Evaluating Dynamic OFDMA Subchannel Allocation for Wireless Mesh Networks on SDRs

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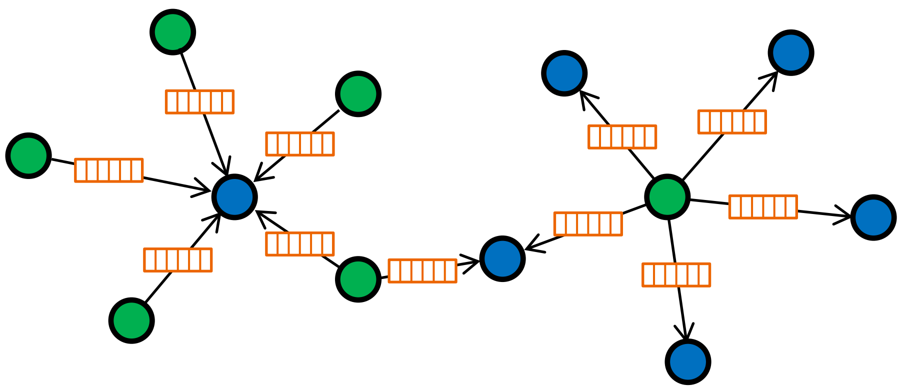
Goal & Overview

Enable OFDMA PHY-layer for Wireless Mesh Networks

- Challenge 1: how to allocate resources to nodes in a distributed mesh?
- Challenge 2: how to prototype such a system on SDRs?



Who can transmit?

Who can receive?

Who uses which OFDM subcarriers?

Challenge 1	Challenge 2	Results
OFDMA	WARPLab limitations	Exploiting good CSI
Subset networks	One step measurem.	Avoiding bad CSI
Allocation strategies	Practical issues	Pros and Cons

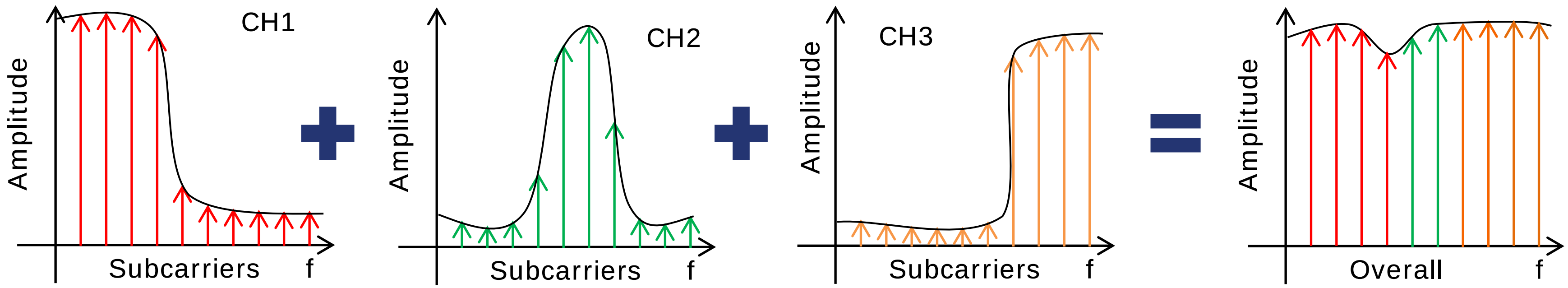
Allocating Subcarriers in a Wireless Mesh Network

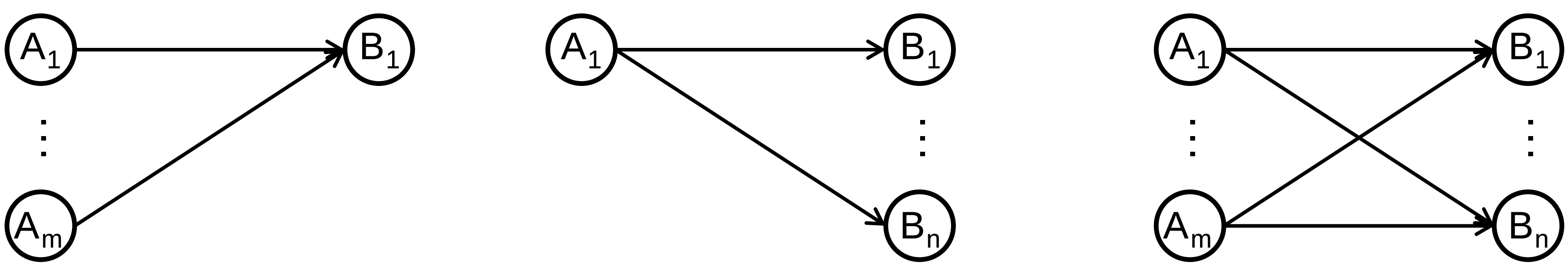
CHALLENGE 1

OFDMA

OFDMA divides bandwidth into flat-fading subcarriers

- Each subcarrier can be assigned to a different link, not to a node
- Gain is achieved by choosing subcarriers with good channel conditions
- Requires Channel State Information (CSI) at the transmitter



