Incorporating Dynamic OFDMA in IEEE 802.11

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Acknowledgements

The presented work arouse from a cooperation between

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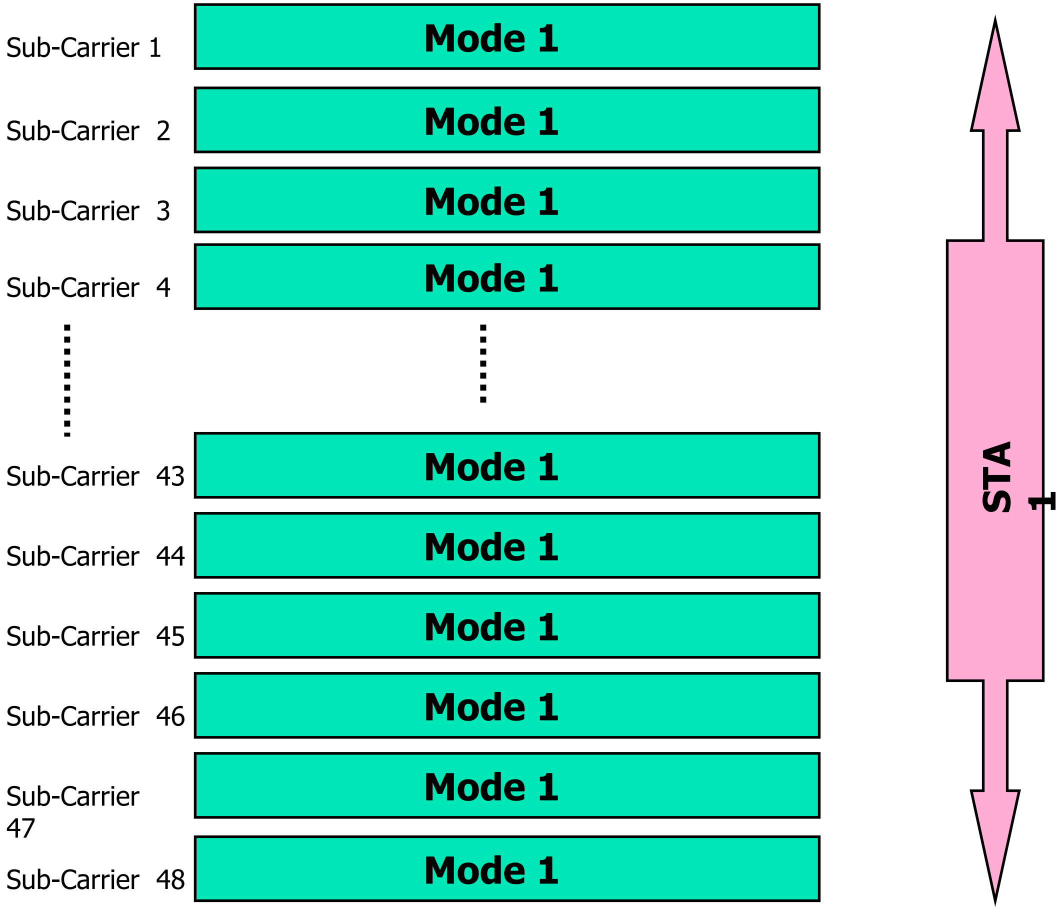
Motivation

