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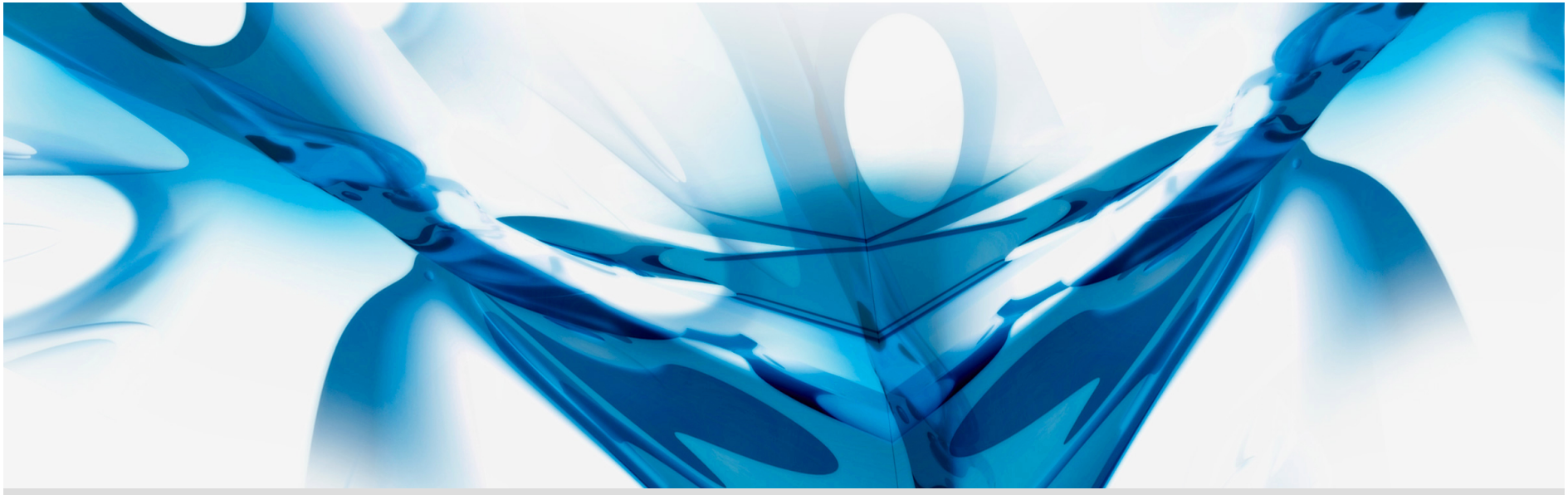


An adaptive protocol for distributed beamforming

Simulations and experiments

Stephan Sigg, Michael Beigl

KIVS 2011, 10.03.2011, Kiel

Outline

Introduction

Distributed beamformig schemes

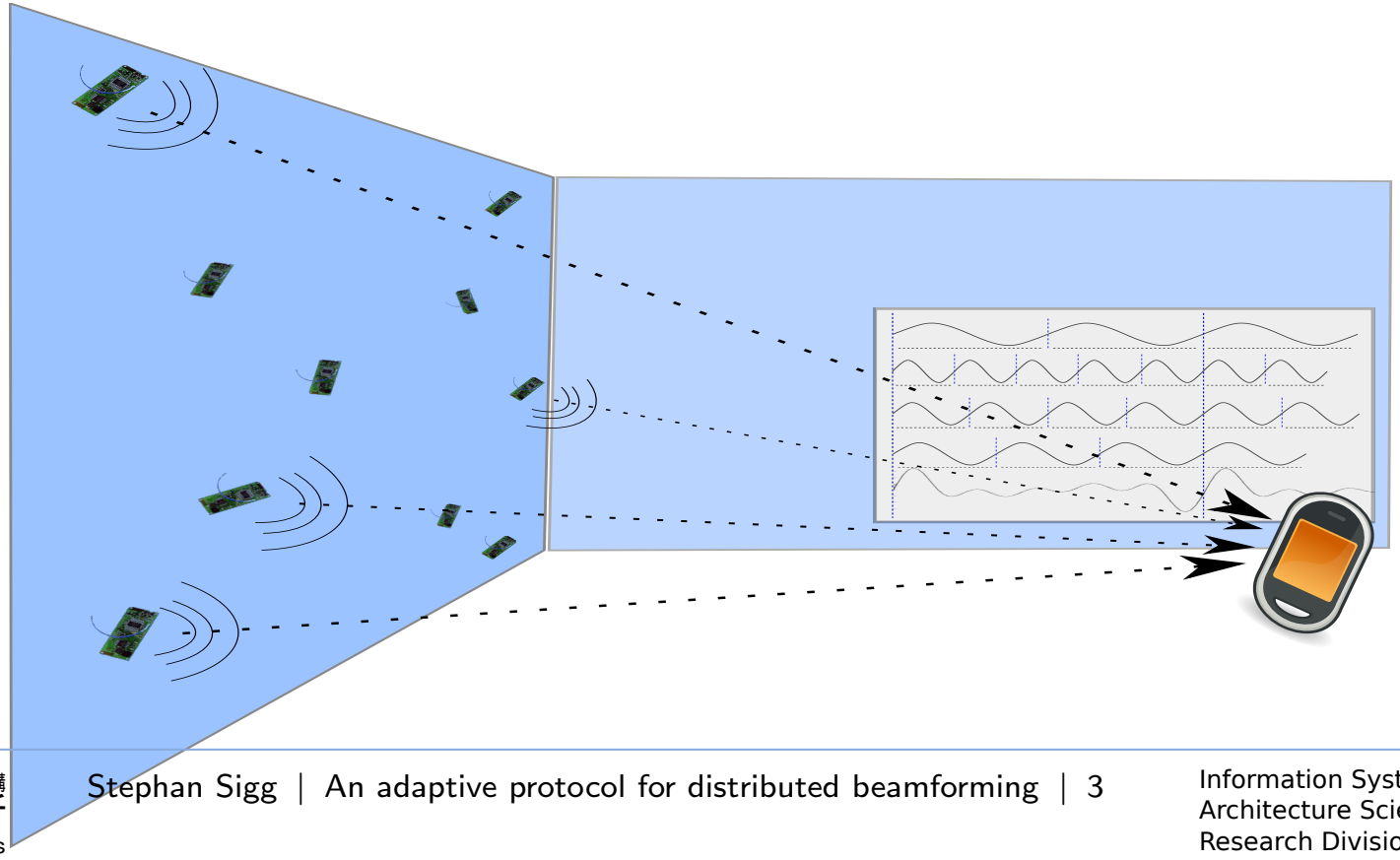
A protocol for distributed adaptive beamforming

Environmental impacts

Conclusion

Introduction

- Distributed adaptive transmit beamforming
  - Distributed nodes synchronise the carrier frequency and phase offset of transmit signals
  - Low power and processing devices
  - Non-synchronised local oscillators



Outline

Introduction

Distributed beamformig schemes

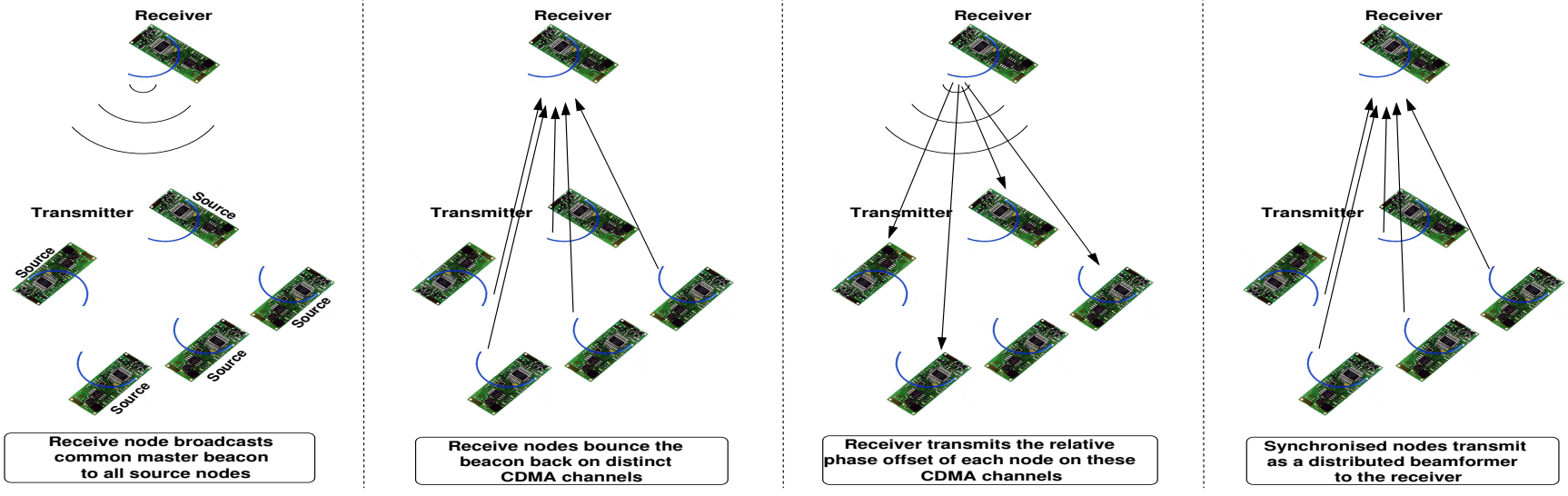
A protocol for distributed adaptive beamforming

Environmental impacts

Conclusion

Introduction

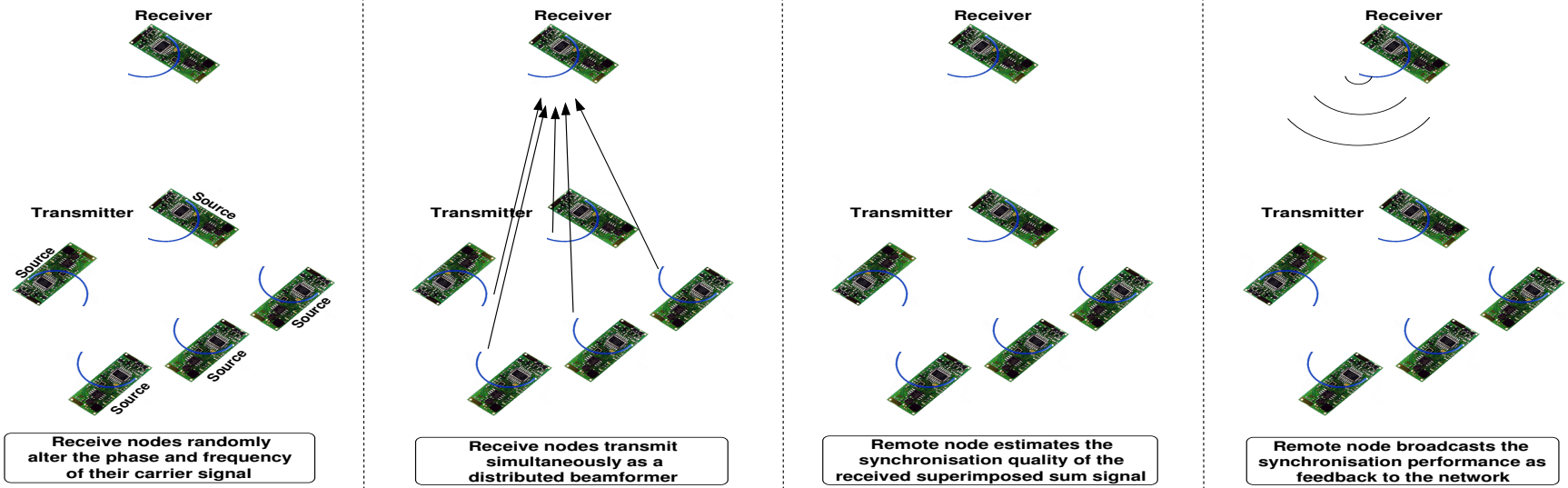
- Distributed synchronisation schemes
  - Closed loop carrier synchronisation[1]