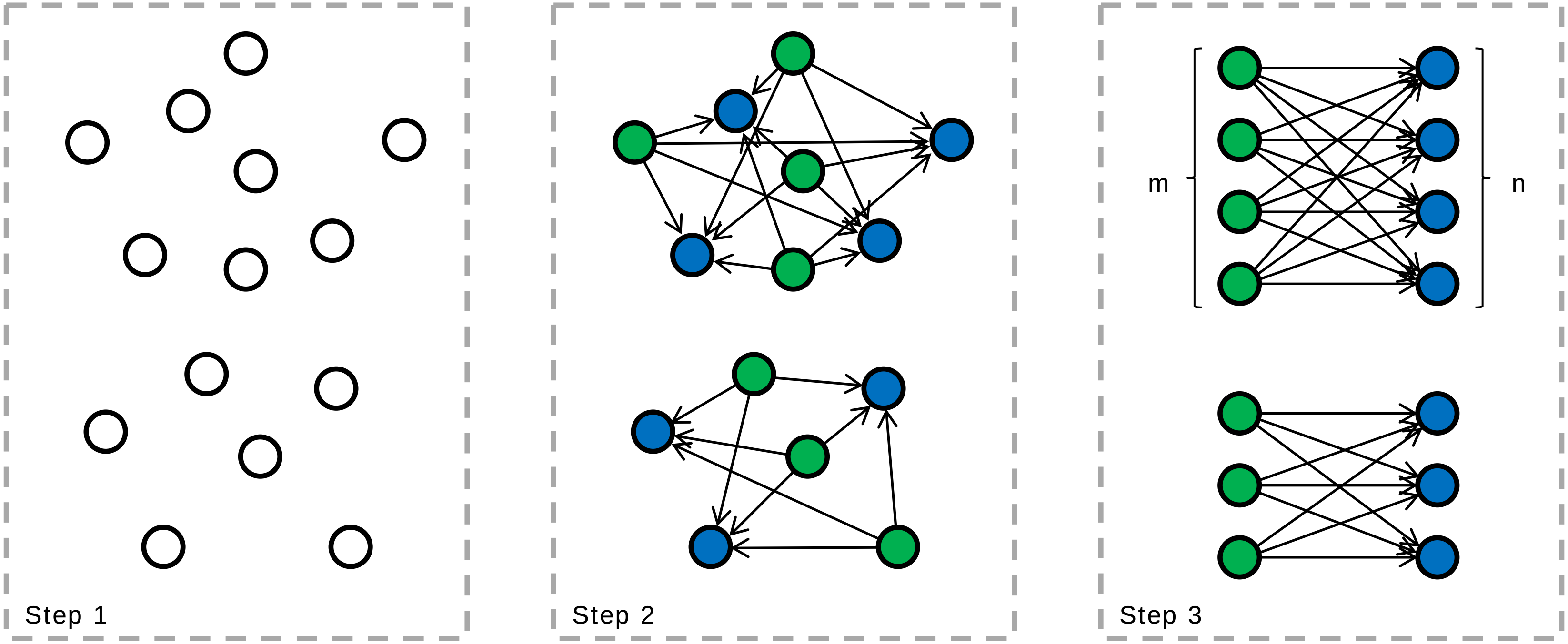


Uplink ($m \neq 1$, $n = 1$) Downlink ($m = 1$, $n \neq 1$) Mesh ($m \neq 1$, $n \neq 1$)

Subset networks

Optimizing allocation for the whole network is problematic

- Signaling CSI over multiple hops may become prohibitive and too slow
- Divide the network into smaller, fully-connected subsets of nodes
- Optimize allocation for each subset network individually

