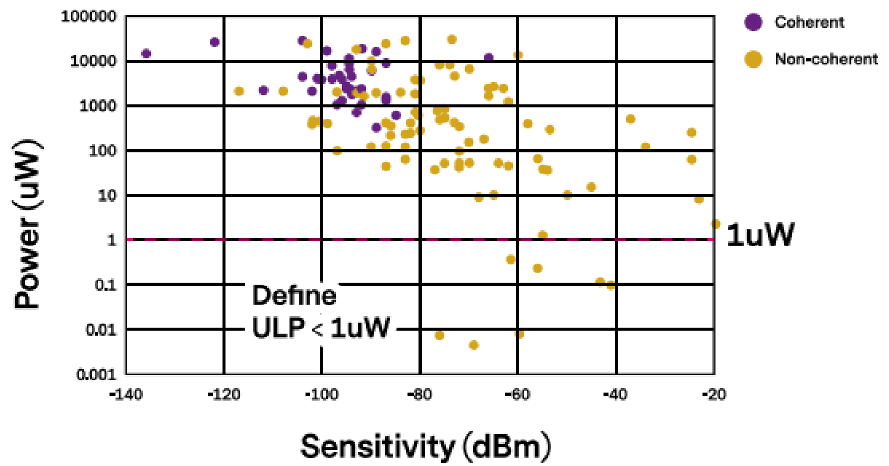


(a) **Power Consumption.**

Talla, V., Hessar, M., Kellogg, B., Najafi, A., Smith, J.R. and Gollakota, S., 2017. Lora backscatter: Enabling the vision of ubiquitous connectivity. *Proceedings of the ACM on interactive, mobile, wearable and ubiquitous technologies*, *1*(3), pp.1-24.

ZED receivers

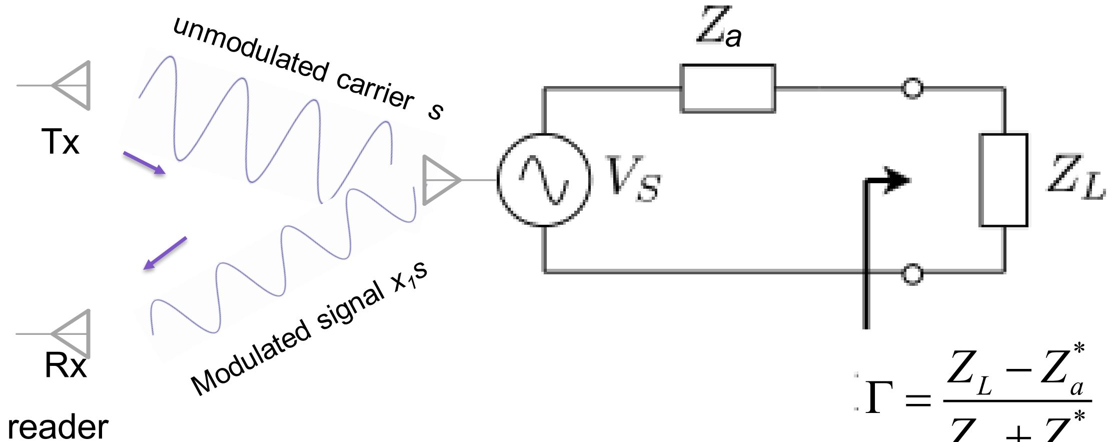
- Ultra-low-power Wake-up radios



https://www.6gchannel.com/items/6g-white-paper-critical-massive-type-communication/

Backscatter communications

- Low-cost, low power radio transmission by reflecting the radio wave imping at the antenna of the device.