[1] Y. Tu and G. Pottie, *Coherent Cooperative Transmission from Multiple Adjacent Antennas to a Distant Stationary Antenna Through AWGN Channels*, Proceedings of the IEEE VTC, 2002

Introduction

- Distributed synchronisation schemes
  - Cosed loop feedback based carrier synchronisation[2]



[2] R. Mudumbai, J. Hespanha, U. Madhow, G. Barriac, *Distributed transmit beamforming using feedback control*, IEEE Transactions on Information Theory 56(1), volume 56, January 2010

Outline

Introduction

Distributed beamformig schemes

A protocol for distributed adaptive beamforming

Environmental impacts

Conclusion

A protocol for distributed adaptive beamforming

$P_{mut,i}$ Probability to alter the phase-offset of device i ($P_{mut,i} \in [0, 1]$)

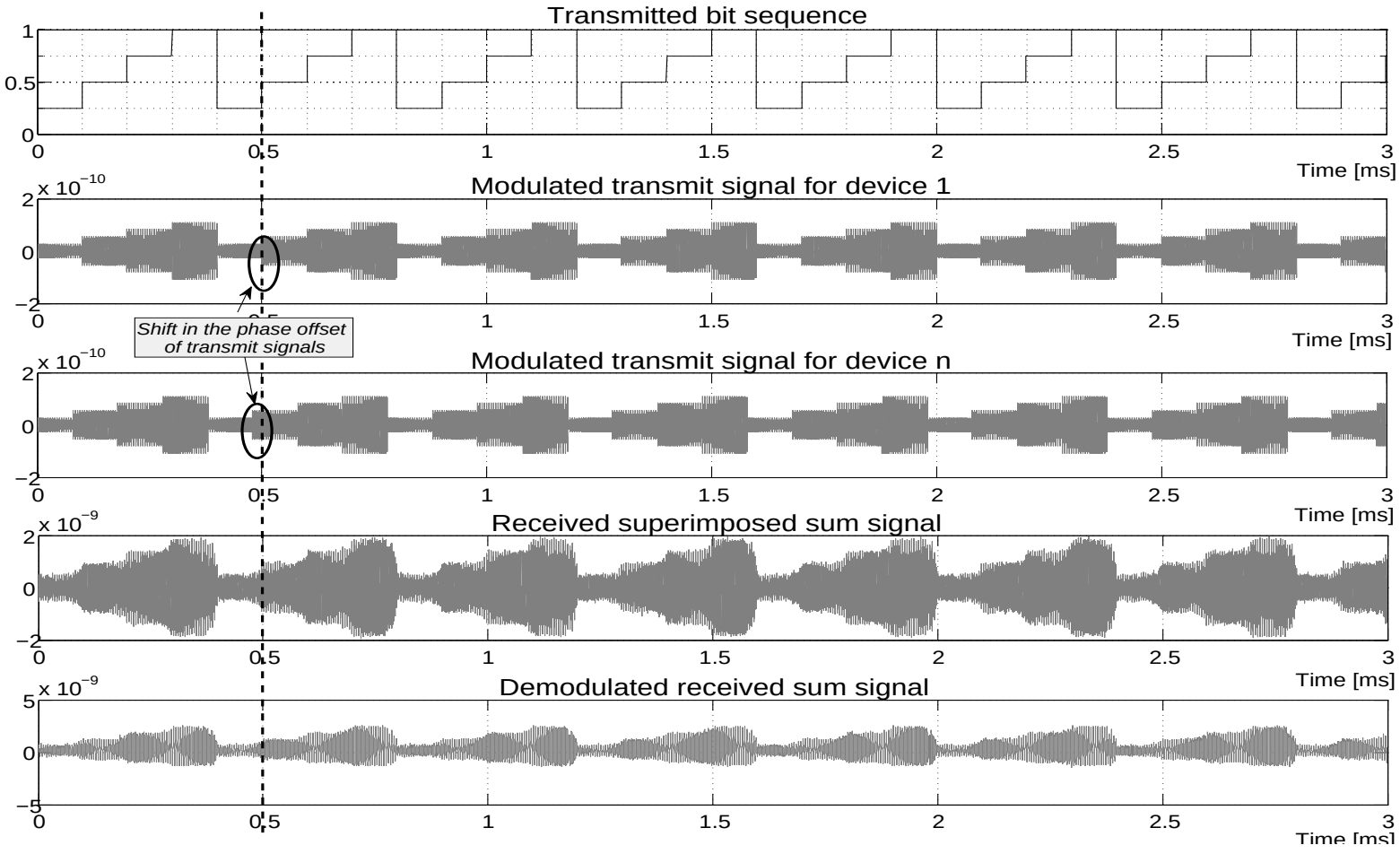
$P_{dist,i}$ Probability distribution for the random process of device i ($P_{dist,i} \in \{\text{normal, uniform, } \ldots\}$)

$P_{var,i}$ Variance for the random phase alteration process of device i ($P_{var,i} \in [0, \pi]$)

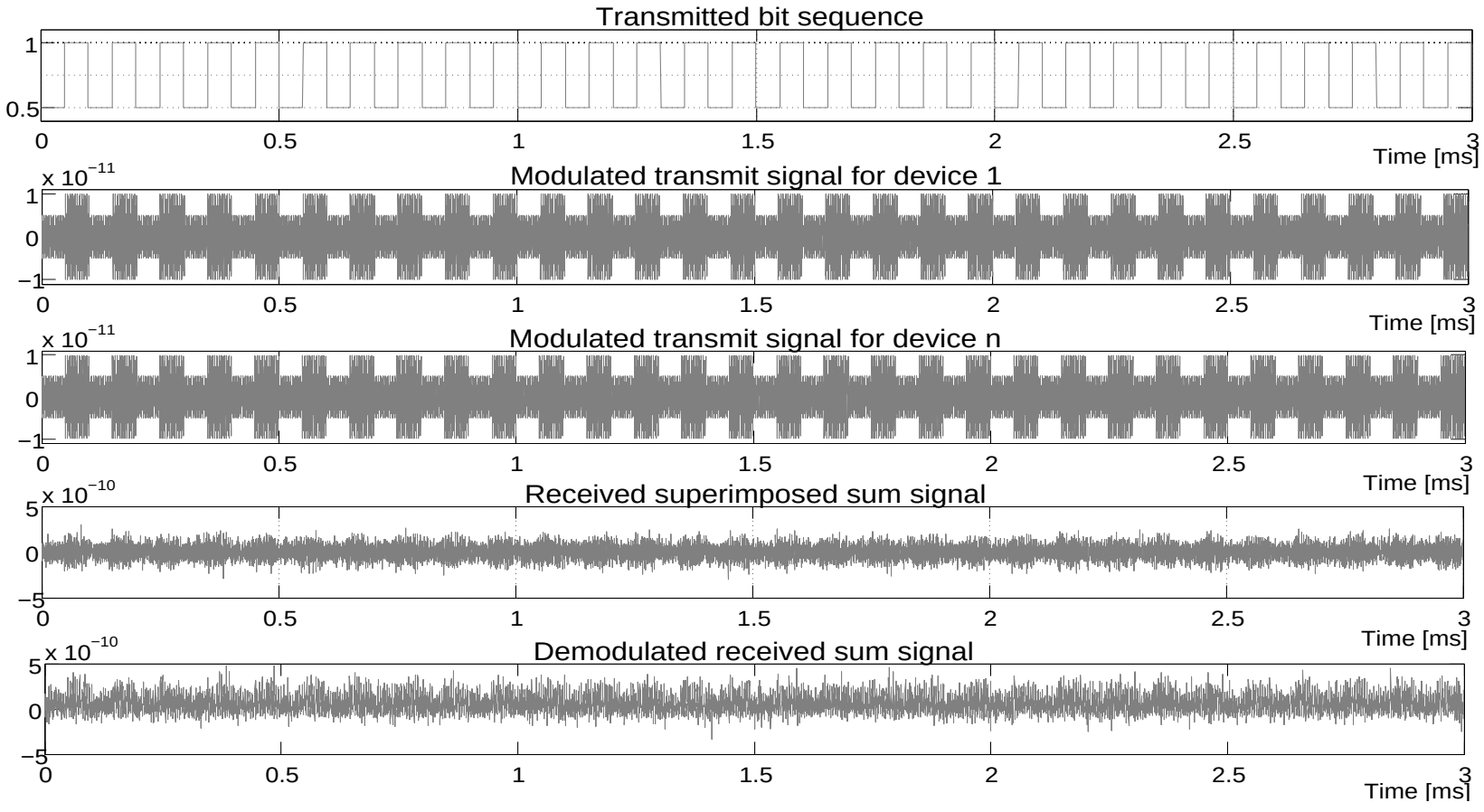
A protocol for distributed adaptive beamforming

1. One device broadcasts a data sequence s_d to devices in its proximity.
2. Devices decide whether to participate in the transmission.
   - Decision parameters: energy, min. # of participating devices, cpu load
3. Closed-loop iterative feedback-based carrier synchronisation is achieved. Devices utilise $P_{mut,i}$, $P_{dist,i}$, $P_{var,i}$.
4. Upon sufficient synchronisation the receiver broadcasts ack.
5. Devices collaboratively transmit s_d.
6. Optimisation parameters $P_{mut,i}$, $P_{dist,i}$ and $P_{var,i}$ are adapted according to the performance achieved in the current environmental setting.

