Leistungseffiziente Funkübertragung mittels Relaystationen

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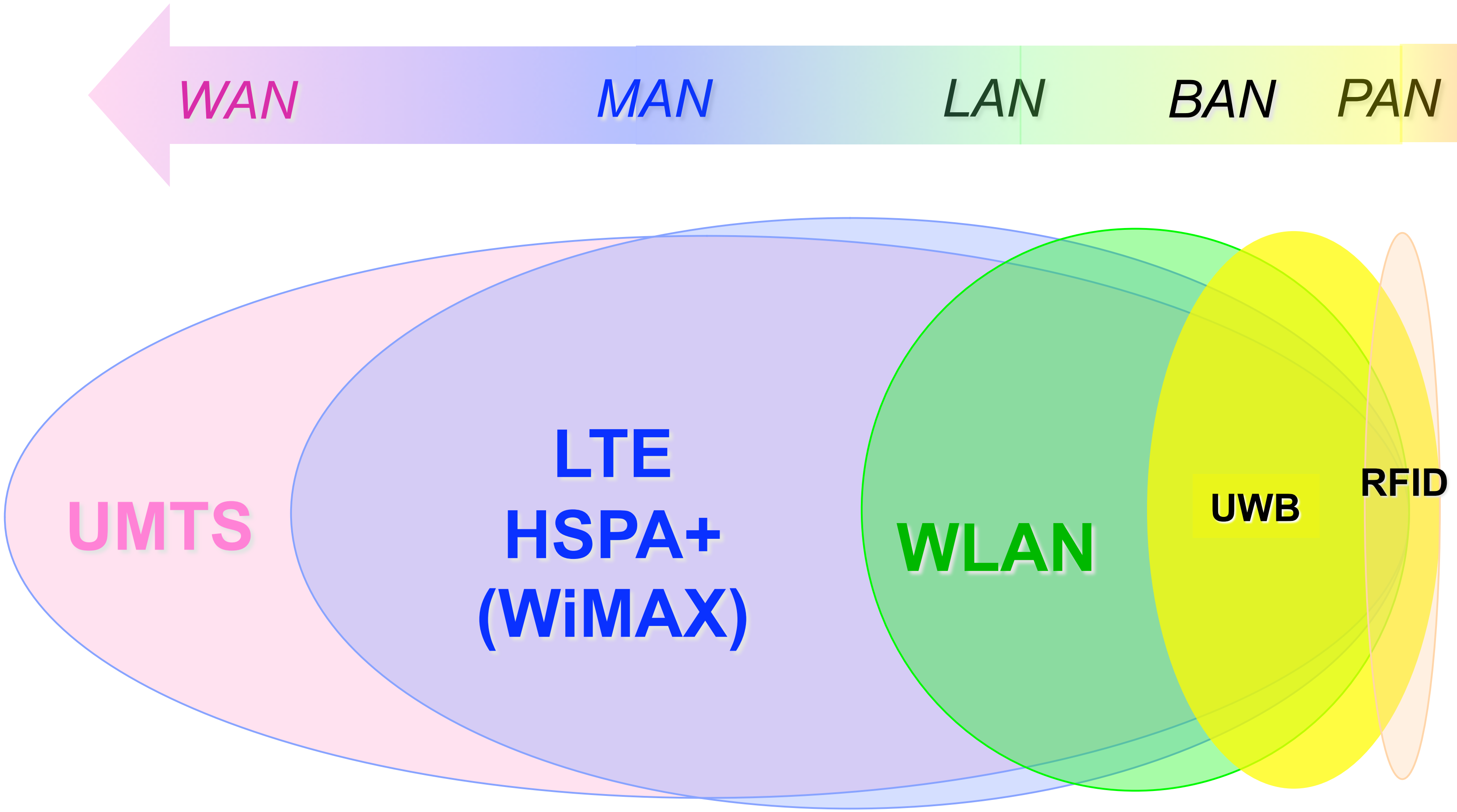
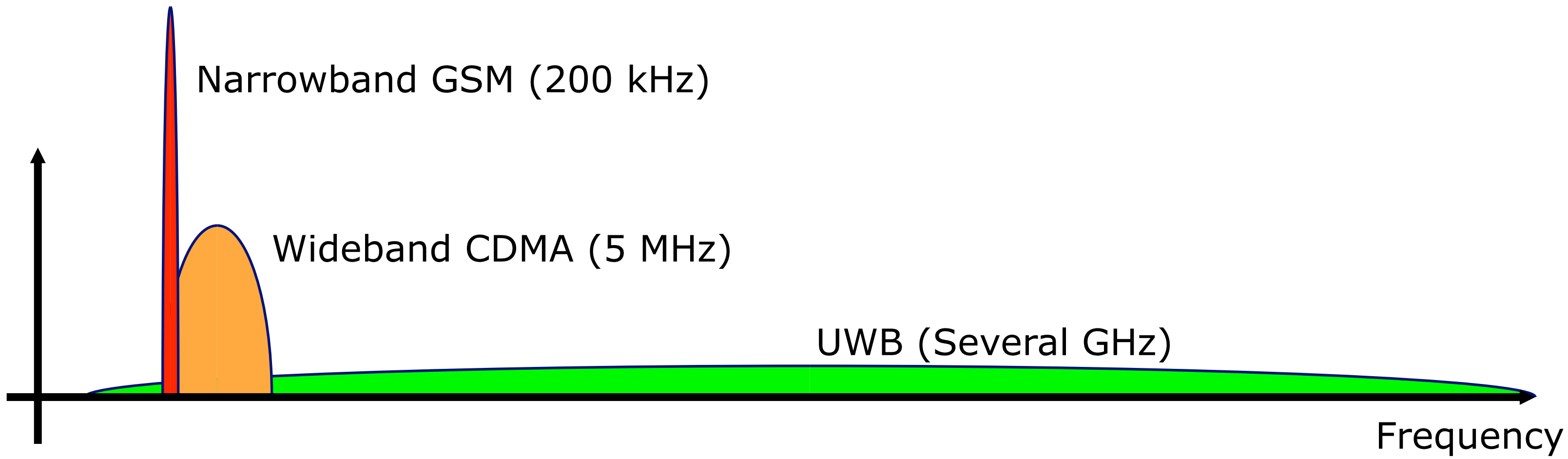
Kplus Kompetenzzentren-Programm