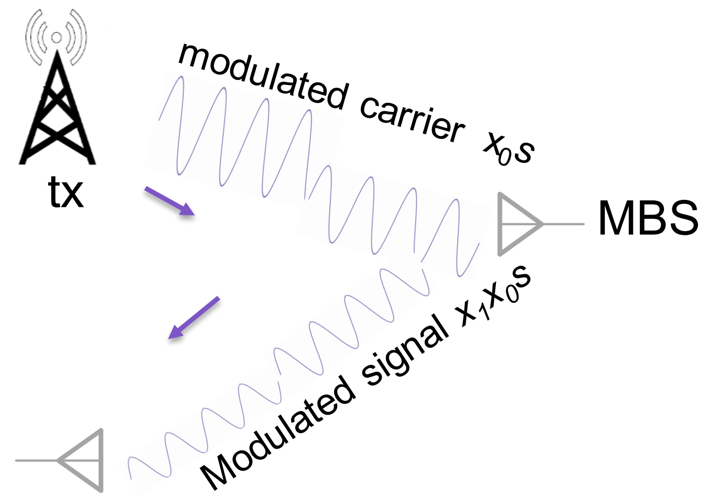


$$\Gamma = \frac{Z_L - Z_a^*}{Z_L + Z_a^*}$$

Γ : reflection coefficient,
Z_L: the antenna load impetence,
Z_a^* : the antenna impedance.

Ambient backscatter communications

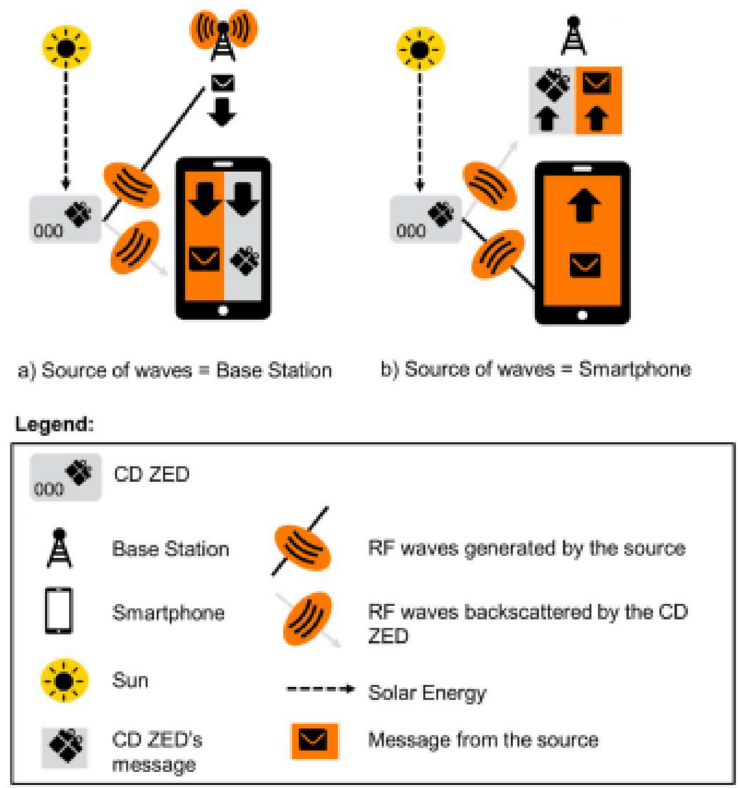
- In traditional backscatter communications, the reader needs to generate unmodulated carrier to illuminate the communicating device.
- In Ambient backscatter communications (AmBC), existing signals in the 'air' will be utilized instead to save power and enhance spectral efficiency
  - such as FM radio, DTV, WiFi, BLE, cellular signals



Ambient backscatter communications in mobile networks

Crowd-Detectable Zero-Energy-Devices (CD-ZED)

- Use cellular generated signals as ambient signal source
- Use mobile devices or base station for receiving the backscattered signal
- Energy harvesting using solar cells because RF energy harvesting has very limited range.



Phan-Huy, D.T., Barthel, D., Ratajczak, P., Fara, R., di Renzo, M. and de Rosny, J., 2021, October. Ambient Backscatter Communications in Mobile Networks: Crowd-Detectable Zero-Energy-Devices. In *2021 IEEE International Conference on RFID Technology and Applications (RFID-TA)* (pp. 81-84). IEEE.