A protocol for distributed adaptive beamforming



A protocol for distributed adaptive beamforming



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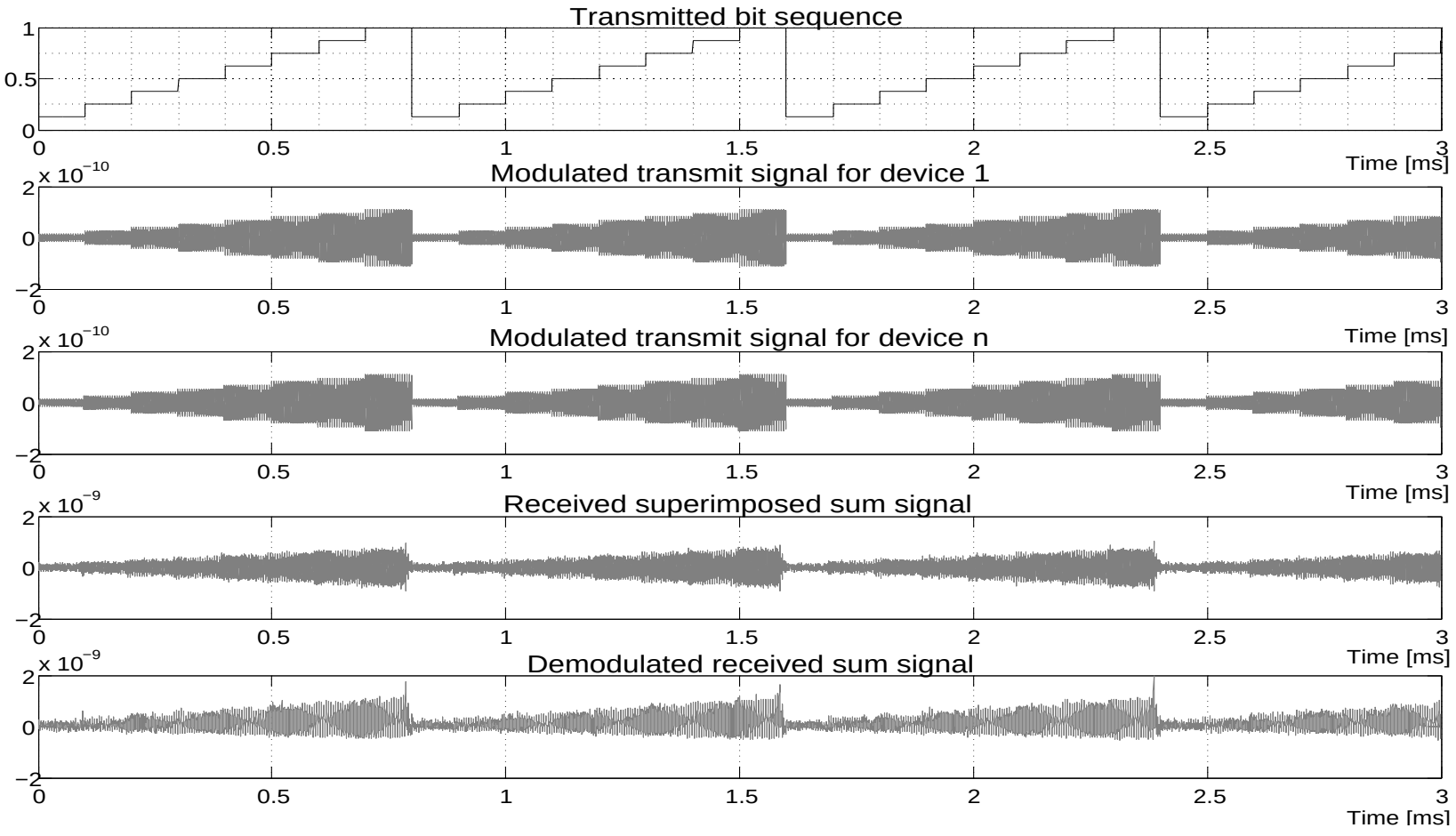

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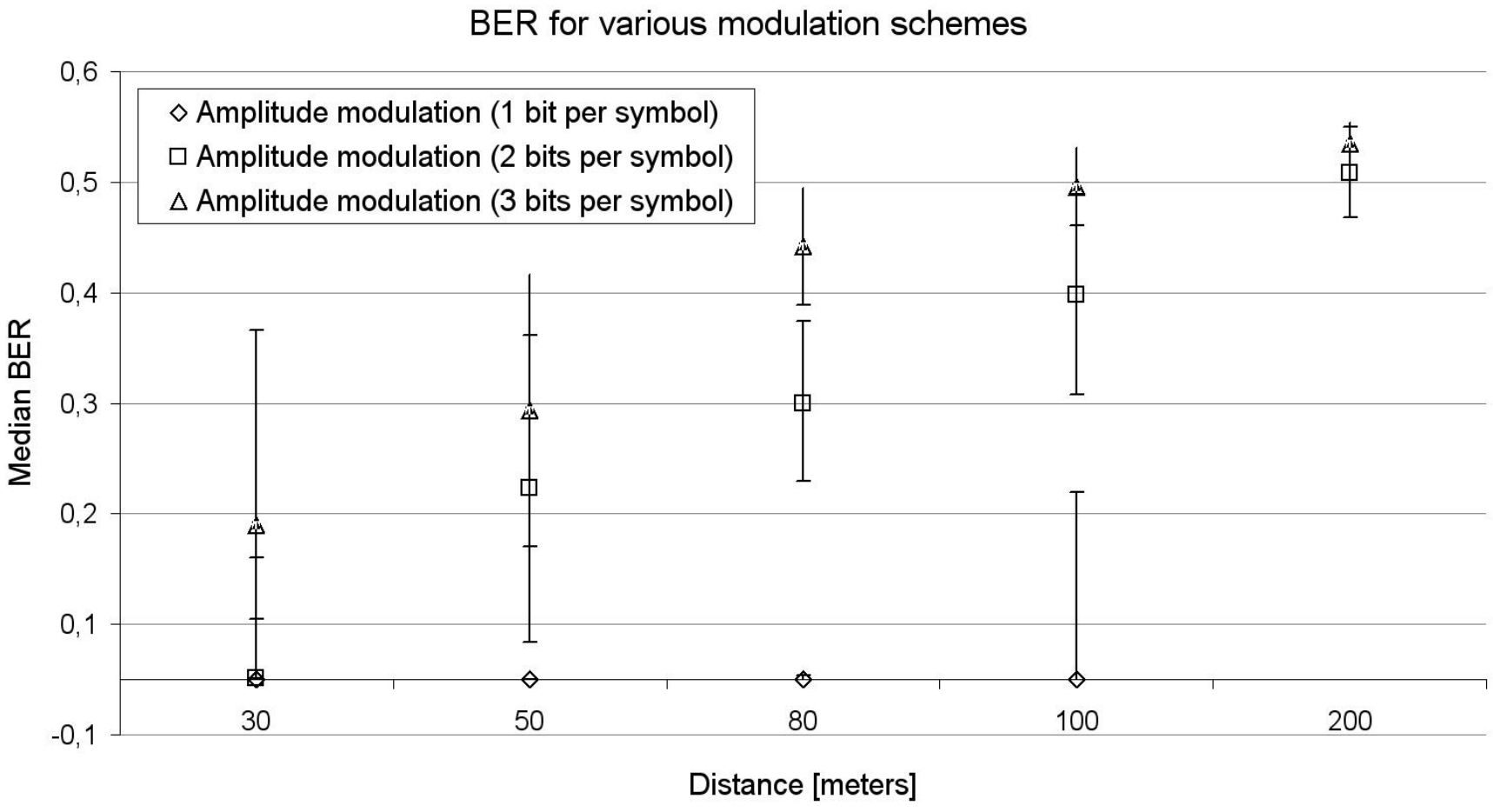

Outline

Introduction

Distributed beamformig schemes

A protocol for distributed adaptive beamforming

Environmental impacts

Conclusion

A protocol for distributed adaptive beamforming

- Beamforming of received signal components based on receiver feedback
- The feedback is impacted by environmental situations
  - Distance between transmitter and receiver
  - Network size
  - Mobility

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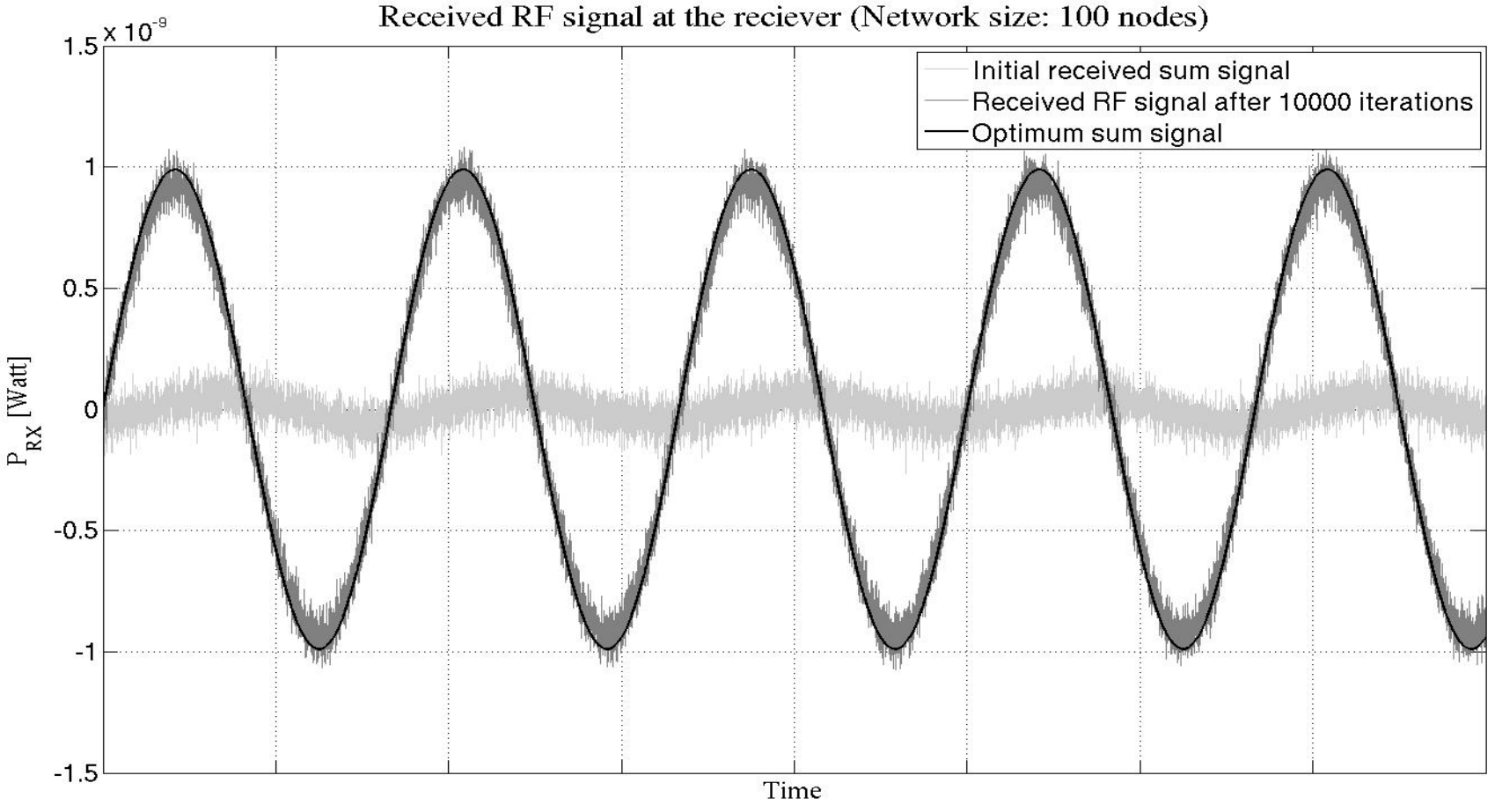
A protocol for distributed adaptive beamforming