Ecology of concurrent radio systems



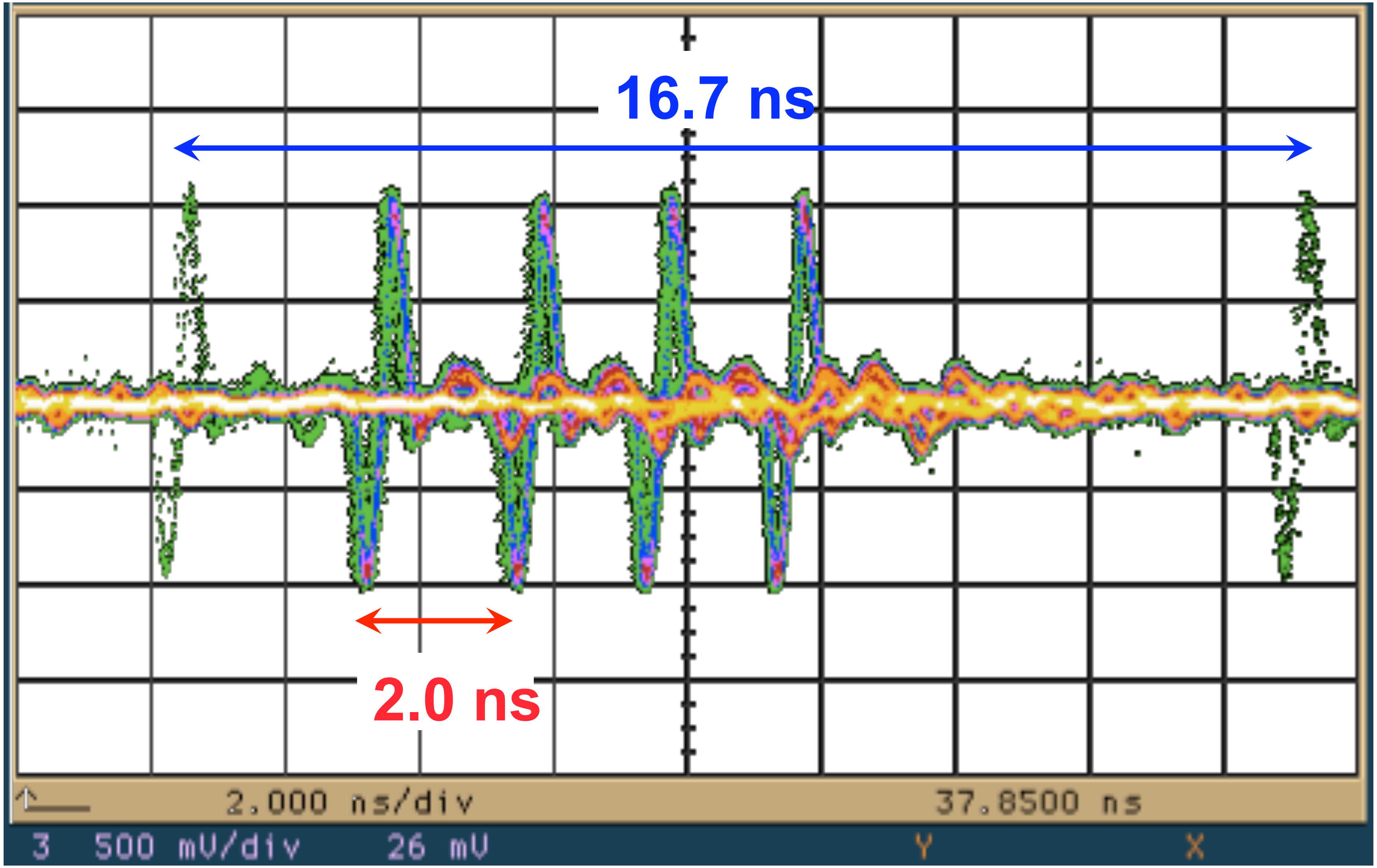
No single wireless technology will do it all