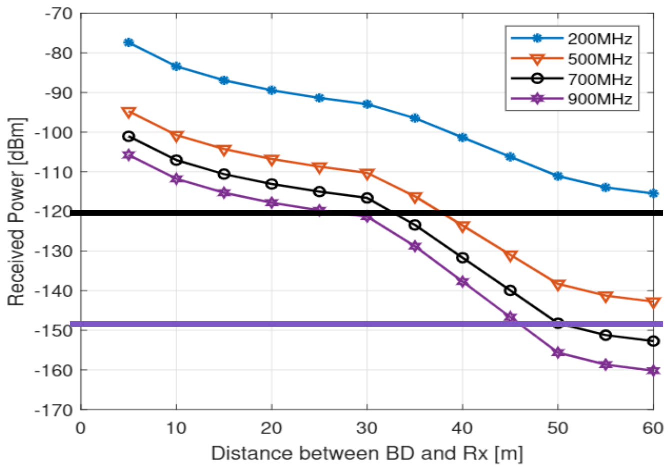
Ambient backscatter communications in mobile networks

Bistatic scenario:

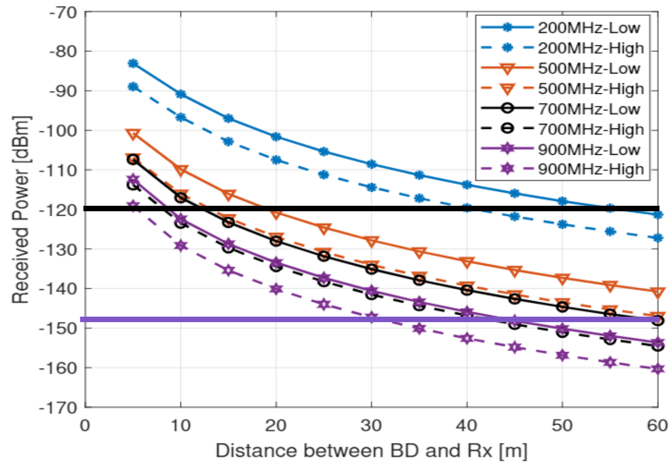
Macro Base stations generate carrier

ITU-R P.14410-10 outdoor D2D propagation model
3GPP TR38.0+1 Indoor hotspot propagation model