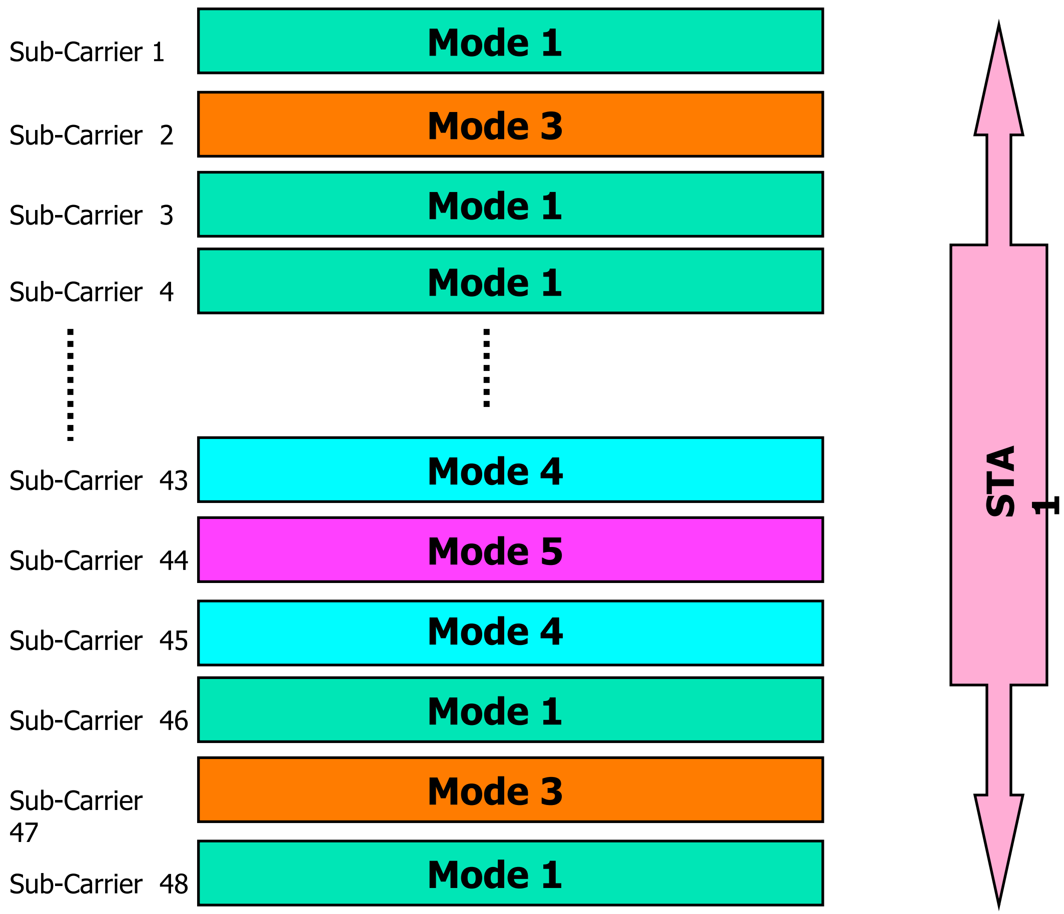
- OFDM-bases physical layers are commonly used for high-speed wireless networks
- Currently used schemes
  - transmit packets sequentially using all OFDM sub-carriers
  - employ the same modulation/coding on all sub-carriers
- Dynamic OFDM schemes are known to outperform these traditional schemes as they
  - choose a modulation/coding scheme individually per sub-carrier (according to the current sub-carrier channel gain)
  - may transmit packets in parallel to several STAs in the downlink using FDM by assigning sub-carrier sub-sets per STA
- This presentation shows the potential of Dynamic OFDM to enhance upcoming 802.11 systems.

"Classical OFDM"



- All sub-carriers assigned to one STA
- Same modulation/ coding scheme applied to all sub-carriers