Large relative (and absolute) bandwidth



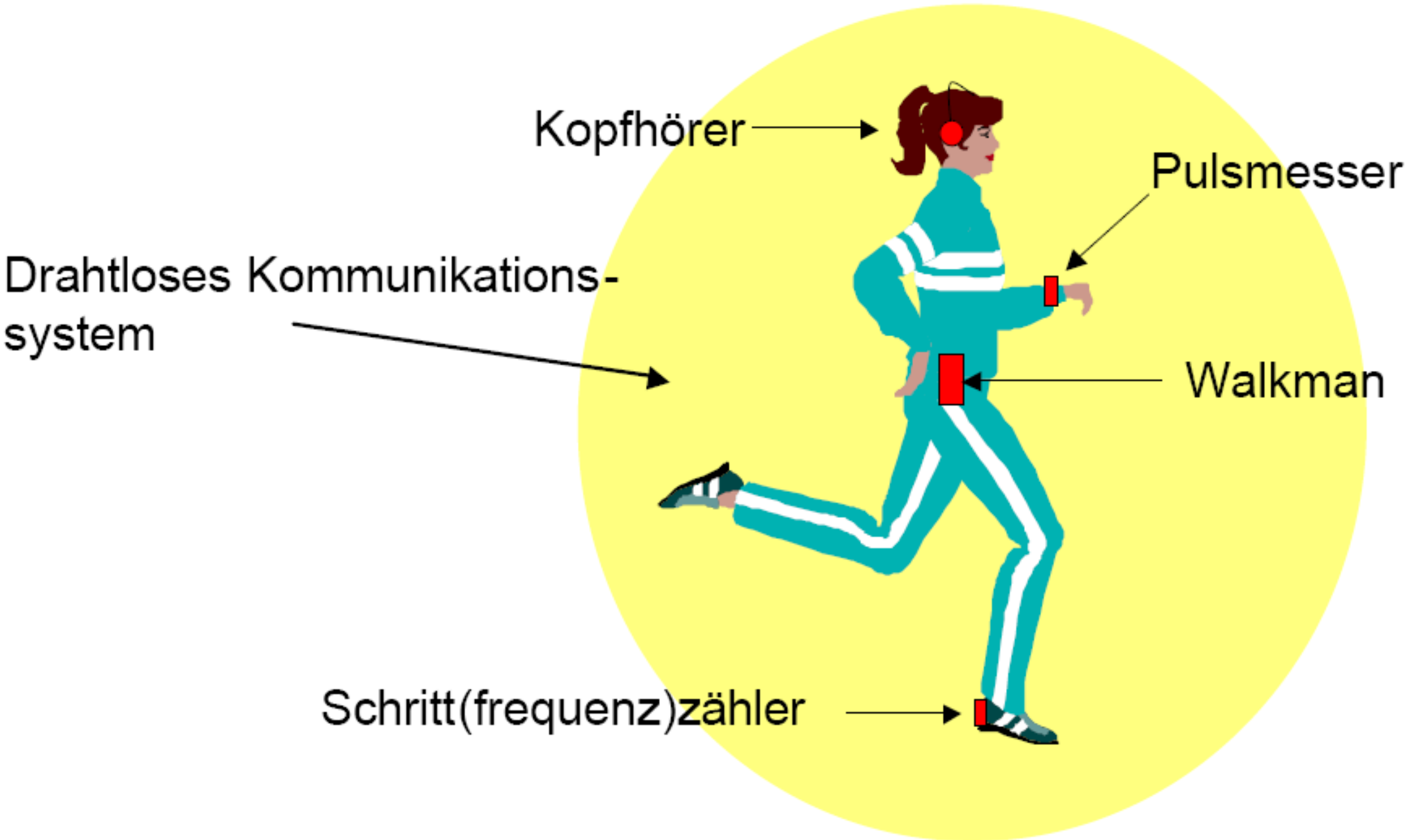
- UWB is a form of extremely wide spread spectrum where RF energy is spread over gigahertz of spectrum
  - Wider than any narrowband system by orders of magnitude
  - Power seen by a narrowband system is a fraction of the total
  - UWB signals can be designed to look like imperceptible random noise to conventional radios