Tag and Receiver on the street



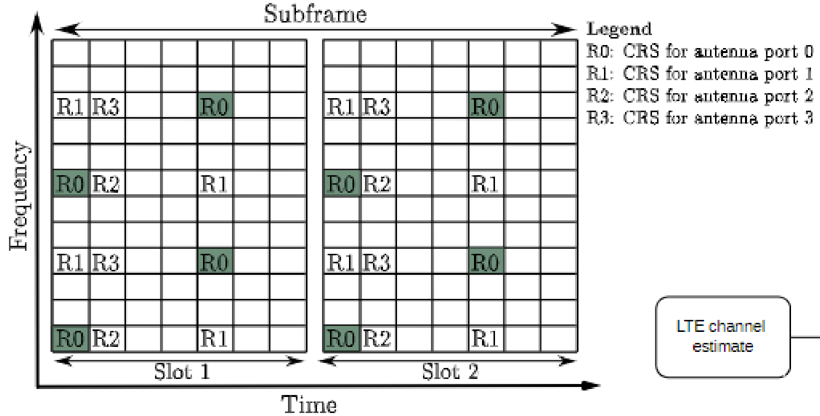
Tag and receiver inside

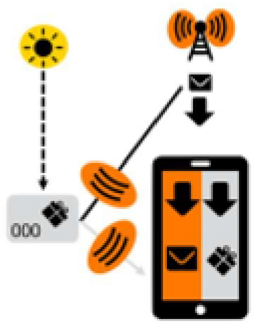


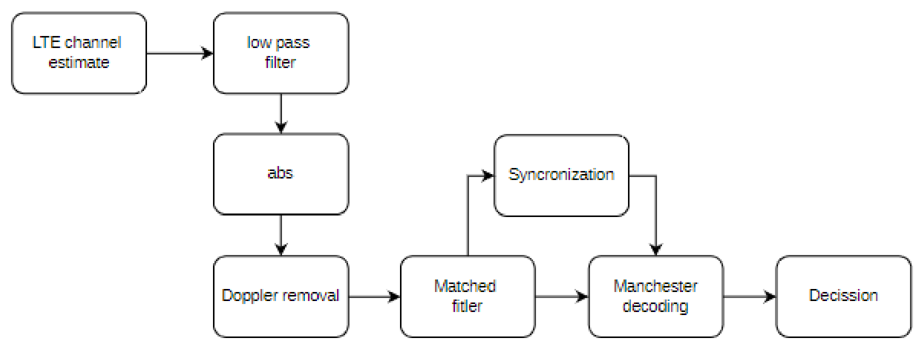
M. U. Sheikh, B. Xie, K. Ruttik, H. Yiğitler and R. Jäntti, "Ultra Low Power Wide Range Backscatter Communication Using Cellular Generated Carrier, Sensors, 2021.

Ambient backscatter communications in mobile networks

- **Mobile system channel estimator can be used as a AmBC receiver at the user device**



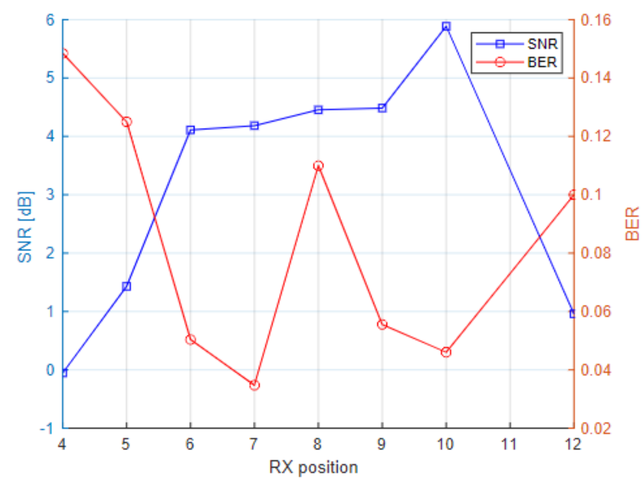




Ambient backscatter communications in mobile networks

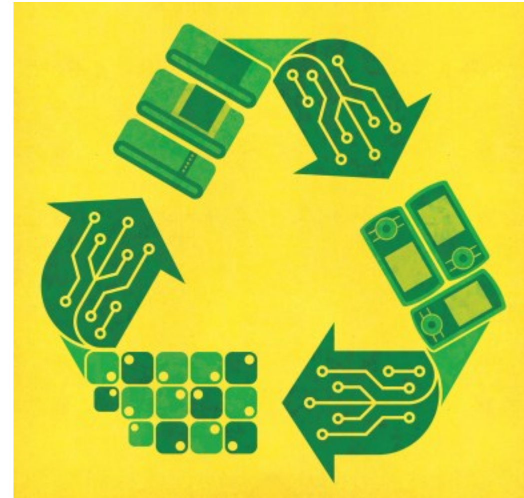
AmBC Rx using LTE cell specific reference signals and channel estimator output.