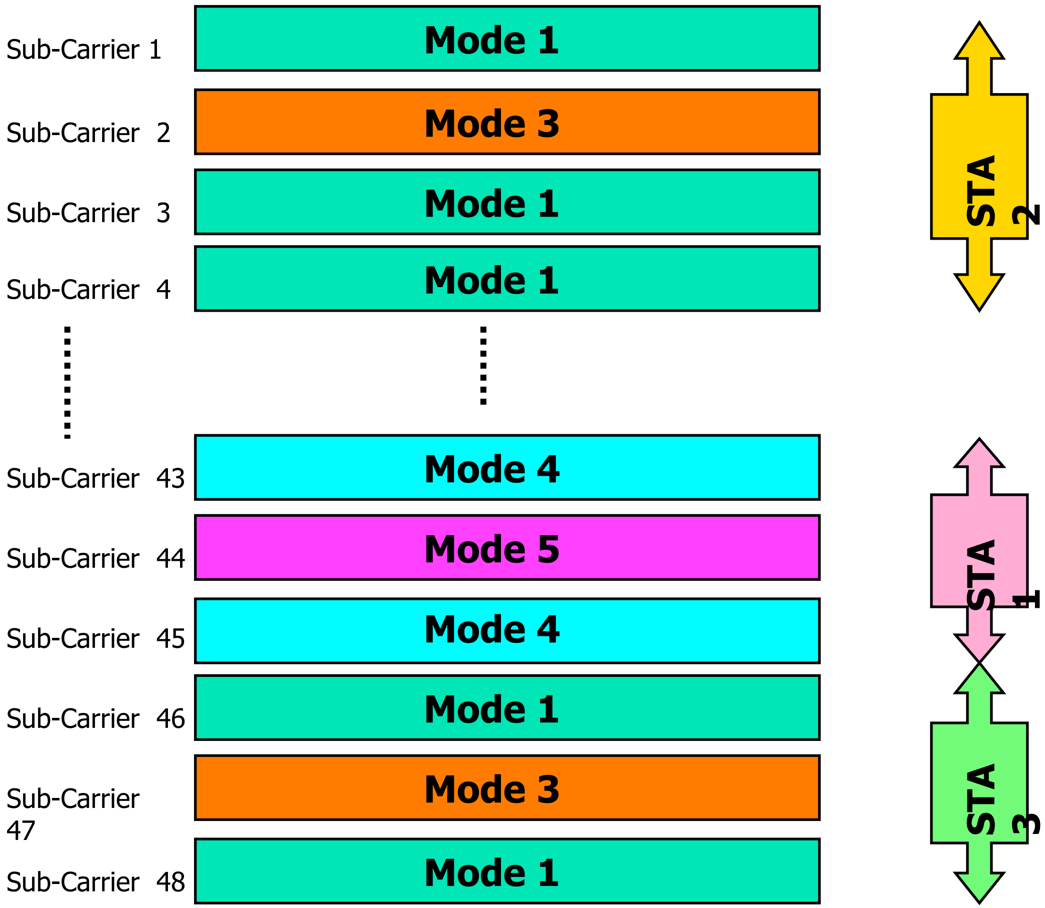
P2P-Mode: Dynamic Single-User OFDM



- All sub-carriers assigned to one STA
- Modulation/ coding per sub-carrier differs according to current channel gain
- Benefit from lower error probability

P2P-DynOFDM: React to frequency variations by specific modulation/power setting per subcarrier

P2MP-Mode: Dynamic Multi-User OFDM



- Subsets of sub-carriers are assigned to different STAs
- Modulation/ coding per sub-carrier according to current channel gain for the specific STA
- Additionally: benefit from multi-user diversity

P2MP-Mode: Enable simultaneous data transmission to different stations via (channel dependent) OFDMA → Exploit multi-user diversity

Required overhead to use Dynamic OFDM

- In order to choose an (optimal) modulation/coding per sub-carrier, we need to
  estimate the channel gain per sub-carrier
  for each transmission
  and
  signal the used modulation/coding per sub-carrier
  from the transmitter to the receiver.

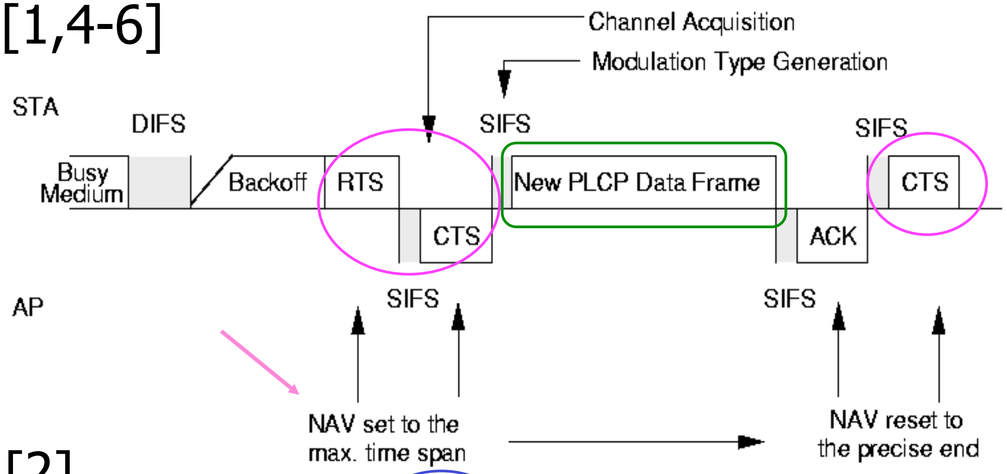
- Additionally, for the multi-user case (parallel transmission of packets), we have to
  signal the assignment of sub-carrier sets from the transmitter
  to the receiver.

- Performance evaluation depends on the technical realization of channel acquisition and signaling.