Peaky signals have low duty-cycle



From ftw. project I0 testbed

Body Area Networks (BANs)



Outline

- Relay Networks
- Ultrawideband Channel Model
- Baseband Discretized Model
- Upper Bound on the Capacity
- Numerical Results
- Conclusion

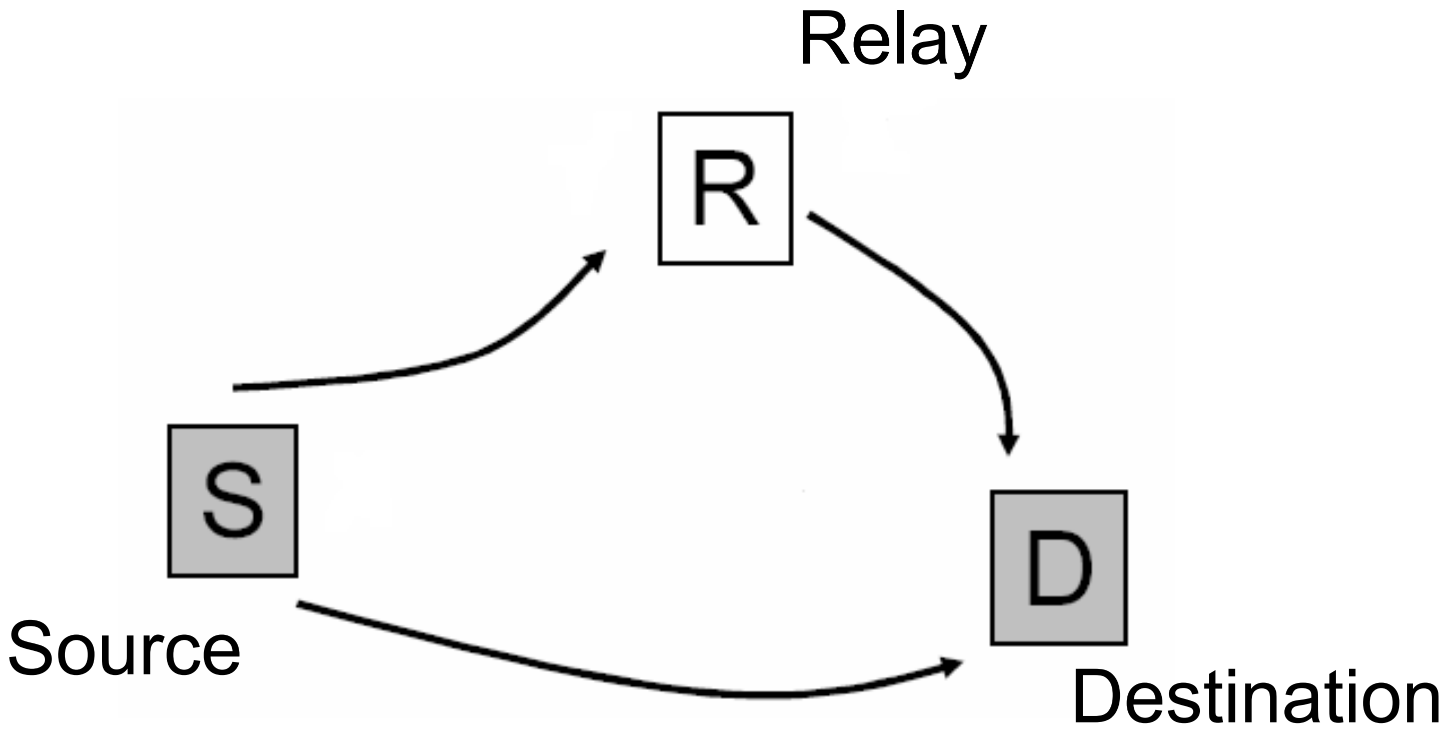
Relaying: some promises …

- Potentially less infrastructure required
  - („bring your own infrastructure", fast roll-out)