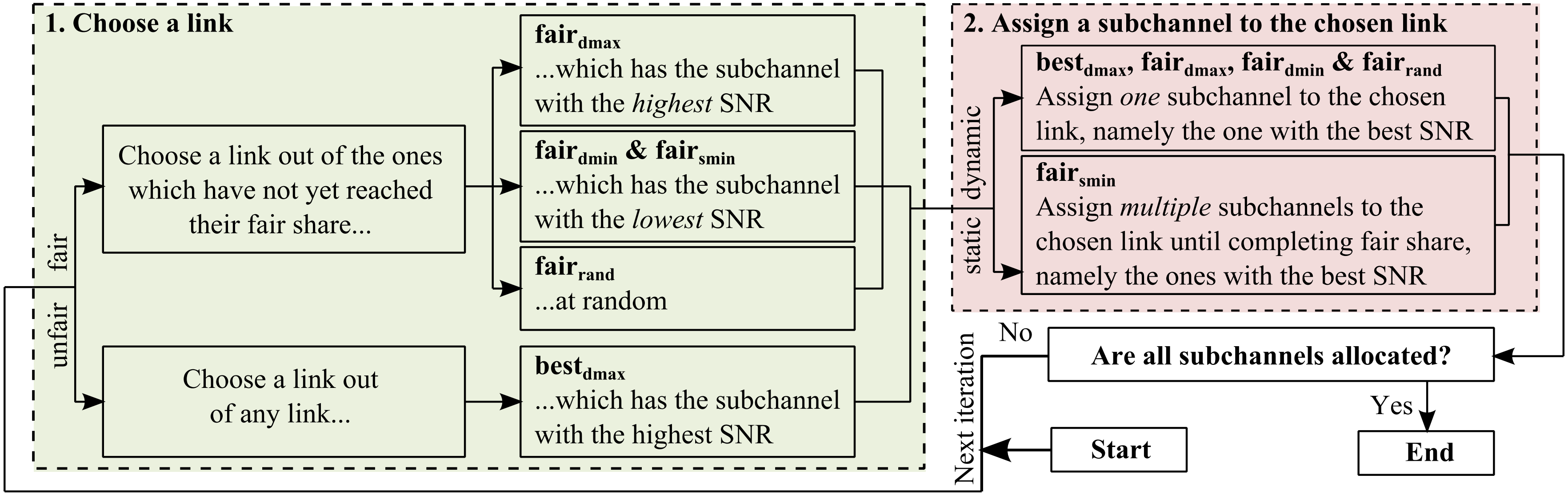


Allocation Strategies

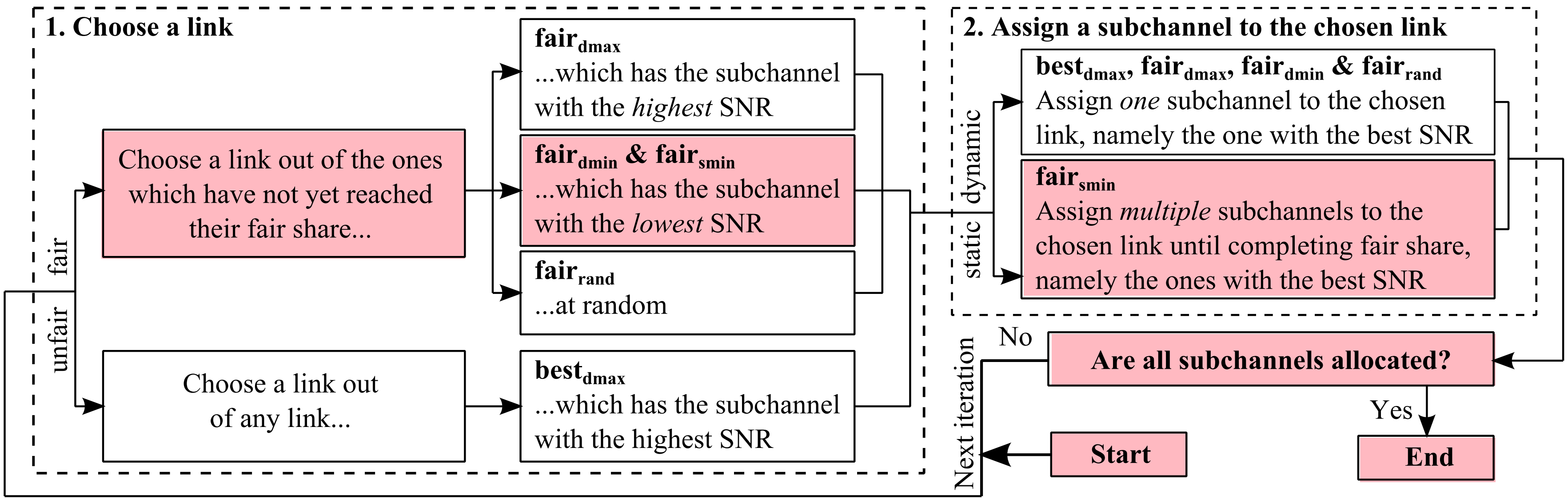
SECURE MOBILE NETWORKING

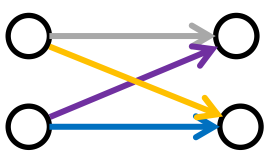
For each subset, we distribute N subcarriers to m x n links