Distance

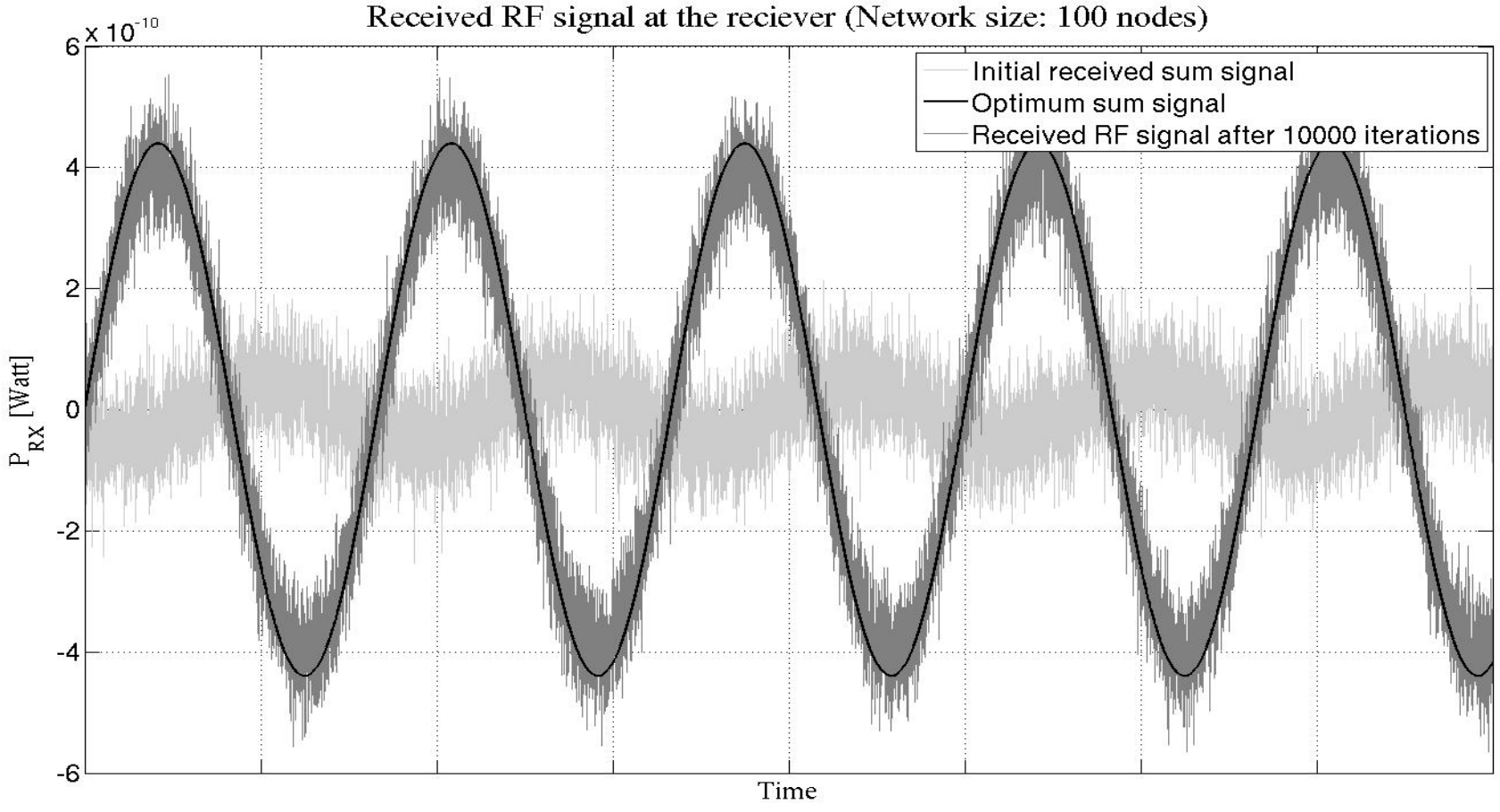
100meters, mutation probability 0.1



A protocol for distributed adaptive beamforming

Distance

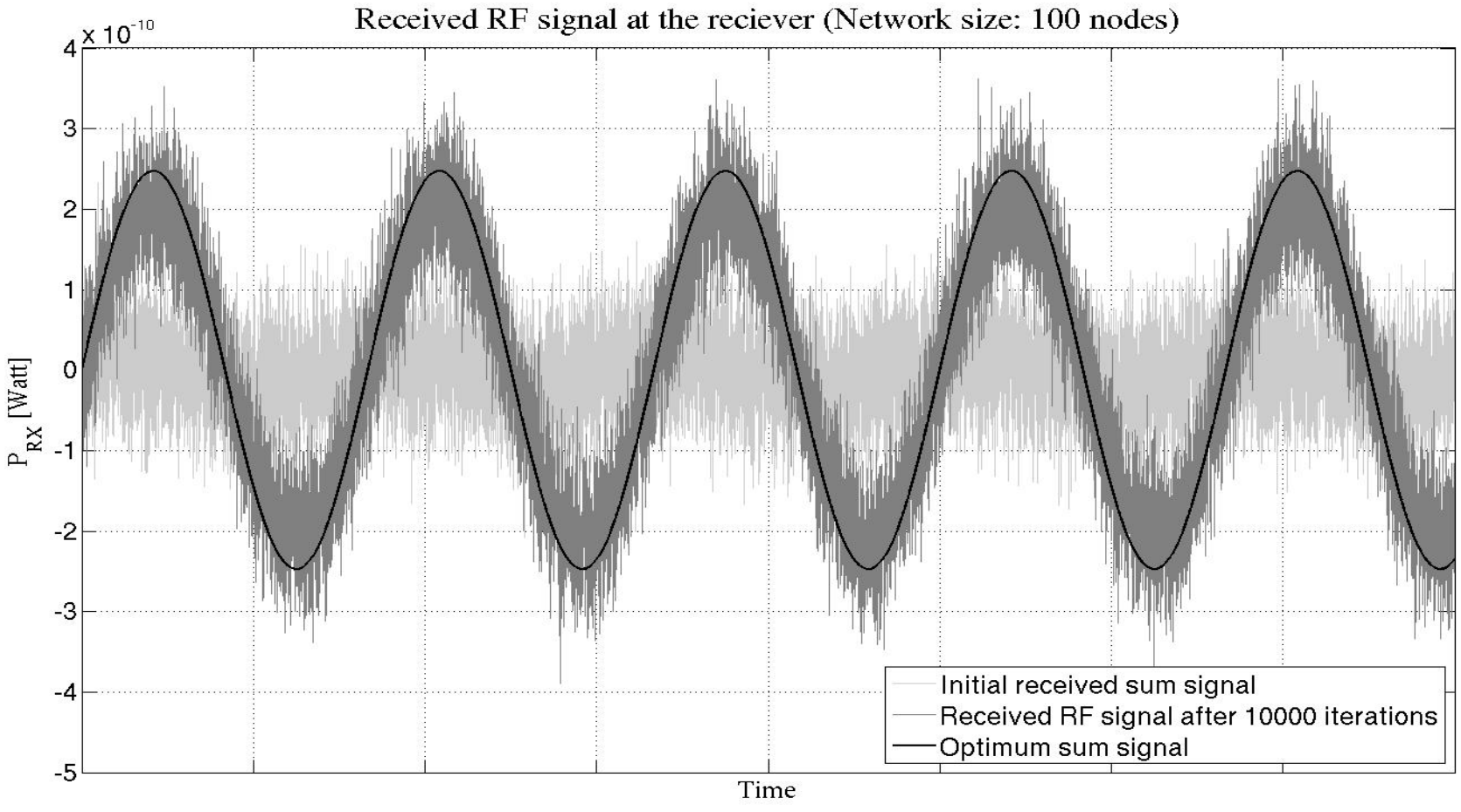
150meters, mutation probability 0.1



A protocol for distributed adaptive beamforming

Distance

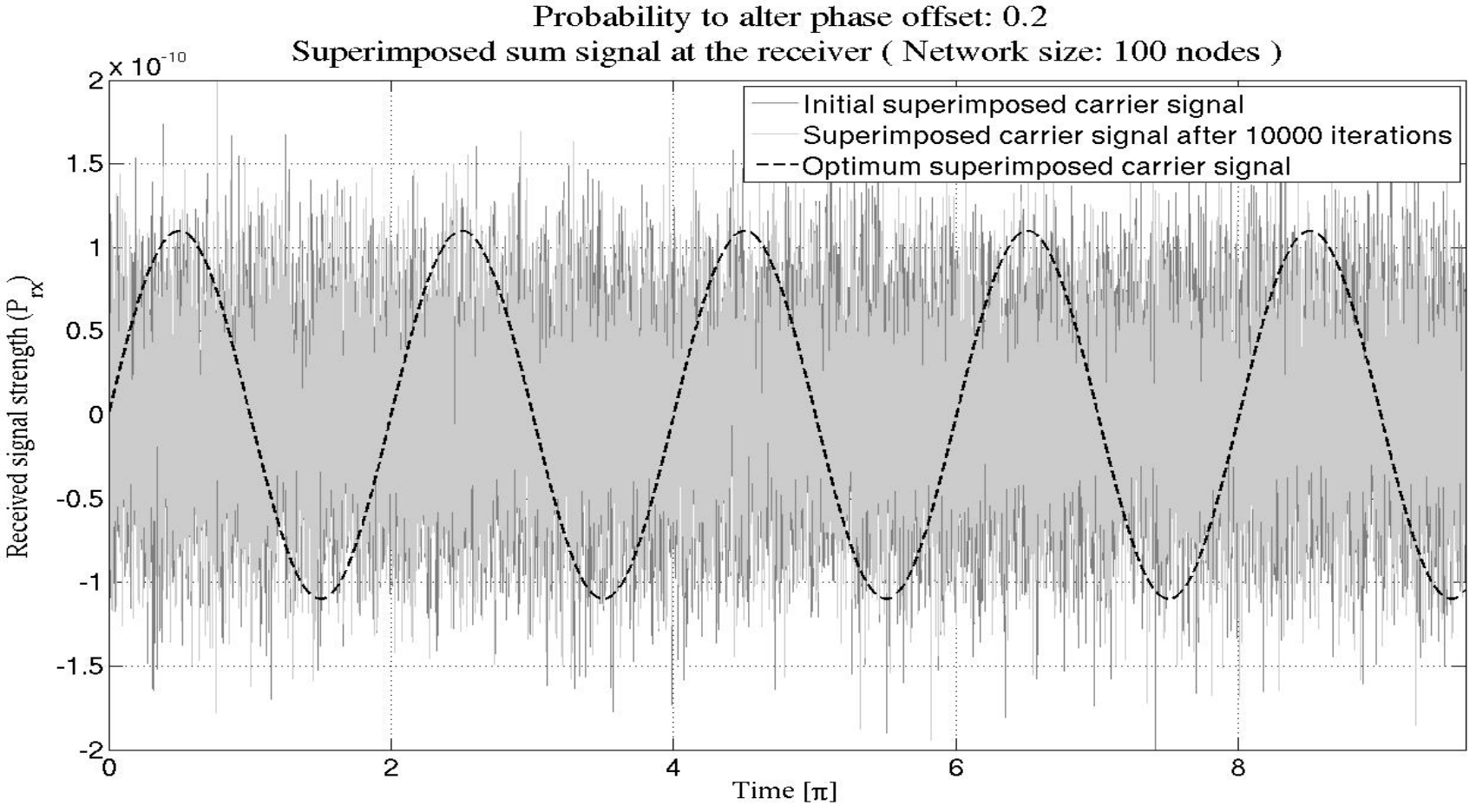
200meters, mutation probability 0.1



A protocol for distributed adaptive beamforming

Distance

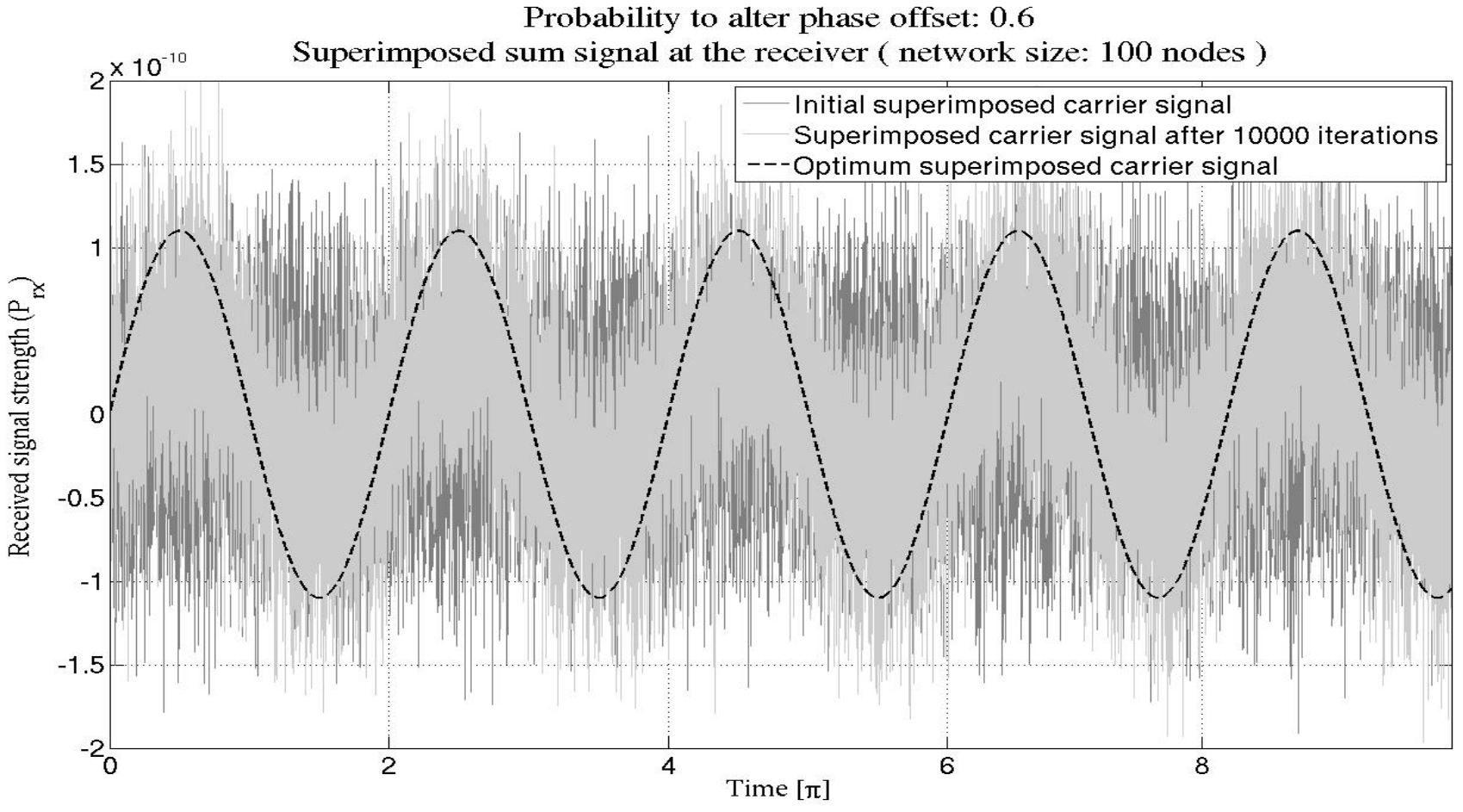
300meters, mutation probability 0.2