- True mesh networking may increase reliability
  - („many roads lead to Rome", route diversity)

- Bridging multiple short hops may require much less total power then direct transmission
  - („pathloss rules!", you can't beat physics)

Relay Network: Toy example



Block diagram of a simple relay network

Ultra-wideband Channel Model

- IEEE 802.15.4a (Thanks to Andy!)

$$h(t) = X \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l} e^{j\phi_{k,l}} \delta(t - T_l - \tau_{k,l})$$

X : The effect of **Shadowing** or large-scale fading (log-normal distribution)

L: The number of **clusters** (Poisson distribution)

K : The number of **rays** in each cluster

Ultra-wideband Channel Model

$$h(t) = X \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l} e^{j\phi_{k,l}} \delta(t - T_l - \tau_{k,l})$$

$a_{k,l}$: The **tap weight** of the k^{th} ray in the l^{th} cluster (Nakagami distribution)

$\Phi_{k,l}$: The **phase** of the k^{th} ray in the l^{th} cluster (uniform distribution $[0,2\pi]$)

T_l: The **delay** of the l^{th} cluster (Poisson distribution)

$\tau_{k,l}$: The **delay** of the k^{th} ray relative to the lth cluster arrival time
(mixture of two Poisson processes)

Kompetenzzentren-Programm

Baseband Discretized Model

- Time domain:

$$y_i = \sum_{k=0}^{K-1} g_k x_{i-k} + z_i, \quad i = 0, ..., K-1$$

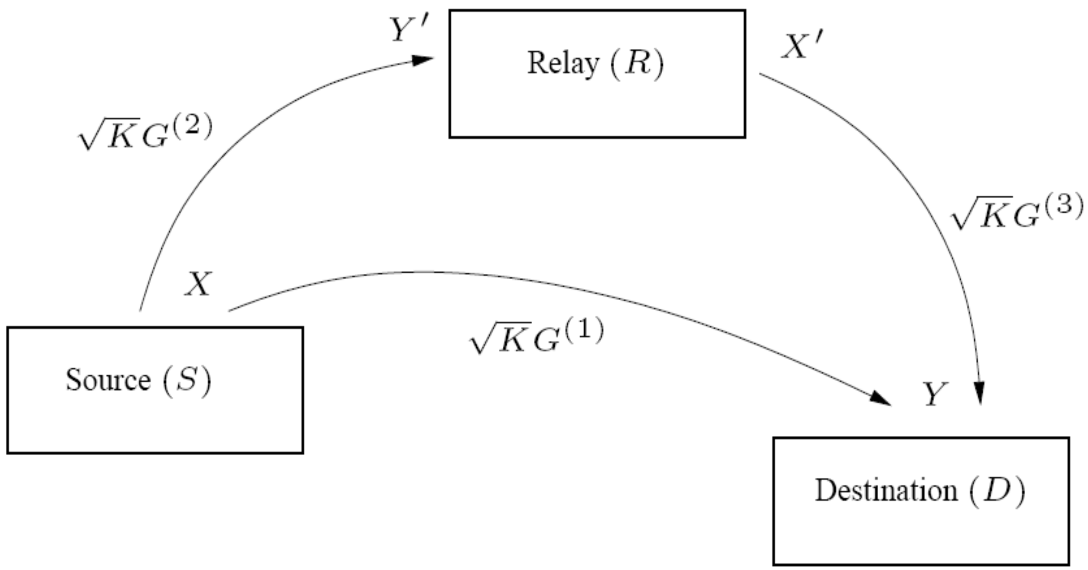
$$g_k = \sum_{i,l:\lfloor \frac{d_{i,l}}{T_s} \rfloor = k} X a_{i,l} e^{j(\phi_{i,l} - 2\pi f_c d_{i,l})}$$

$$K = \frac{T_c}{T_s}$$

- Frequency domain

$$Y_i = \sqrt{K} G_i X_i + Z_i, \quad i = 0, ..., K-1$$

Base band- Discretized Model



$$Y_k = \sqrt{K}G_k^{(1)}X_k + \sqrt{K}G_k^{(3)}\acute{X}_k + Z_k$$

$$\acute{Y}_k = \sqrt{K}G_k^{(2)}X_k + \acute{Z}_k$$

where $\quad Z \sim N(0, N) \qquad \acute{Z} \sim N(0, \acute{N})$

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Upper Bound on the Capacity

Upper bound on the K-block delay-constrained capacity of a general relay network:

$$C \leq \underbrace{\max}_{p(X,\acute{X})} \min\{\frac{1}{K}\sum_{i=1}^{K} I(X_i, \acute{X}_i; Y_i), \frac{1}{K}\sum_{i=1}^{K} I(X_i; Y_i, \acute{Y}_i | \acute{X}_i)\}$$