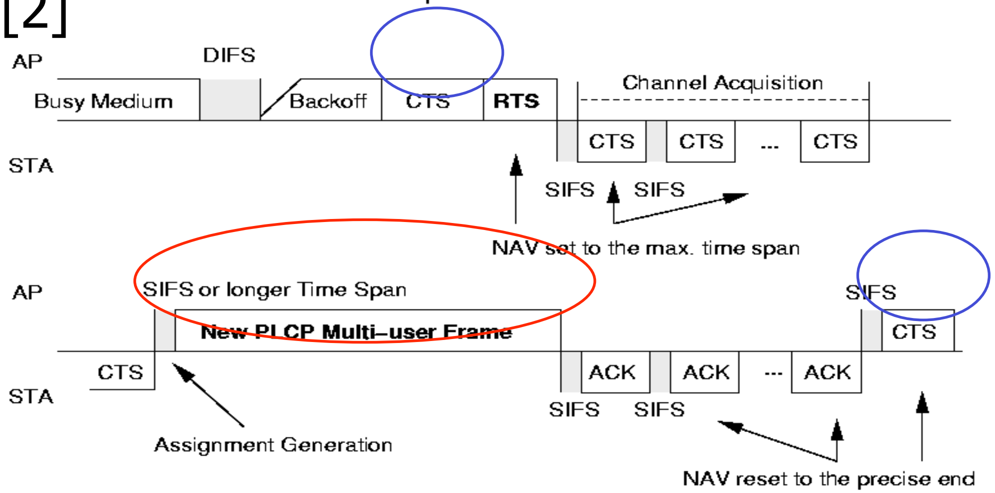
- The following results include all the required overhead if Dynamic OFDM were to be included in 802.11-2007 assuring downward compatibility with legacy devices.

Incorporation of Dynamic OFDM in 802.11

- Dynamic Single-User OFDM [1,4-6]
  - → different modulation per sub-carrier according to sub-carrier channel gain



- Dynamic Multi-User OFDM [2]
  --> additionally exploit multi-user diversity



→Protocol overhead to include Dynamic OFDM considered in performance evaluation

Performance Evaluation

Comparison state-of-the art IEEE 802.11n with Dynamic OFDM Enhancements:

- Channel Model / Simulation Details
- Results: Exploiting the degrees of freedom
  - Baseline experiments
  - Reduce MAC overhead ←→ enable frame aggregation
  - Exploit Multi User Diversity ←→ enable P2MP mode
  - Add spatial layers

802.11n & Channel Model

- Simulations for 11n considering
  - A-MPDUs Frame Aggregation [10]
  - 2x2x20 MHz Spatial Multiplexing [10]
  - Channel Model E (Large Office) [8,9]

- Sub-Carrier Specific Attenuation
  - MatLab used to generate impulse response of channel for each transmission [8,11]
  - Impulse response used to calculate channel matrix H
    --> sub-carrier specific attenuation

- Results of reference simulations verified against results of IEEE 802.11n WG (c.f. 11-07/2860)