A protocol for distributed adaptive beamforming

Distance

300meters, mutation probability 0.6

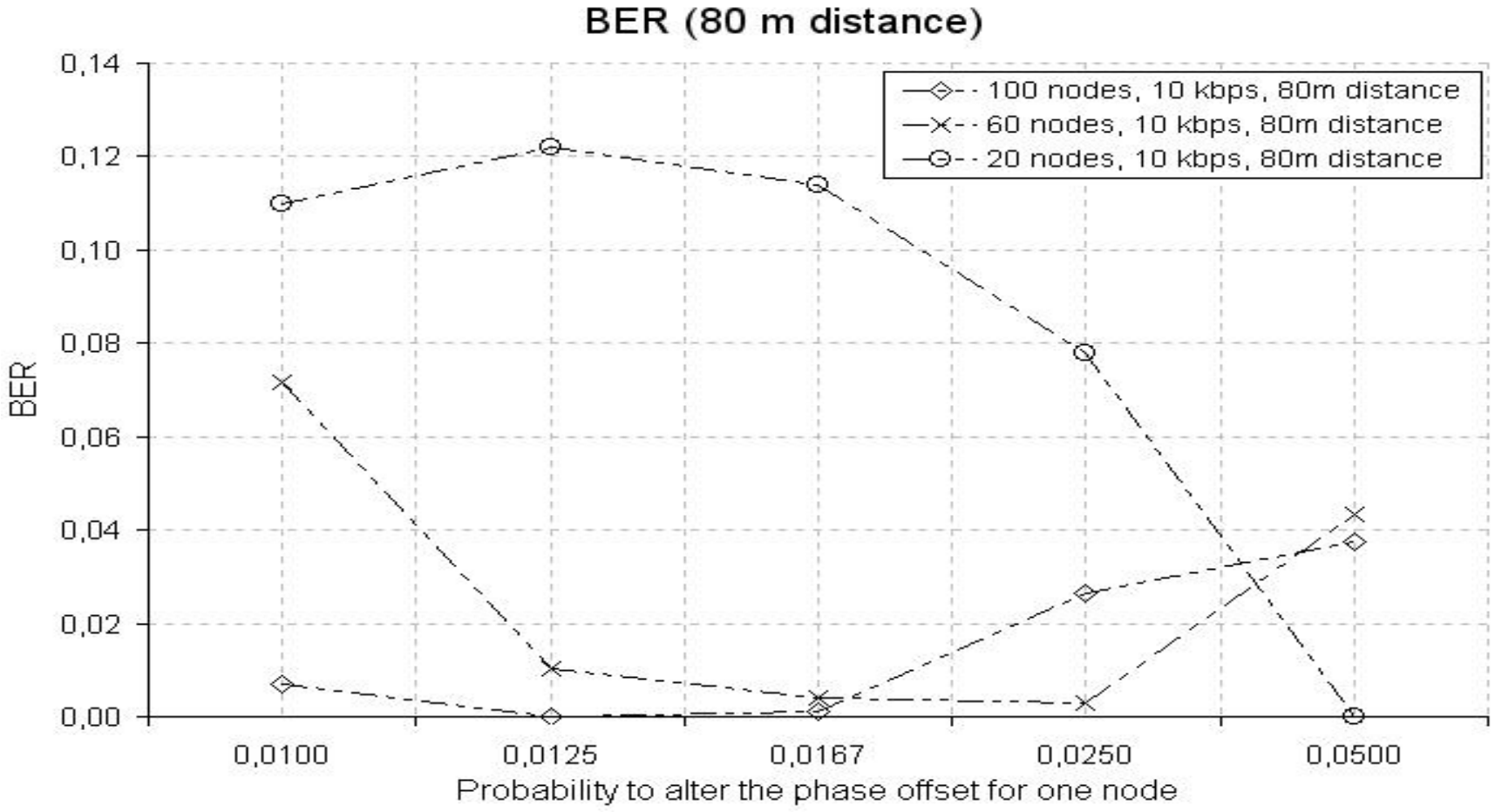


A protocol for distributed adaptive beamforming

- Beamforming of received signal components based on receiver feedback
- The feedback is impacted by environmental situations
  - Distance between transmitter and receiver
  - Network size
  - Mobility

A protocol for distributed adaptive beamforming

Network size



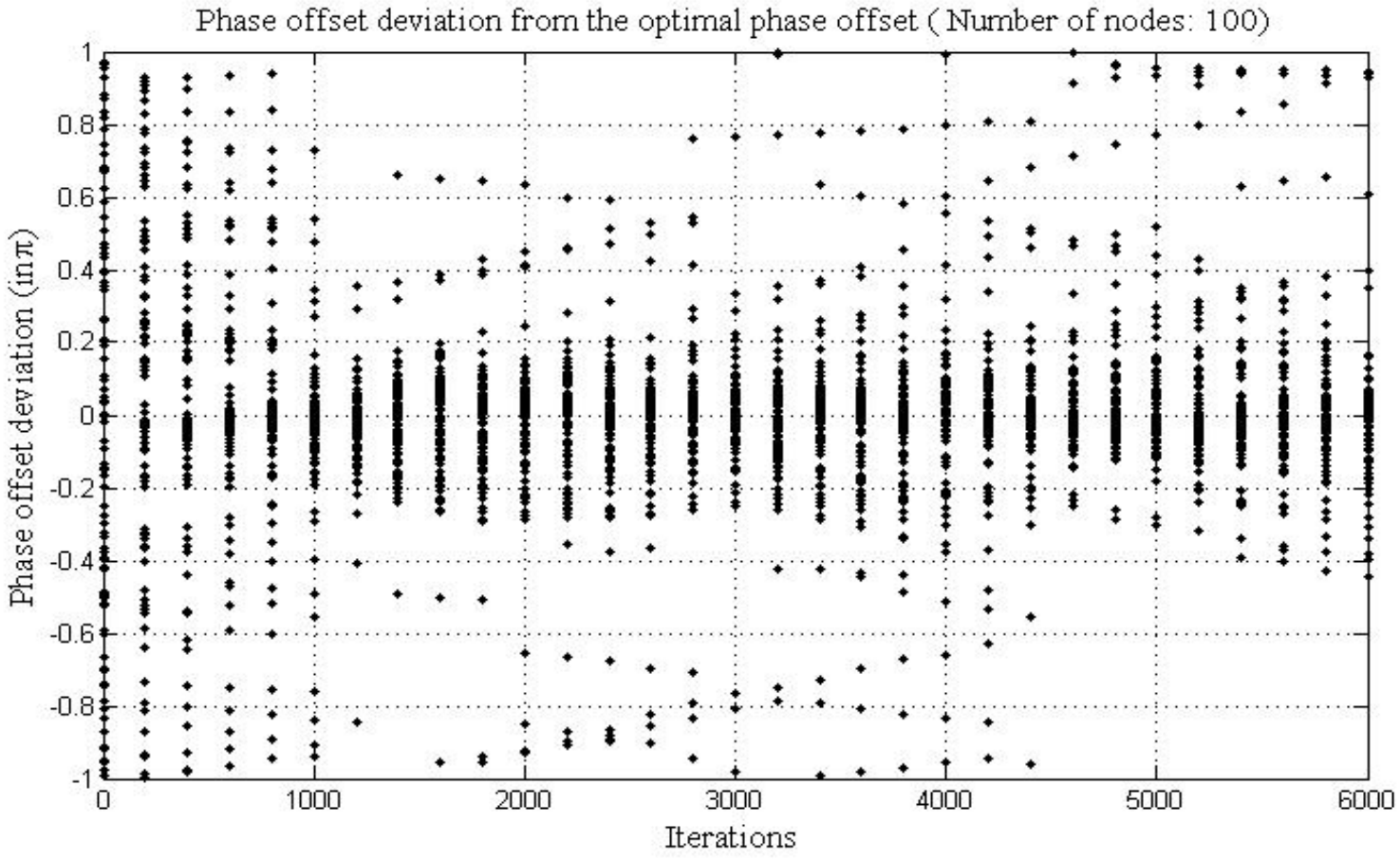
A protocol for distributed adaptive beamforming