T. Cover and A. El Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inform. Theory, vol. IT-25, no. 5, pp. 572–584, Sept. 1979.*

Upper Bound on the Capacity

With the assumptions:

$$\rho_i \triangleq \mathbb{E}\{X_i X_i'^*\}/E_s$$

$$|X_k| = |X_k'| = \sqrt{E_s}$$

We get:

$$I(X_i, X_i'; Y_i) \leq \frac{1}{2}\log\left(1 + \frac{KE_s}{N}\left(\left|G_i^{(1)}\right|^2 + \left|G_i^{(3)}\right|^2 + 2\Re\left\{G_i^{(1)} G_i^{(3)*}\rho_i\right\}\right)\right)$$

$$I(X_i; Y_i, Y_i' | X_i') \leq \frac{1}{2}\log\left(1 + \frac{KE_s\left(N'|G_i^{(1)}|^2 + N|G_i^{(2)}|^2\right)(1 - |\rho_i|^2)}{NN'}\right)$$

Upper Bound on the Capacity (frozen channel)

By applying Jensen's inequality:

$$C \leq \underbrace{\max}_{\rho_0,\ldots,\rho_{K-1}} \min \left\{ \frac{1}{2}\log\left(1+\frac{E_s}{N}\sum_{i=0}^{K-1}\left|G_i^{(1)}\right|^2+\left|G_i^{(3)}\right|^2+2Re\{G_i^{(1)}G_i^{(3)^*}\rho_i\}\right), \right.$$

$$\left. \frac{1}{2}\log\left(1+\frac{E_s}{N\acute{N}}\sum_{i=0}^{K-1}\left(\acute{N}\left|G_i^{(1)}\right|^2+N\left|G_i^{(2)}\right|^2\right)\left(1-|\rho_i|^2\right)\right) \right\}$$

Upper Bound on the Ergodic and Outage Capacities

$$C_{ergodic} = \mathop{\mathbb{E}}_{\boldsymbol{G}^{(1)},\boldsymbol{G}^{(2)},\boldsymbol{G}^{(3)}} \{C\}$$

$$\boldsymbol{G}^{(k)} = (G_0^{(k)}, G_1^{(k)}, \cdots, G_{K-1}^{(k)}) \qquad k = 1, 2, 3$$

$$C_{outage}(p) = \max_{C_0}\{C_0\} \quad \text{subject to} \quad \mathrm{P}\left(C \geq C_0\right) \geq p$$