- First, a link is chosen using a certain strategy, which can be fair or not
- Second, one or more subcarriers of the chosen link are assigned
- Fair strategies assign to each link the same number of subcarriers



Allocation example





$fair_{smin}$

Subchannels							
L2	L3	L4	L1	L1	L2	L4	L3

Links			
0	0	0	0
SC 4&5	SC 1&6	SC 2&8	SC 3&7

Protocol Overview

1. Network is divided into fully connected subset networks

2. Nodes are grouped into transmitter and receiver groups

3. CSI is measured for all m x n links in the subset network **Demo!**

4. CSI feedback is sent to transmitters

5. Each node calculates allocation based on CSI and strategy **Demo!**

6. Data is sent according to allocation **Demo!**

OFDMA Prototype on WARP

CHALLENGE 2

Rapid Prototyping Limitations

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Implementation on WARPLab for fast and easy results

- Rapid prototyping allows flexible implementation, but is not real-time
- Transferring data from Matlab to boards and back is slow
- While suitable for lab experiments, real-world changes much faster

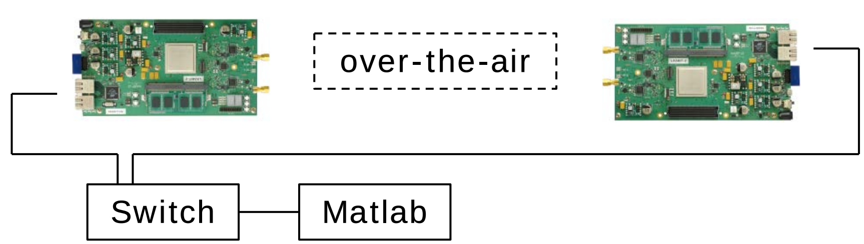
Rapid Prototyping Cycle

1. Samples are calculated in Matlab
2. Samples are transferred to TX board via Ethernet **(~ms)**
3. Data is sent over the actual wireless medium **(~µs)**
4. Received signal is sent back to Matlab via Ethernet **(~ms)**
5. Data is post-processed offline

- Channel is measured **(~ms)**
- Channel allocation is calculated in Matlab
- Data is sent according to channel allocation **(~ms)**

Milliseconds elapse!

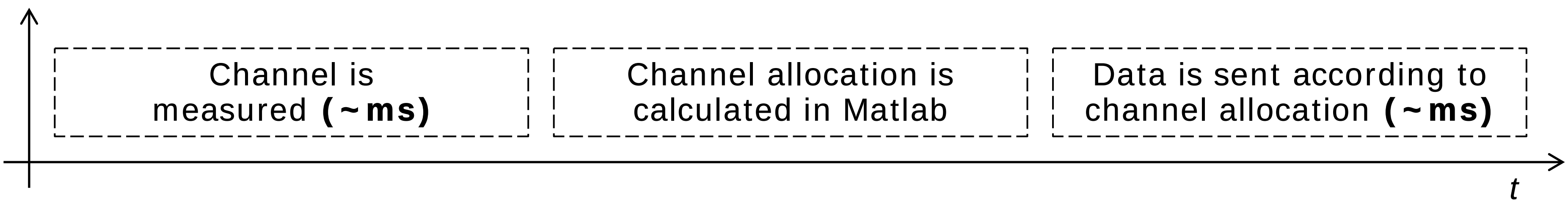
Channel may change much faster!



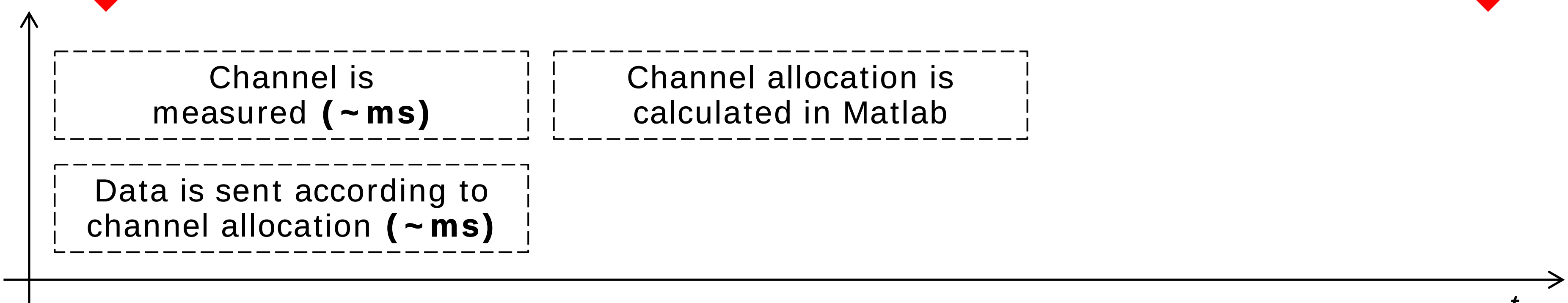
Implementation Challenge

Overcome limitation of slow CSI feedback

- While still using Matlab for easy and flexible implementation ...
- ... run allocation algorithms on up-to-date channel information
- Provide a framework that can be used for any allocation algorithm