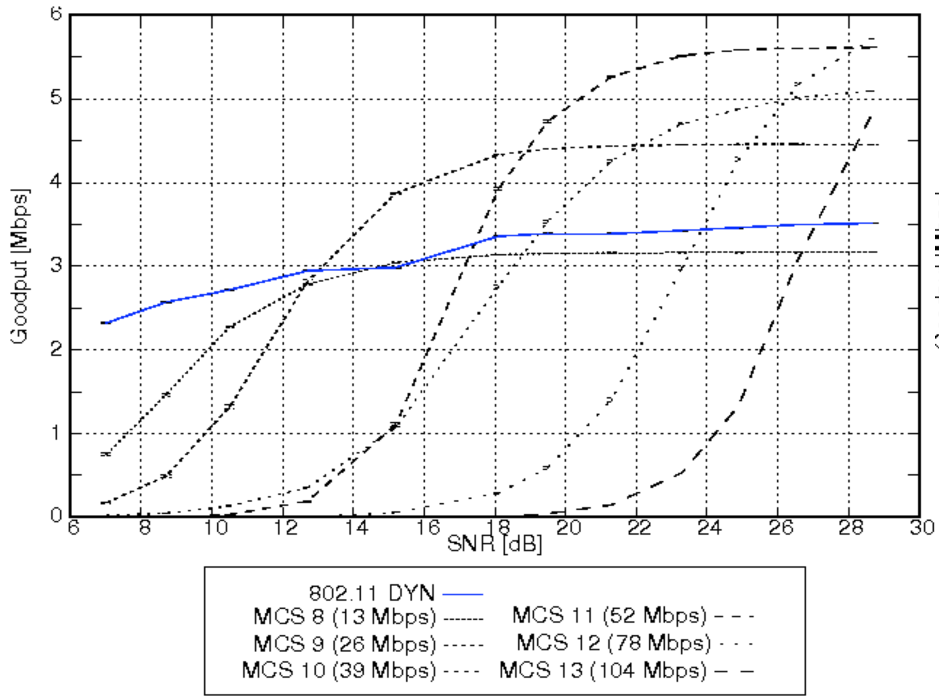
Simulation Details

- Large PDUs (1536 Byte, RTS/CTS enabled for 11n) & small ones (200 Byte, RTS/CTS disabled for 11n)
- Saturation mode (always "enough" packets in queue)
- P2P scenario: one transmitter, one receiver, no further stations, one-way traffic only
- P2MP scenario: one transmitter, several (4) receivers, no further stations, one-way traffic only, all receivers at same distance to transmitter
- Performance metric: MAC Goodput [bit/s]

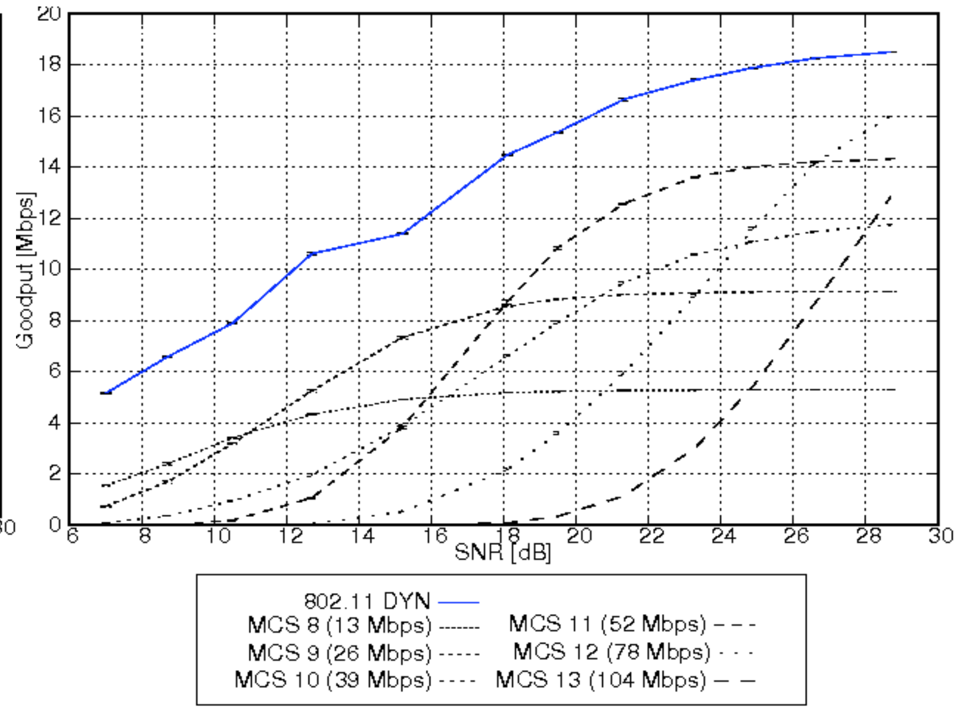
Results I – Baseline

- 1 spatial stream, no frame aggr., P2P scenario

Small PDUs (200 Byte)



Large PDUs (1536 Byte)