	Parameter	Value
Tx	Baseband signal generator	R&S SMBV100A Vector Signal Generator
	Antenna	R&S HK033 VHF/UHF coaxial dipole
	Carrier frequency	486MHz
	Bandwidth	7.68 MHz
	TX power level	15 dBm
	Peak envelop power	29.09 dBm
BD	Baseband signal generator	Tektronix AFG 31000 Arbitrary Function Generator
	Antenna	RaTLSnake M6 telescopic antenna
	Symbol duration	10 ms
	Synchronization	13 bit Braker code
	Encoding	Manchester
	Modulation scheme	OOK
Rx	Device	NI USRP-B210
	Antenna	RaTLSnake M6 telescopic antenna
	AD converter	12 bits



IoT Sustainability challenge

- The United Nations found that people generated 44.7 million metric tons of e-waste globally in 2016, and expects that to grow to 52.2 million metric tons by 2021.
- Semiconductors are being added to products that previously had none - making them e-waste when they reach the end of their life cycle. Adding intelligence in the devices also shorten their lifetime turning products that might last 15 years into ones that must be replaced every five years which makes the problem worse.
- There is also alarming number of small connected devices such as trackers, jewelry, or wearables that are designed to fail once the battery dies.

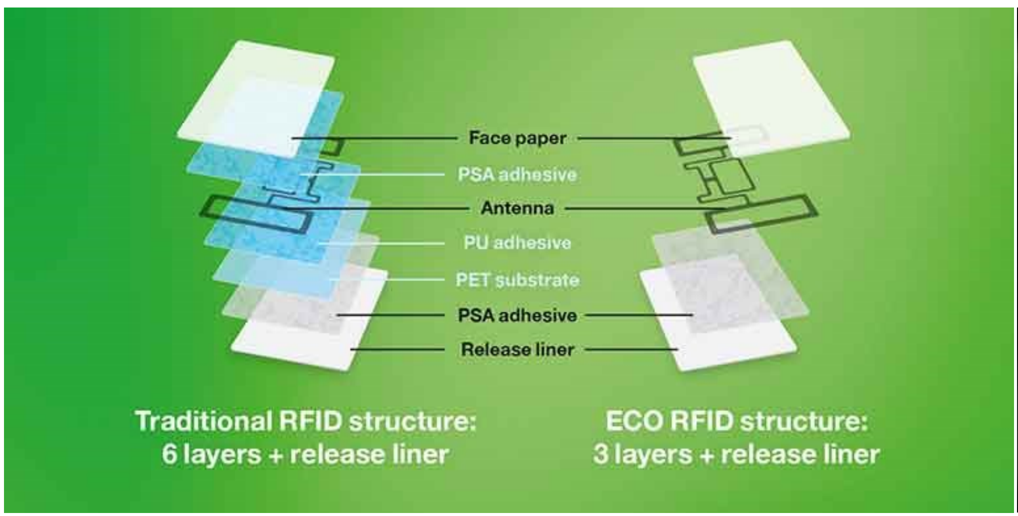


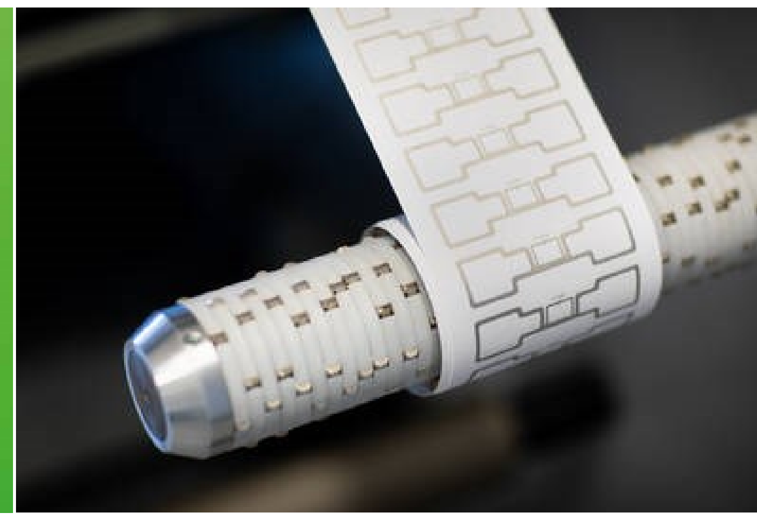
S. Higginbotham, "The internet of trash [Internet of Everything]," in *IEEE Spectrum*, vol. 55, no. 6, pp. 17-17, June 2018, doi: 10.1109/MSPEC.2018.8362218.