- Beamforming of received signal components based on receiver feedback
- The feedback is impacted by environmental situations
  - Distance between transmitter and receiver
  - Network size
  - Mobility

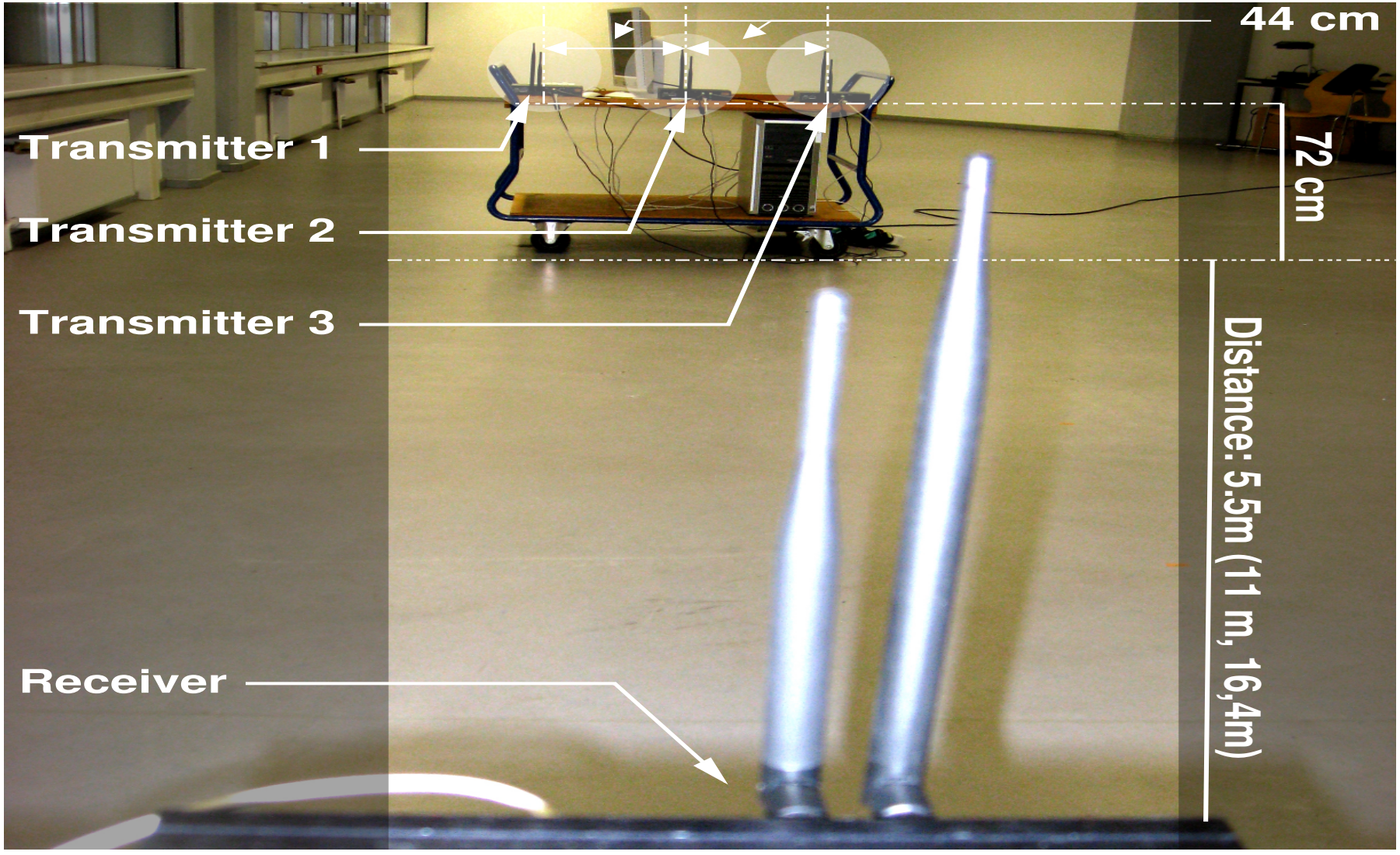
A protocol for distributed adaptive beamforming

Mobility

Receiver moving at 5m/sec following a random walk model



A protocol for distributed adaptive beamforming



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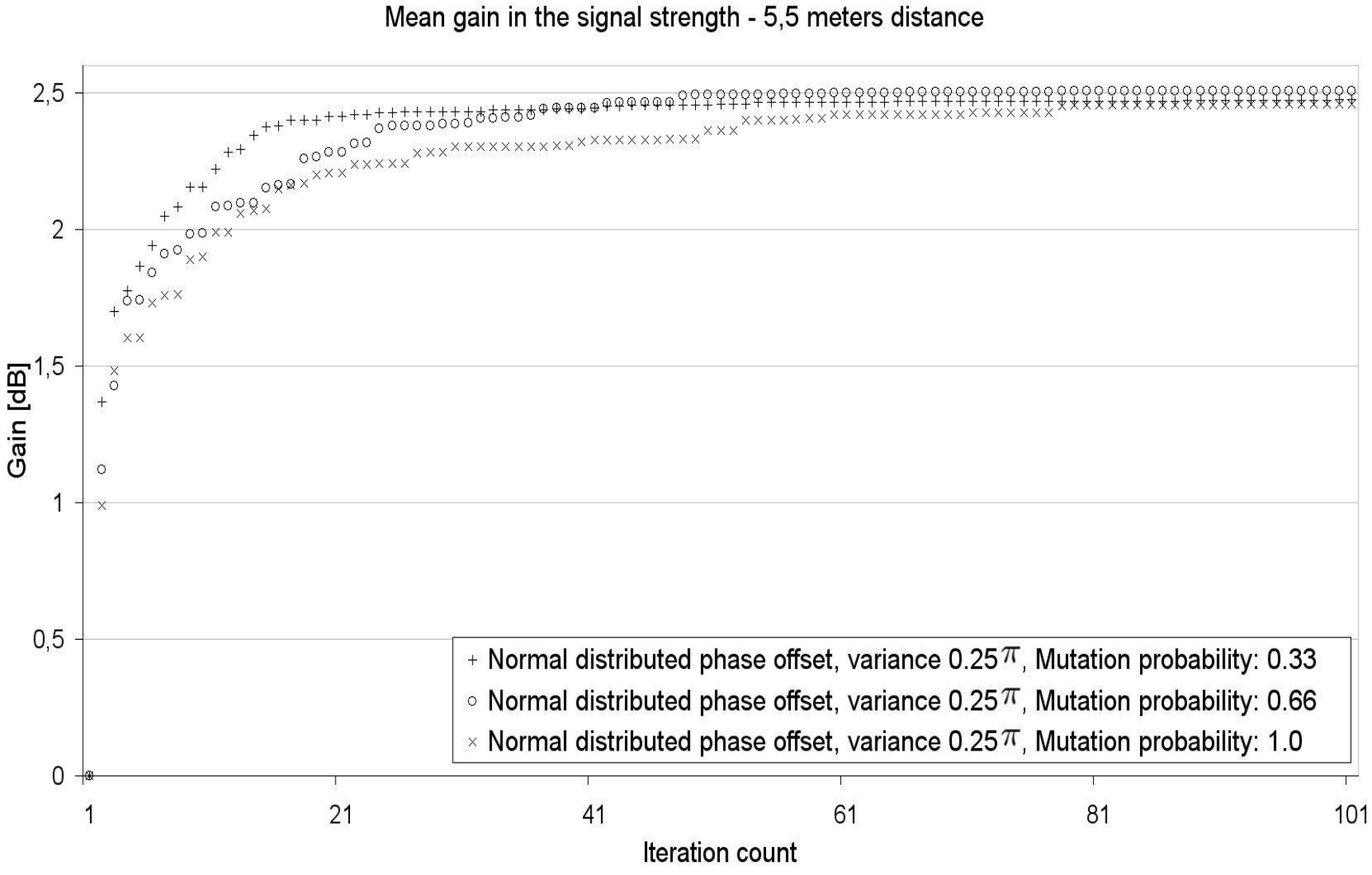