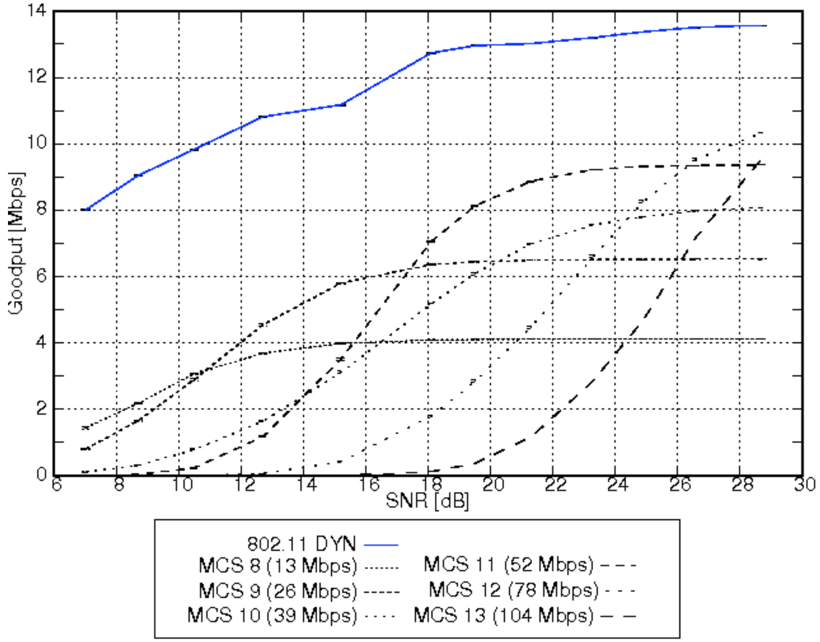


DynOFDM can dramatically improve system performance for low SNRs (300%) for small packets. It constantly outperforms 11n for large packets

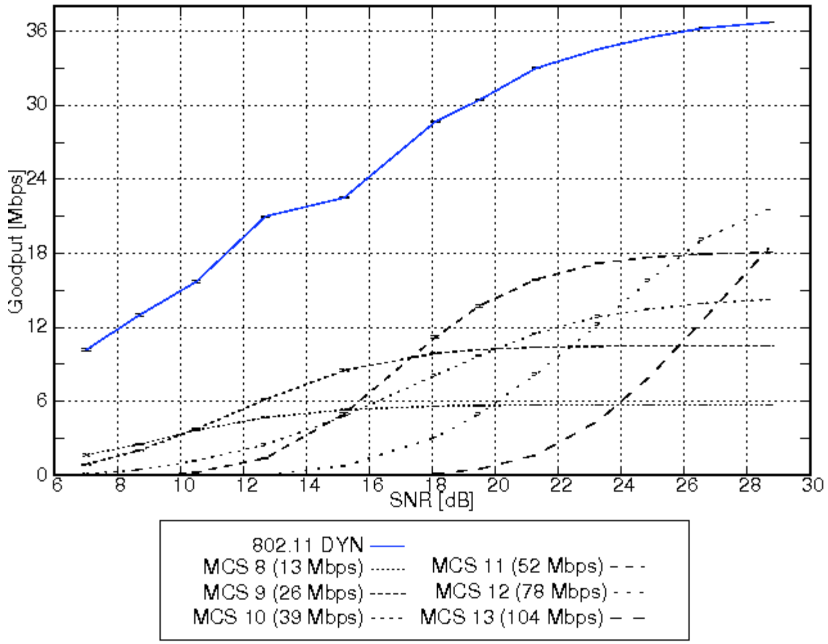
Results II – Reduction of MAC Overhead

- 1 SS, frame aggr. activated, P2P scenario

Small PDUs (200 Byte) – FA with 4 PDUs



Large PDUs (1536 Byte) – FA with 2 PDUs

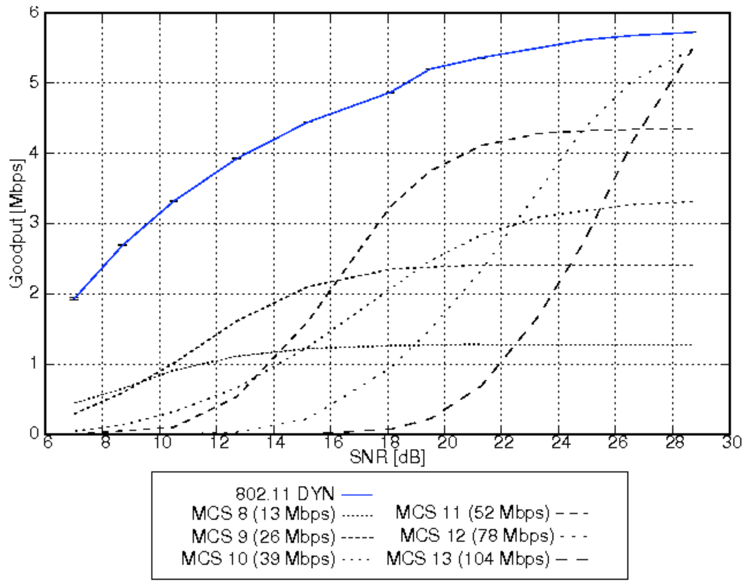


By leveraging the protocol overhead (for both, 11n and DynOFDM), DynOFDM always outperforms 802.11n