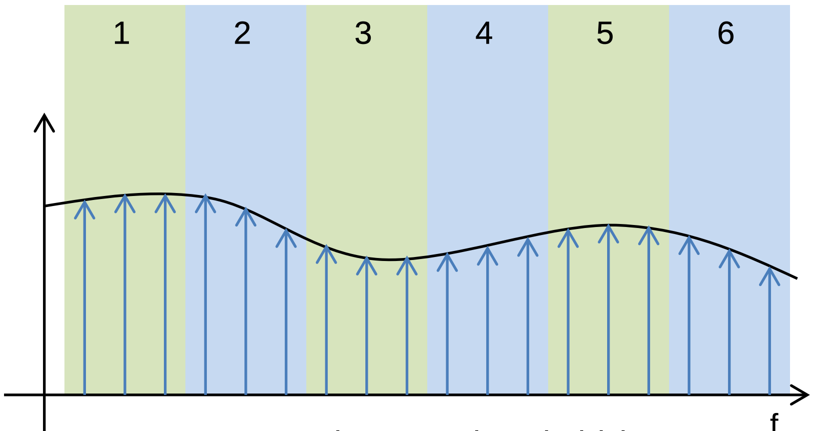
Essentially, we want to build a time machine!



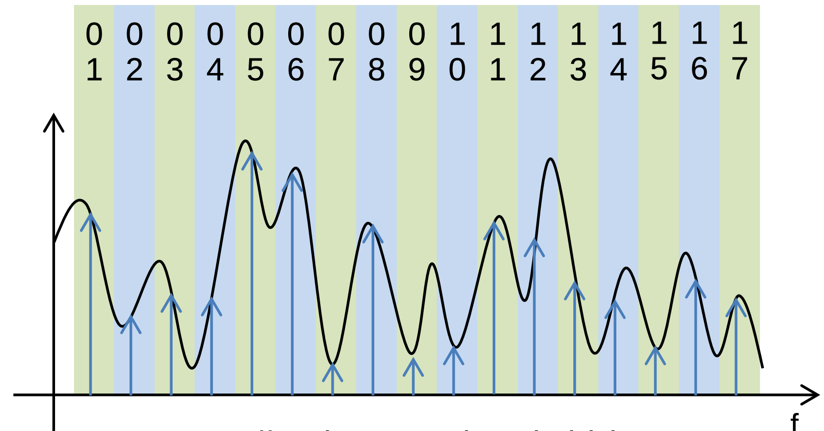
One Step Measurement

We measure CSI and perform the transmission in one step

- Key technique is to exploit coherence bandwidth b_{coh} of the channel
- b_{coh} is range of frequencies over which channel quality is constant
- Subcarriers are grouped to subchannels which are narrower than b_{coh}



Large coherence bandwidth



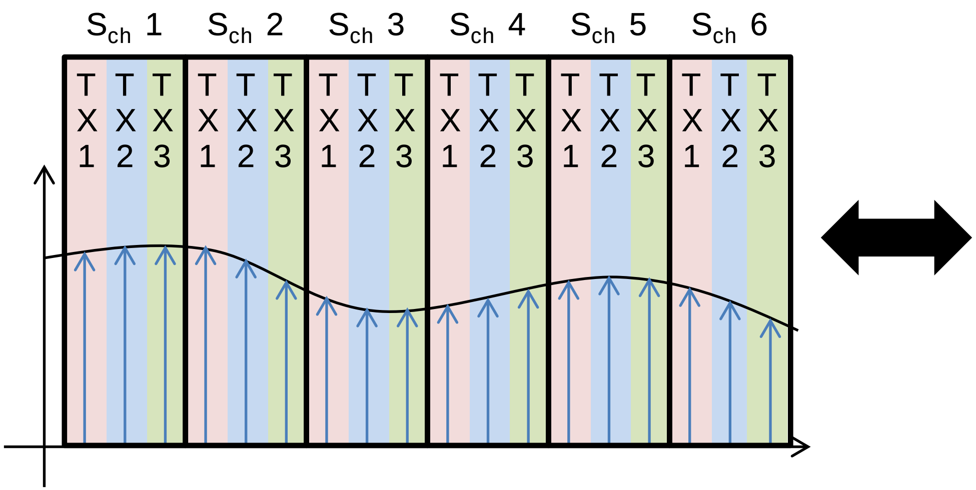
Small coherence bandwidth

The performance on each subcarrier of a subchannel is similar
Knowing the performance on one subcarrier, the rest can be extrapolated