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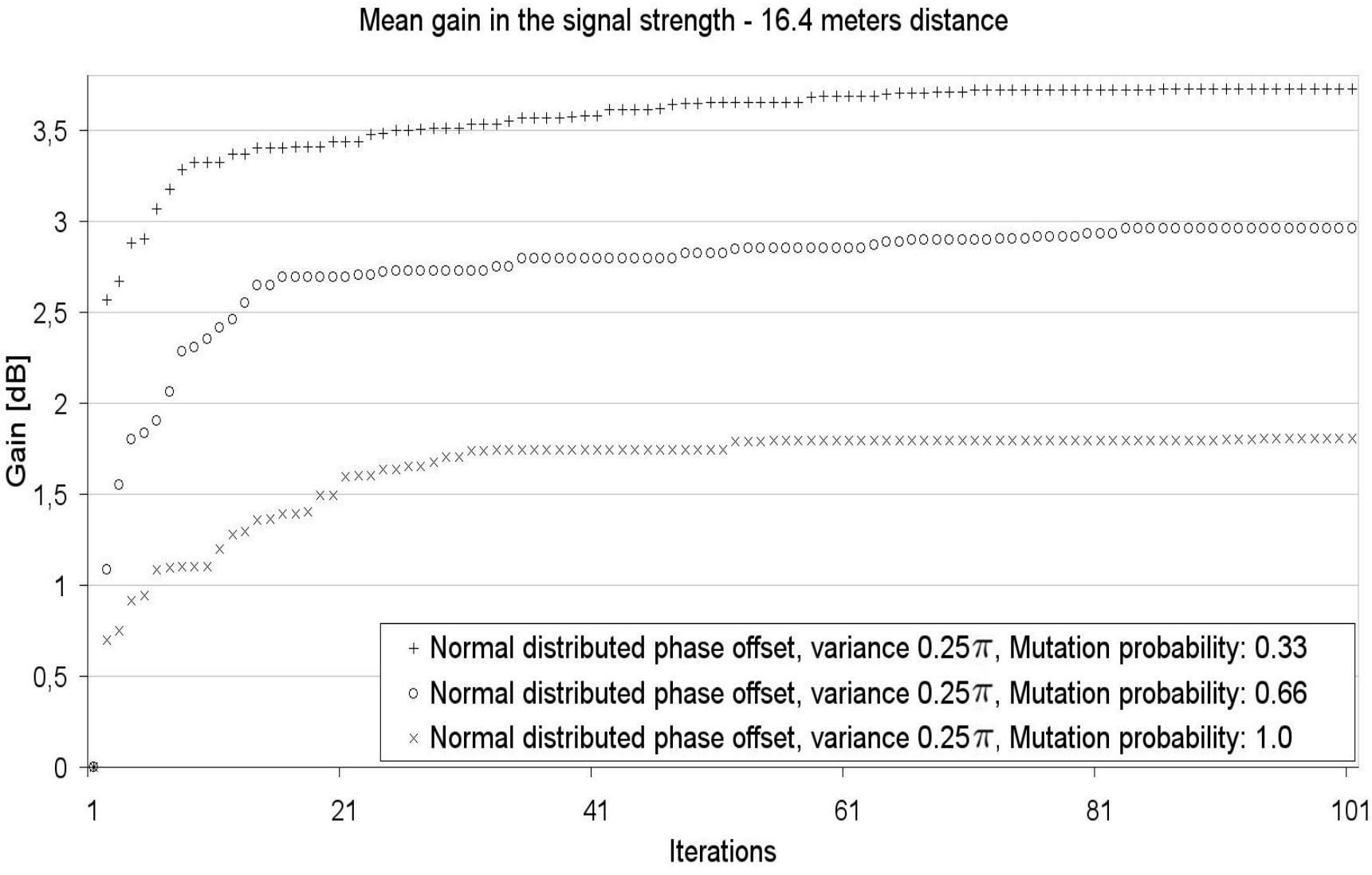


Outline

Introduction

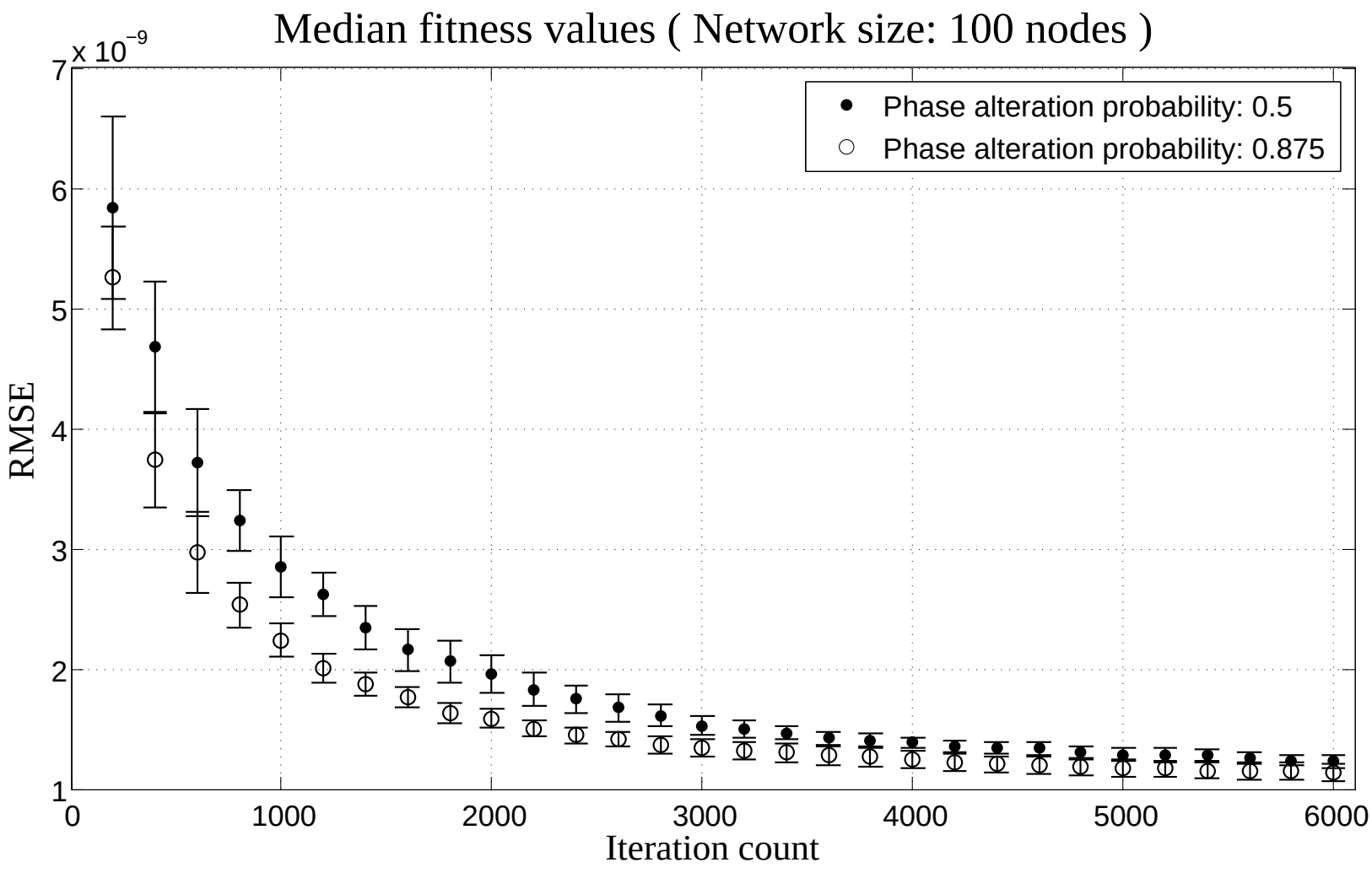
Distributed beamformig schemes

A protocol for distributed adaptive beamforming

Environmental impacts

Conclusion

A protocol for distributed adaptive beamforming



Conclusion

- We investigated a protocol for feedback based distributed adaptive beamforming
- The protocol is environment adaptive and thus enables emergent and organic behaviour.
- It was shown that the synchronisation performance can be improved already with straightforward learning methods
- Further work
  - Study more advanced learning methods
  - Develop a sensor node able to alter phase and frequency offset
  - Case studies in sensor network instrumentations

Questions?

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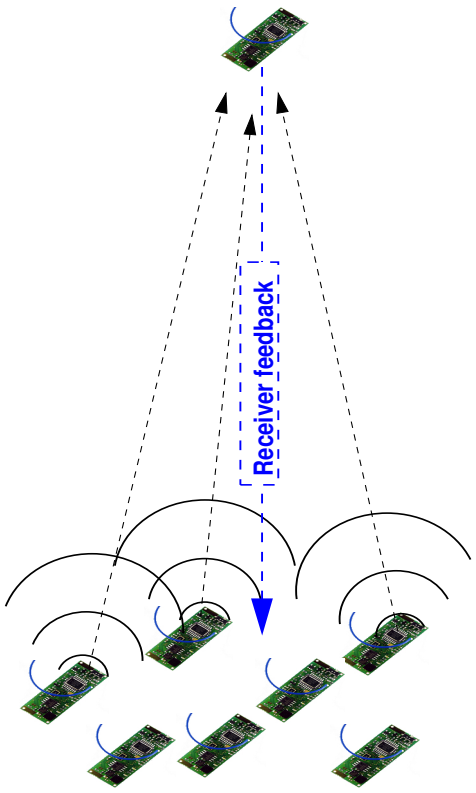
Introduction



- Cosed loop feedback based carrier synchronisation
  - Algorithm always converges to the optimum [a]
  - Expected optimisation time $\mathcal{O}(n)$ when in each iteration the optimum Probability distribution is chosen [a]
  - Optimisation time can be improved by factor 2 when erroneous decisions are not discarded but inverted [b]
  - Phase and frequency synchronisation feasible[c]

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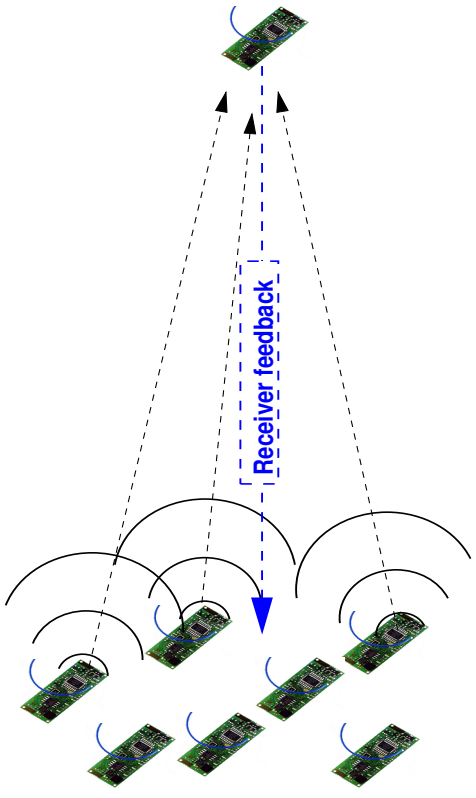
[a] R. Mudumbai, J. Hespanha, U. Madhow, G. Barriac, *Distributed transmit beamforming using feedback control*, IEEE Transactions on Information Theory 56(1), volume 56, January 2010

[b] J. Bucklew, W. Sethares, *Convergence of a class of decentralised beamforming algorithms*, IEEE Transactions on Signal Processing 56(6), volume 56, 2008

[c] M. Seo, M. Rodwell, U. Madhow, *A Feedback-Based Distributed phased array technique and its application to 60-GHz wireless sensor network*, IEEE MTT-S International Microwave Symposium Digest, 2008

Introduction



- We derived that
  - Expected optimisation time of synchronisation algorithm $E[T_{\mathcal{P}}] = \Theta(n \cdot k \cdot \log(n))$ [a]
    - Uniform distributed phase offset
    - Mutation probability: $\frac{1}{n}$
  - Asymptotically optimum optimisation approach [b]
    - $E[T_{\mathcal{P}}] = \Theta(n)$