Example of a product that is designed to fail as the battery runs out: The smart basketball.

Sustainable backscatter commuications

- Backscatter devices can be manufactured in environmentally friendly manner
- In the future the chip could be replaced by organic electronics components





ECO RFID by Stora Enso

Sustainable Zero-Energy Machine Type Communications for 6G

- **Ambient backscatter communications is a promising technology for ultra-low-power data transmission.**
- **In downlink case, the reference signals transmitted by the base station could be used as the ‘Ambient signal’.**
  - Independent of the downlink data transmission (In LTE always present, in NR can be scheduled based on need)
  - Channel estimator can be utilized to implement the backscatter receiver (modem firmware software).
  - Chanel estimator can track the backscatter signal and thus interference between backscatter device and downlink information signals can be avoided.

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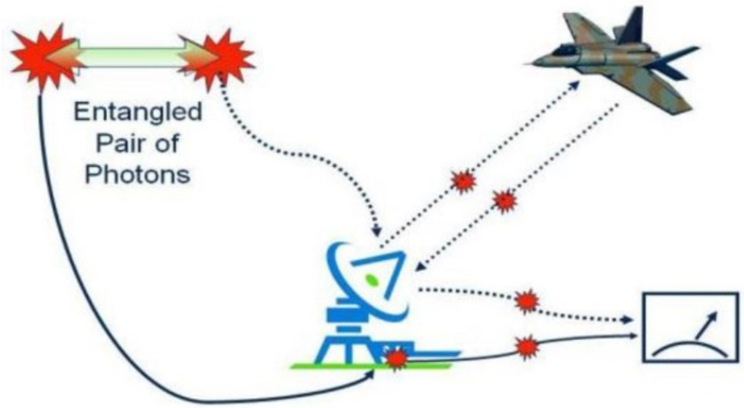
…and beyond

Secure backscatter communications for beyond 6G mobile systems

Microwave Quantum Backscatter Communications

Quantum radar is an emerging remote-sensing technology that utilizes non-classical quantum correlations to enhance the detector sensitivity.

Microwave quantum backscatter communications applies the quantum radar techniques for wireless communications.



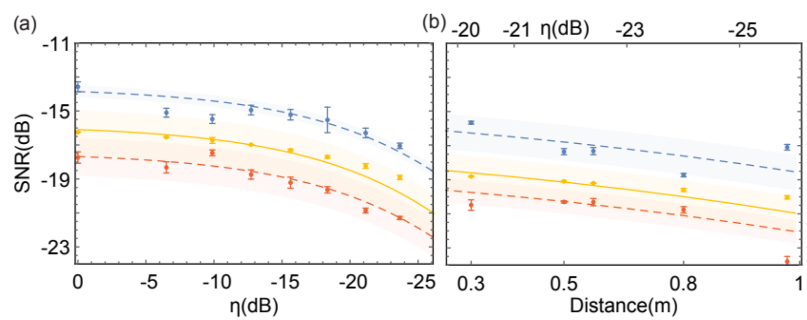
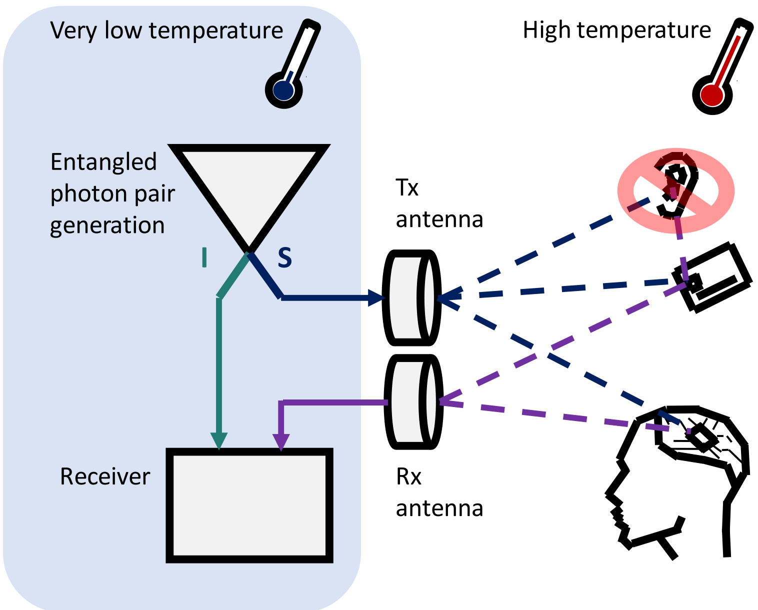