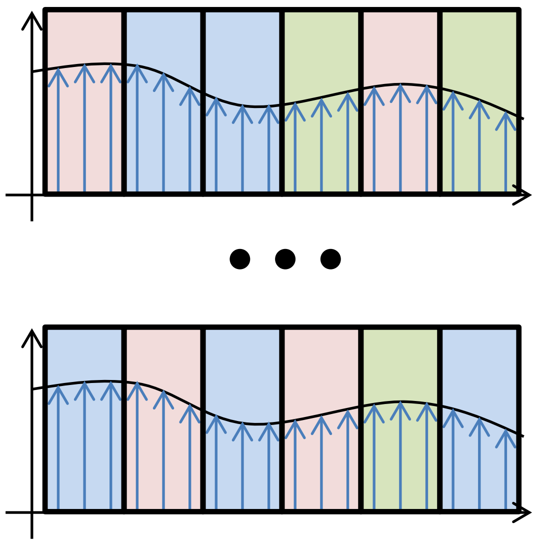
One Step Measurement

Allocate one subcarrier to each sender in each subchannel

- All transmissions follow such a static allocation for transmission
- Each receiver gets data from each transmitter on each subchannel
- Thus can deduce performance of each transmitter on each subchannel



There must be at least the same number of subcarriers per subchannel than transmitters



See in retrospect how any allocation would have performed

Practical Issues

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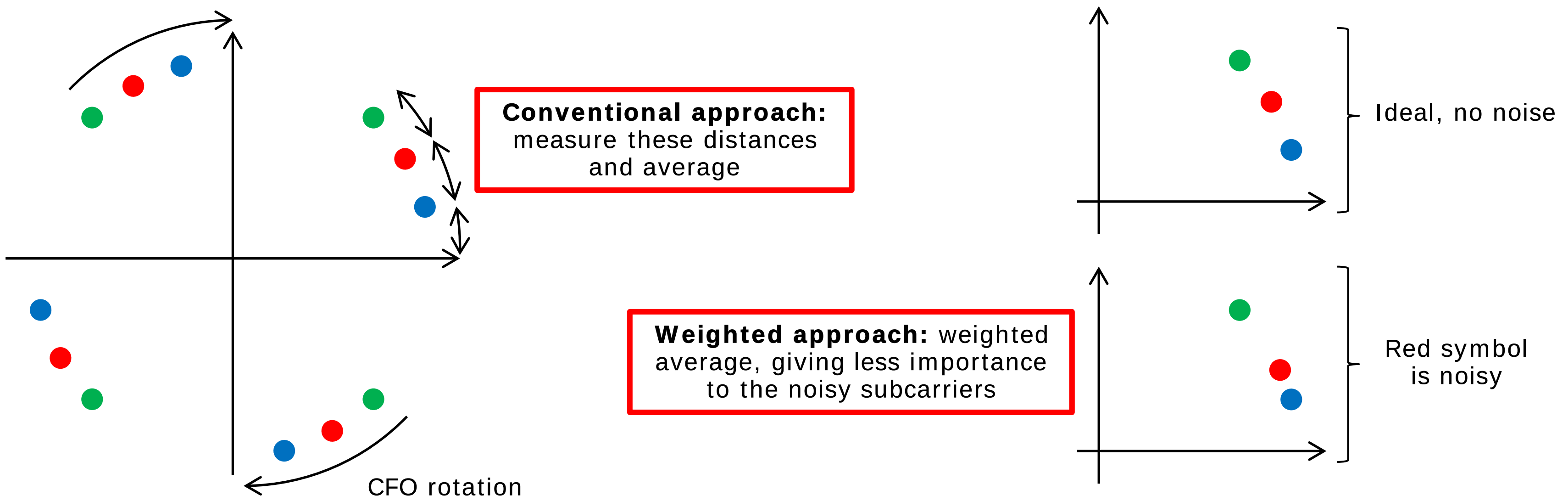
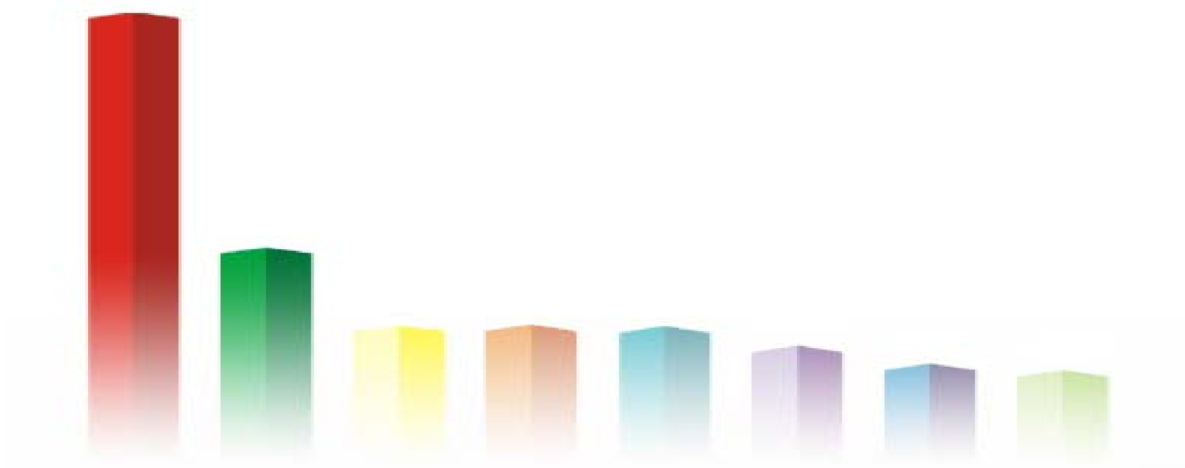
CFO is calculated and corrected based on known pilots