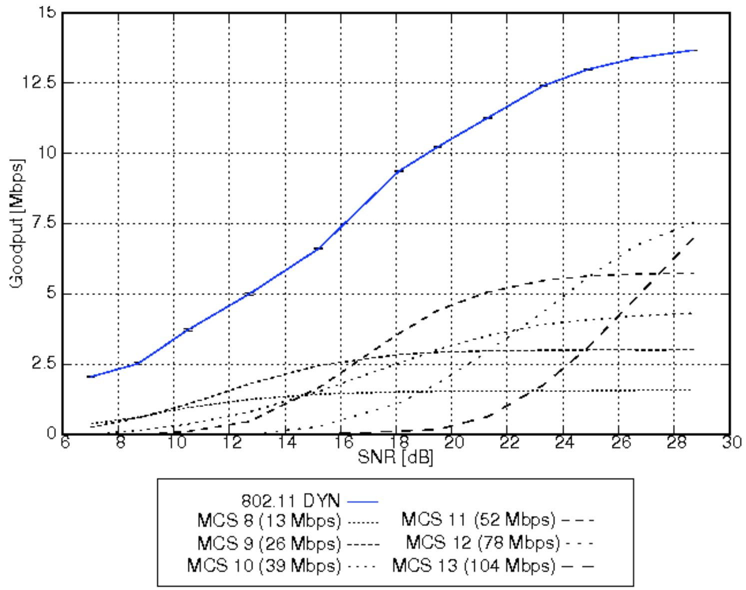
Results III – Adding Multi-user Diversity

- 1 SS, frame aggr. activated, P2MP (4 STA) scenario
- Equal PDU number aggregated into one channel access

Small PDUs (200 Byte) – FA with 16 PDUs for 11n, FA with 4 PDUs for 11DYN



Large PDUs (1536 Byte) – FA with 8 PDUs for 11n, FA with 2 PDUs for 11DYN

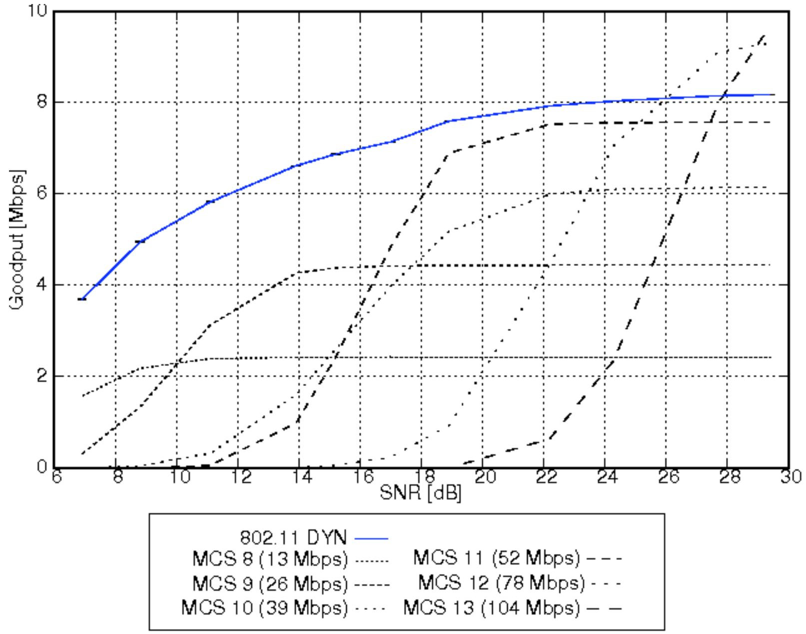


Overhead due to post-backoff leverages protocol overhead for 11n and DynOFDM. Aggregated throughput increased by approx. 50%