FIG. 3. **Low reflectivity quantum correlated noise radar.** The inferred signal to noise ratio (SNR) of calibrated QI (blue) and symmetric CI (red), and the measured coherent-state illumination with digital heterodyne detection (yellow) as a function of (a) the total signal loss η and (b) object distance from the transmitting and receiving antennas for free space illumination. The error bars are calculated similar to Fig. 2. For both panels the signal photon number is $N_S = 0.5$. The shaded regions are the theoretical uncertainties extracted by fitting the experimental data. The SNR of the coherent state with homodyne detection is not presented in this figure since the expected advantage at the chosen N_S is smaller than systematic errors in this measurement.

Barzanjeh, S., Pirandola, S., Vitali, D. and Fink, J.M., 2020. Microwave quantum illumination using a digital receiver. *Science Advances*, *6*(19), p.eabb0451.

Microwave Quantum Backscatter Communications

N_s	Average number of generated photons
N_z	Average number of thermal photons
η	Round trip transmissivity (RTT)
M=WT	number of independent mode pairs
W	Phase matching bandwidth
T	Pulse duration

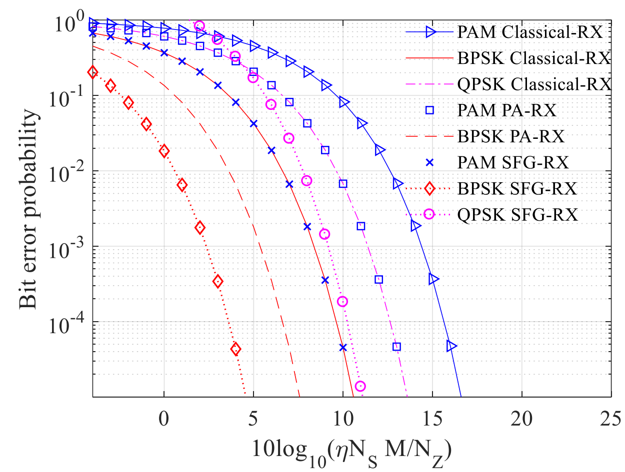


Secure transactions

- Quantum key exchange
- Low probability of detection

Biomedical & laboratory applications

- Low electromagnetic exposure
- Low interference to precision instruments



- R. Jäntti, R. Di Candia, R. Duan, and K. Ruttik, “Multiantenna Quantum Backscatter Communications,” Quantum Communications and Information Technology 2017 (QCIT'17) Workshop at Globecom 2017.
- R. Di Candia, R. Jäntti, R. Duan, J. Lietzen, K. Hany and K. Ruttik, “Quantum Backscatter Communications: A New Paradigm,” In Proc. ISWCS 2018, 28-31 August, Lisbon, Portugal, 2018.
- K. Hany and R. Jäntti, “Quantum backscatter communication with photon number states,” Workshop on Quantum Communications and Information Technology (QCIT'18) at IEEE Globecom 2018, December 9-13, Abu Dhabi, 2018.
- H. Khalifa and R. Jäntti, “Retrieving quantum backscattered signals in the presence of noise” IEEE GLOBECOM 2019 Workshop on Quantum Communications and Information Technology, 9-13 December, Waikola, HI, USA, 2019.
- R. Jäntti, R. Duan, J. Lietzen, H. Khalifa, and L. Hanzo, ”Quantum Enhanced Microwave Backscattering Communications,” IEEE Communications Magazine, 2020.