- Low quality subcarriers have strong impact on average CFO estimation
- Solution: weight the contribution of each subcarrier according to SNR



Performance of allocation is measured in CAP / SER / BER

- CAP is the capacity based on the SNR measured on each subcarrier
- Throughput cannot be directly measured due to WARPLab delays



One Step Measurements in an OFDMA Testbed

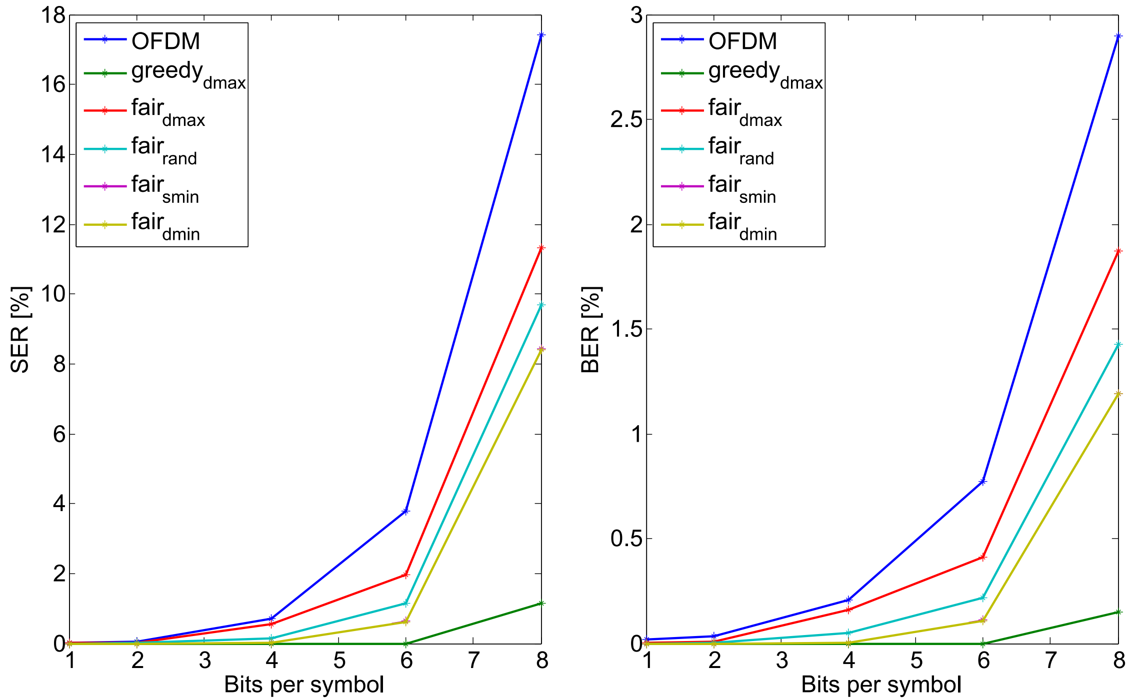
RESULTS

Exploiting good subchannels

Performance of strategies in a 4x4 subset network

- One WARP for TX and one for RX, modeling each antenna as a node
- We measure the CAP, SER and BER for all our allocation strategies
- SER $fair_{dmin}$ is best, as overall bad links at least get best subcarriers