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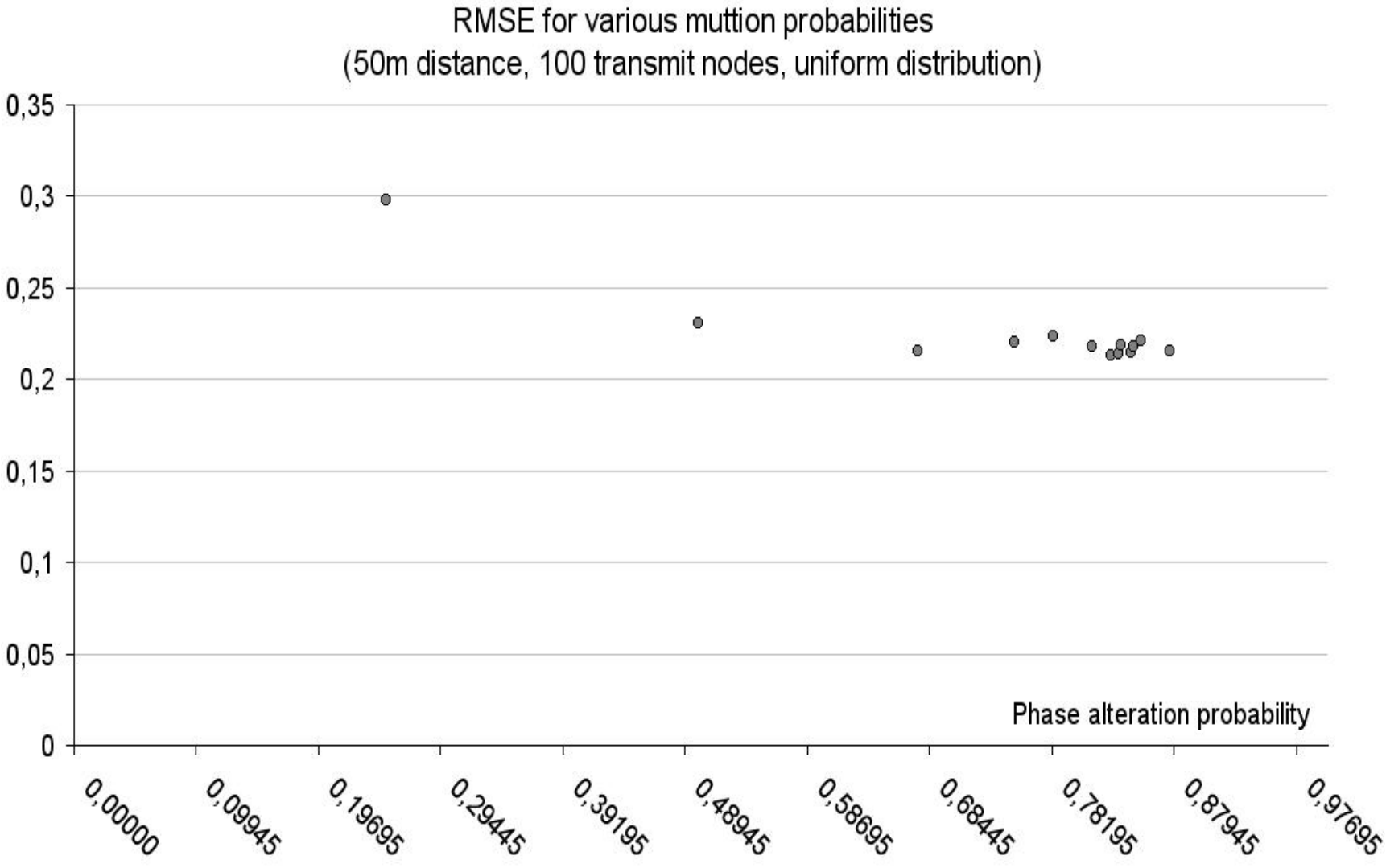
[a] S.Sigg, R.Masri, M.Beigl, *Feedback based closed-loop carrier synchronisation: A sharp asymptotic bound, an asymptotically optimal approach, simulations and experiments*, IEEE Transactions on Mobile Computing (TMC), 2011

[b] R.Masri, S.Sigg, M.Beigl, *An asymptotically optimal approach to the distributed adaptive transmit beamforming in wireless sensor networks*, Proceedings of the 16th European Wireless Conference, 2010

A protocol for distributed adaptive beamforming

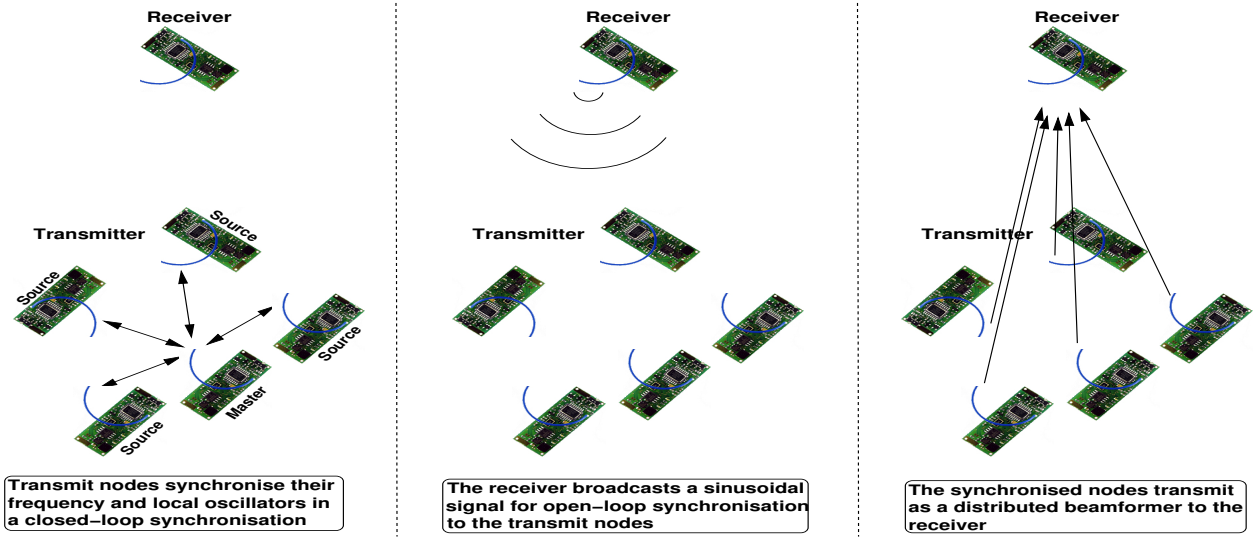
Experimental setting	
Separation of transmit antennas [m]	0.44
Distance to receive antenna [m]	5.5 / 11 / 16.4
Transmit frequency [MHz]	$f_{TX} = 2400$
Receive frequency [MHz]	$f_{RX} = 902$
Iterations per experiment	400
Mobility	stationary
Identical experiments	12
Transmit devices	3
Receive devices	1
Algorithmic configuration	
Random distribution of the phase alteration	normal distribution
Phase alteration probability	0.33 / 0.66 / 1.00
Variance for normal distributed phase offset [π]	0.25 / 1
Hardware	
Gain of receive antenna [dBi]	$G_{RX} = 3$
Gain of transmit antenna [dBi]	$G_{TX} = 3$

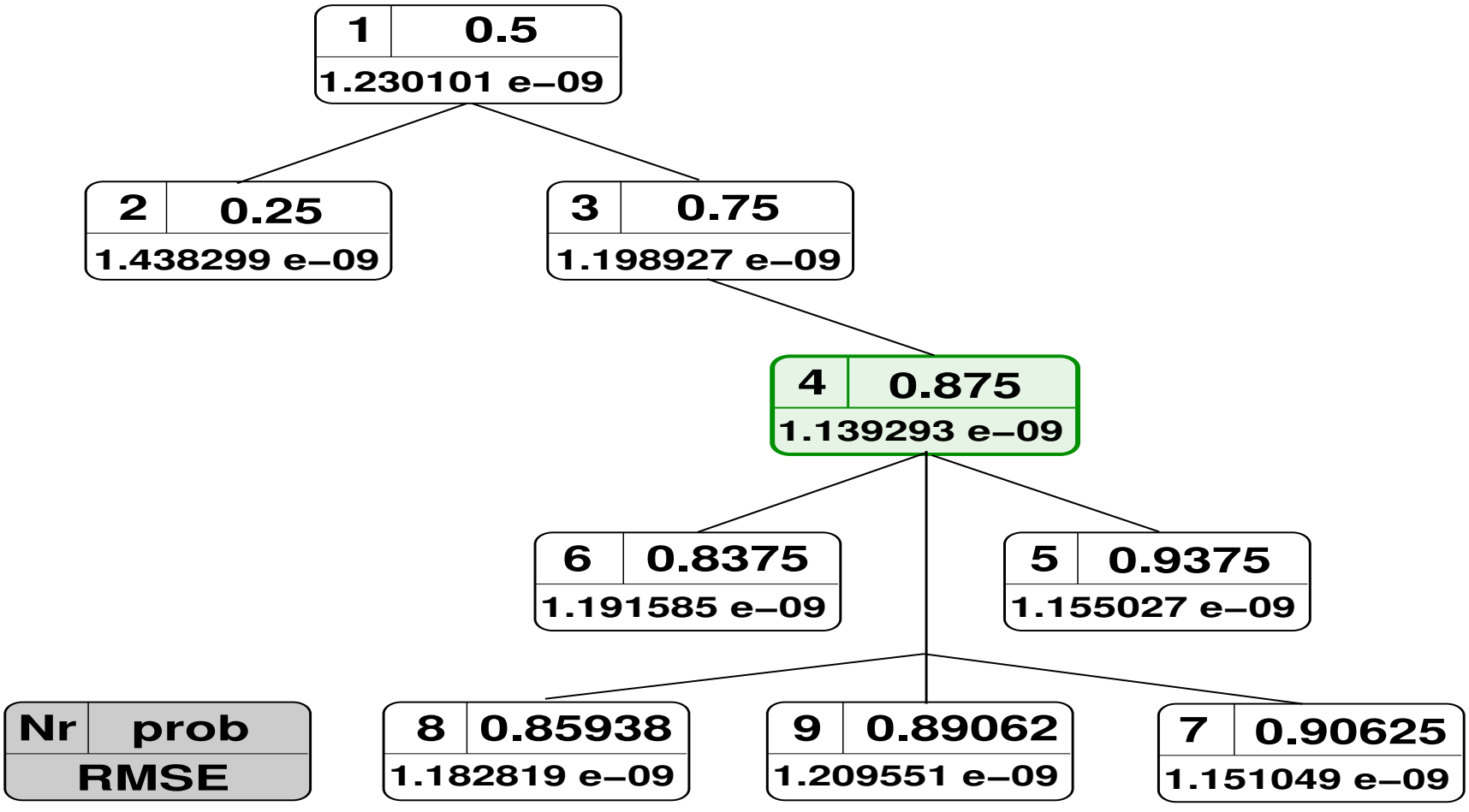
A protocol for distributed adaptive beamforming



Introduction

- Distributed synchronisation schemes
  - Open loop carrier synchronisation[3]



[3] R. Mudumbai, G. Barriac and U. Madhow, *On the feasibility of distributed beamforming in wireless networks*, IEEE Transactions on Wireless Communications, Vol 6, May 2007

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