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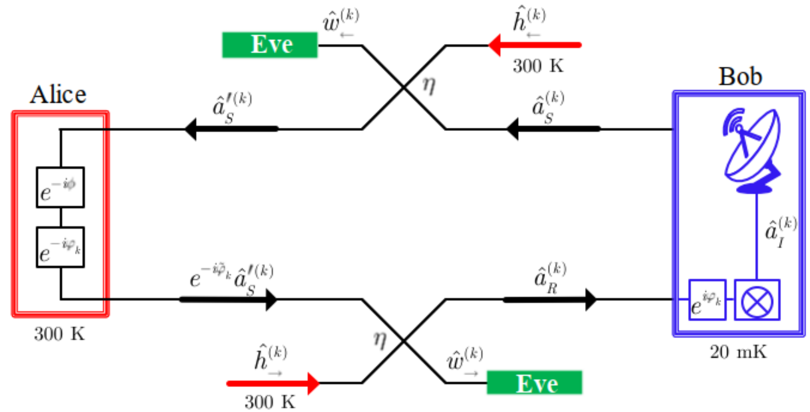
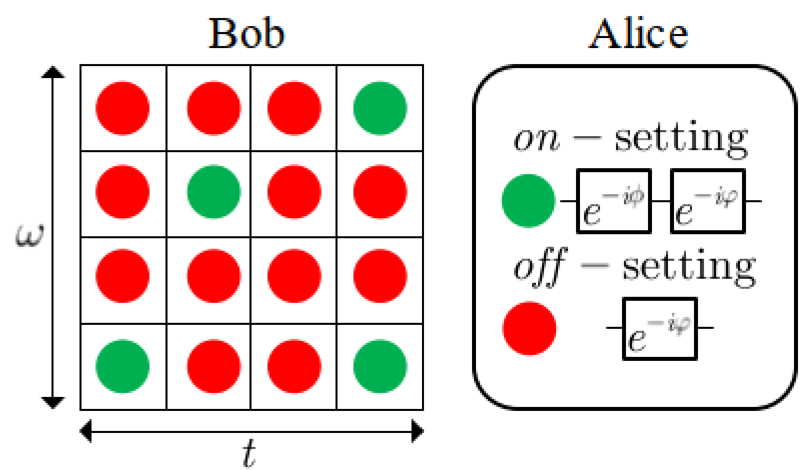
Covert Microwave Quantum Backscatter Communications

Two way covert microwave quantum communications:

- Alice and bob share a key.
- Eaves dropper cannot detect the transmission of the carrier to illuminate the tag, nor can she detect the backscatter signal.



Theorem 7. *Let Alice and Bob share a publicly available codebook and a secret random sequence of length n. Then, they can communicate* $\bar{m} = \frac{2}{\log 2} c_B \beta \delta \eta^4 \sqrt{n} + \log \epsilon$ *bits over n channel usages with error probability bounded by* ϵ*, by keeping* $P^{(\mathrm{Eve})} \leq \delta$*. Here,* β *is a constant that depends on the detector:* $\beta = 4$ $(\beta = 2)$ *for the TMSV state and SC state transmitters with the optimal collective (local) receiver, and* $\beta = 1$ *for the coherent state transmitter with a homodyne receiver.*



R. Di Candia, H. Yigitler, G. S. Paraoanu, and R. Jäntti, "Two-way covert microwave quantum communications" https://arxiv.org/abs/2004.07192

Conclusions

Sustainable Zero-Energy Machine Type Communications for 6G…

- Ambient backscatter is a potential technology for 6G MTC
- Backscatter devices can be manufactured in an environmentally friendly manner such that e-waste can be minimized or completely avoided.

…and beyond

- As microwave quantum technology matures, backscatter communications using classical devices and quantum readers offers a way towards secure beyond 6G MTC.