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Numerical Results

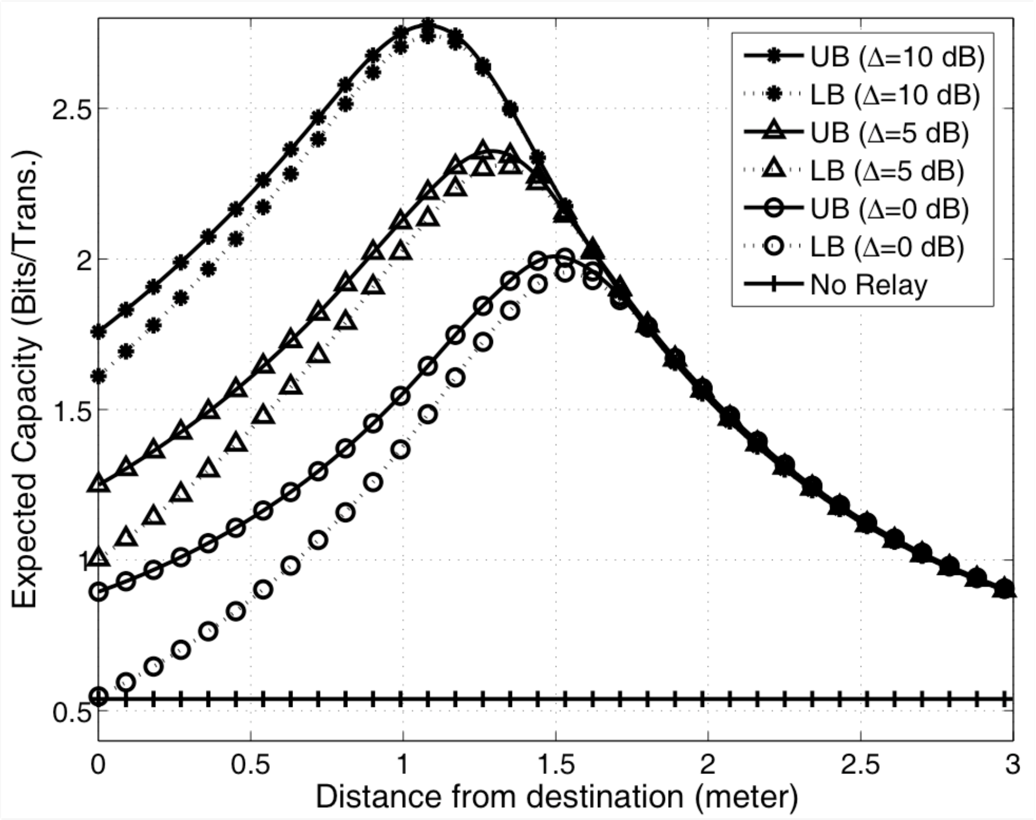

Fig. 2. Upper and lower bounds on the expected capacity of a UWB-linked relay network vs. relay's distance from the destination.

Kompetenzzentren-Programm

Numerical Results

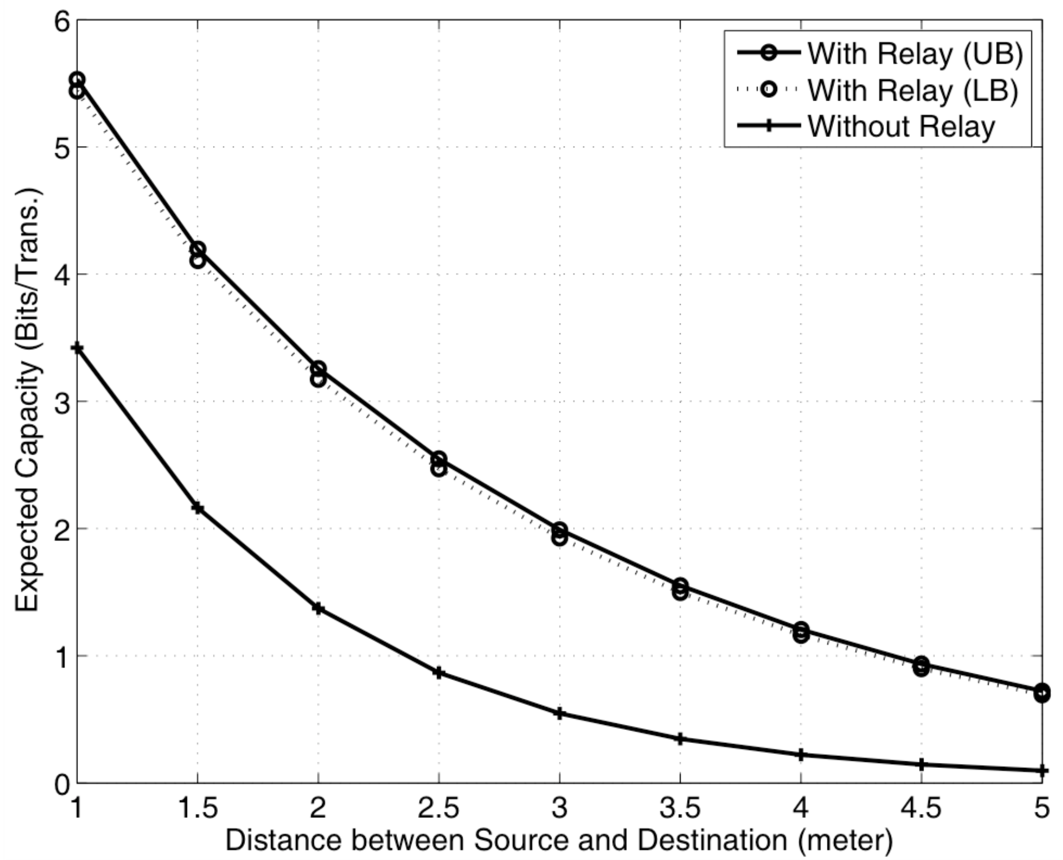

Fig. 4. Bounds on the expected capacity of a UWB-linked relay network vs. distance between source and destination (d_1).