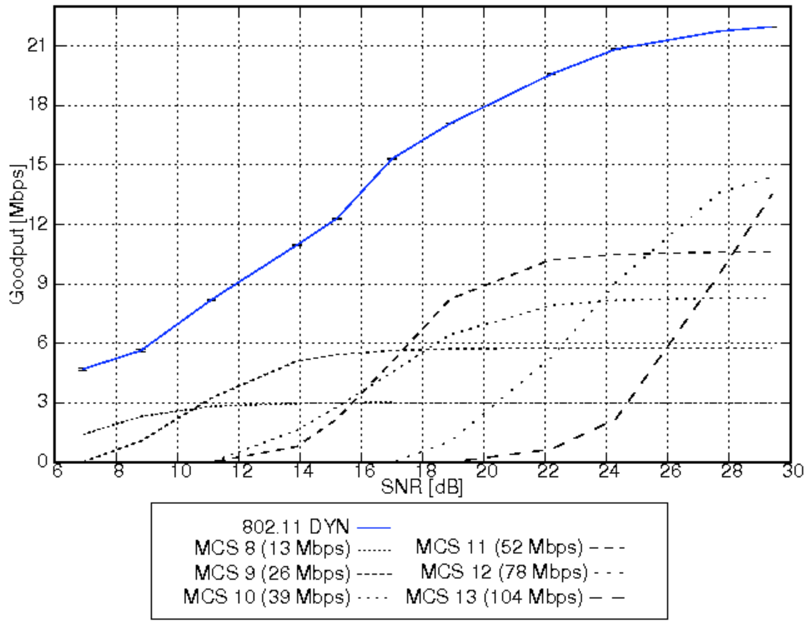
Results IV – Adding Spatial Layers

- 2 SS, frame aggr. active, P2MP scenario (4 STA)

Small PDUs (200 Byte) – FA with 16 PDUs for 11n, FA with 2 PDUs for 11DYN



Large PDUs (1536 Byte) – FA with 8 PDUs for 11n, FA with 2 PDUs for 11DYN



DynOFDM outperforms IEEE 802.11n except for small packets transmitted for high SNRs: 4 terminals are not enough to fully exploit the diversity for more SSs

Summary

- It is possible to incorporate Dynamic OFDM in IEEE 802.11 upholding backward compatibility with legacy devices (even down to 1st generation WLANs).
- Dynamic OFDM can easily outperform the upcoming IEEE 802.11n system for large packet sizes and in most cases also for very small packets considering all the required protocol overhead.
- Both, exploiting the frequency diversity per sub-carrier as well as the multi-user diversity is one main focus of future WLAN system (IEEE 802.11 TGac). The presented ideas and results are actively fed into this task group.

References

[1] 11-07/0720r2 -- Dynamic Point-to-Point OFDM Adaptation for IEEE 802.11a/g Systems

[2] 11-07/2062r1 -- Dynamic Multi-user OFDM for 802.11 systems

[3] 11-07/2187r1 -- Another resource to exploit: multi-user diversity

[4] J. Gross, M. Emmelmann, O. Puñal, and A. Wolisz, "Dynamic Point-to-Point OFDM Adaptation for IEEE 802.11 Systems," accepted for publication at IEEE/ACM International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM), October 2007.

[5] J. Gross, M. Emmelmann, O. Puñal, and A. Wolisz: 802.11 DYN: Protocol Extension for the Application of Dynamic OFDM(A) Schemes in 802.11a/g Systems, Technical Report TKN-07-002, Telecommunication Networks Group, Technische Universitaet Berlin, May 2007.

[6] J. Gross, M. Emmelmann, O. Puñal, and A. Wolisz: Dynamic Point-to-Point OFDMA Adaptation for IEEE 802.11a/g Systems, doc. 11-07/720, IEEE 802.11 WNG SC Wireless Next Generation Standing Committee, Montreal, Canada, May 14 -- 18 2007.

[7] 11-06/0067r3 -- TGn Joint Proposal Phy Results

[8] 11-03/940r4 -- TGn Channel Models

[9] 11-03/802r23 -- Usage Models

[10] TGn Draft most rece3int verssion

[11] L. Schumacher "WLAN MIMO Channel Matlab program," download information: www.info.fundp-ac-be/~lsc/Research/IEEE_80211_HTSG_CMSC/distribution_term.html

[12] James Gross, Oscar Puñal, and Marc Emmelmann: Multi-User OFDMA Frame Aggregation for Future Wireless Local Area Networking. IFIP/TC6 NETWORKING 2009, May 11—15, 2009, Aachen, Germany.

[13] James Gross and Marc Emmelmann: System and method for incorporating dynamic orthogonal frequency-division multiplexing into wireless network protocols. USPTO Application #: 20080232490, pending patent.

[14] 11-09/138 -- OFDMA related issues in VHTL6.

Thank you for your attention

Backup Slides

P2MP OFDM for 802.11: Modified PLCP Header

- 1st 24 bits of PLCP header in compliance with legacy 802.11
--> everybody may decode the header and discard it if
- the RATE field indicates Dynamic OFDM to be used in the payload
- Additional signaling indicates used mode per sub-carrier and terminal