Allocation Strategy	CAP [mbps]	Gain OFDM
OFDM	174.3	0%
$best_{dmax}$	224.3	28.7%
$fair_{dmax}$	192.0	10.2%
$fair_{rand}$	192.9	10.7%
$fair_{smin}$	192.7	10.5%
$fair_{dmin}$	192.8	10.6%

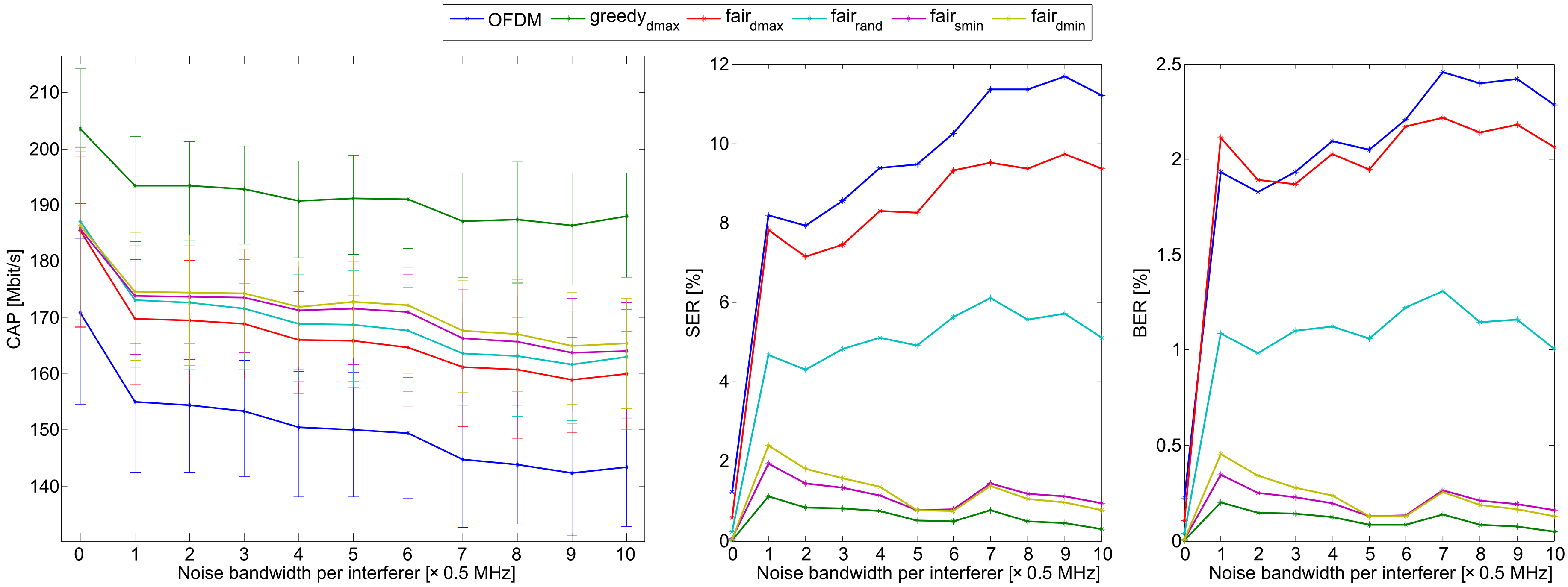


Avoiding noisy subchannels

SECURE MOBILE NETWORKING

We place interferers to send noise on part of subcarriers

- Setup is identical, but two of the four senders transmit artificial noise
- Noise bandwidth can be increased from 0 to 5 MHz in steps of 0.5 MHz
- Interference has strong impact on $fair_{dmax}$, which performs as OFDM



Discussion & Conclusion

Visit our demo!

Discussion

Issue	Advantage	Limitation
Mesh OFDMA	Dividing network into subsets gives tradeoff between local and global	Forming optimal subsets in a distributed manner is not straightforward
Allocation Strategies	Provide capacity increase of 10% to 30% and reduce BER by factor of 10	Fairness limits the capacity increase and non-fair strategies may not serve nodes
One Step Measurem.	Allows to evaluate OFDMA subcarrier allocations in retrospect	Coherence bandwidth of the channel needs to be large enough for all TXs
Extensibility	Other schemes requiring CSI are possible, e.g., adaptive bit rates	Schemes such as MIMO cannot use this idea as # of possible signals is infinite

Conclusions

- We design allocation strategies for OFDMA with multiple TX and RX
- We evaluate OFDMA using WARPLab and one step measurements
- We achieve significant capacity and BER/SER improvements

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