Kompetenzzentren-Programm

Numerical Results

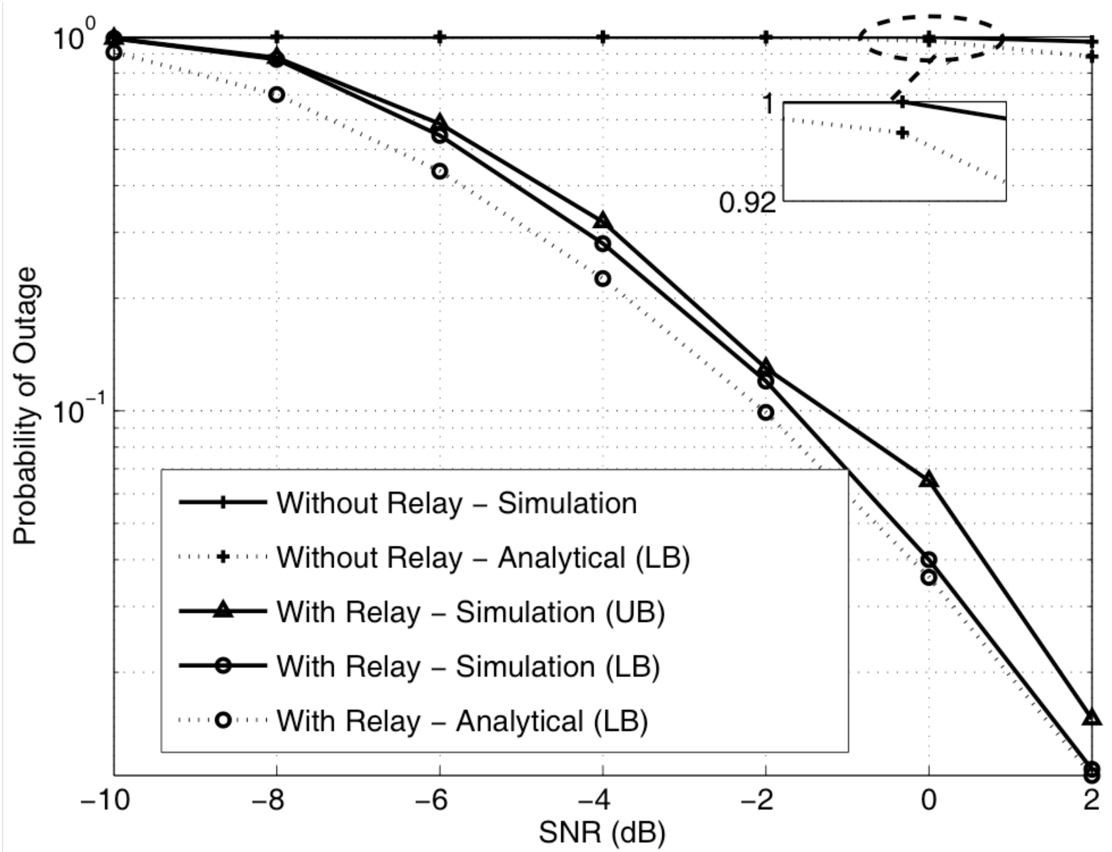

Fig. 5. Bounds on the probability of outage of a UWB-linked relay network vs. SNR.

Conclusion

- We computed upper (and lower) bounds on the ergodic and outage capacities of relay networks when we have an ultra-wideband channel.
- The capacity of the ultra-wideband channel improves substantially, using a relay node.
- There is an optimum position for the relay position between the source and the destination – but the precise optimization of position is not critical

Parts of this work were previously published as

- Z. Zeinalpour-Yazdi, M. Nasiri-Kenari, J. Wehinger, C. F. Mecklenbräuker: "Upper Bounds on the Ergodic and Outage Capacities of Relay Networks Using UWB Links," in Proc. 40th Asilomar Conference on Signals, Systems, and Computing, pp. 646–650, Pacific Grove (CA), USA, Oct. 29–Nov. 1, 2006.
- Z. Zeinalpour-Yazdi, M. Nasiri-Kenari, B. Aazhang, J. Wehinger, C. F. Mecklenbräuker: Bounds on the Delay-Constrained Capacity of UWB Communication with a Relay Node, IEEE Trans. Wireless Communications, Vol. 8, No. 5, pp. 2265-2273, May 2009.

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