DCF modeling and optimization of long-distance IEEE802.11n point-to-point links

Michael Rademacher
michael.rademacher@h-brs.de

19. ITG Fachtagung Mobilkommunikation Osnabrück. May 21, 2014

Hochschule Bonn-Rhein-Sieg

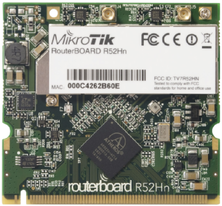
Fraunhofer FOKUS

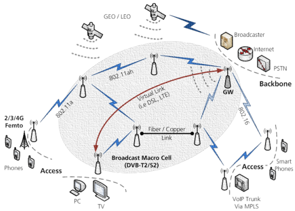
Network Research

Introduction

- WiFi based Long Distance networks (WiLD)
  - Are used to overcome the digital divide in rural areas
  - Off-the-shelf IEEE802.11 hardware operating in the ISM-Band
  - Wireless Mesh Network (WMN), WiBACK
- Our previous work on WiLDs
  - Make 802.11a suitable for long distance point-to-point links
  - Maximize the throughput by exploiting 802.11n
- A lot of measurements on different links (distances)
  - Uni-directional traffic, maximum modulation (and frame-aggregation)

e.g. 200 Mbps: 802.11n, 10 km, 40 MHz, 2x2 MIMO, MCS 15





Motivation

1. The 802.11 point-to-point performance depends on:

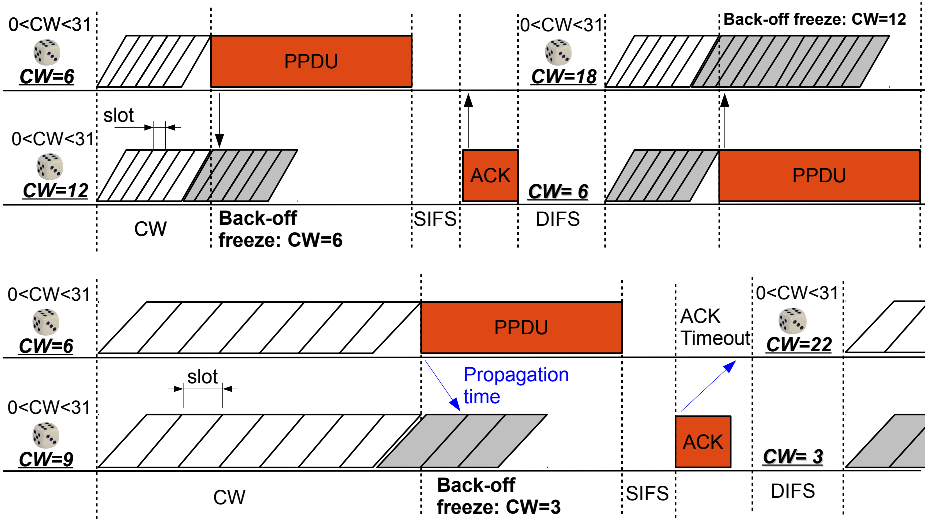
Environment	**Traffic**	**MAC parameter**
Distance	Protocol (e.g IP/UDP)	Slot time (σ)
MCS	Payload size	Contention Window (CW)
BER	Frame aggregation	Max. retransmission (R)

2. The **MAC** was designed by the IEEE compromising:
   - **Numerous stations** in a cell (AP)
   - Spatial restrictions of a **few hundred meters**

   } **Optimization potential!**

Mathematical modeling instead of countless measurements

Background: Distributed Coordination Function (DCF)



State of the Art

- 802.11 MAC layer modeling has been well researched
- Mainly based on two publication by Bianchi or Cali et. al
- Numerous extensions have been published
- Only a few publications deal with the topic of WiLD
  - Large WMN instead of point-to-point links
  - Simulations for validation and different assumptions (no BER)

- A revised version of Binachis' model was chosen as a base:
  - Based on conditional probability
  - Well studied by several researchers
  - Validated against simulations

Methodology - 802.11 MAC modeling in a nutshell

Two important observations for saturated link conditions:

- The presence of a discrete time-scale (slot time σ)
- Only three different events can occur on the channel
  1. Transmission **successful**: P_s and T_s
  2. **Collision**: P_c and T_c
  3. **Idle**: P_i and σ

1-3 Can be expressed with a constant transmission and collision probability!

- Saturation throughput (S):

$$S[\frac{\text{Bit}}{Time}] = \frac{P_s E[P]}{P_i\ \sigma + P_s\ T_s + P_c T_c}$$

- Average access delay (D):

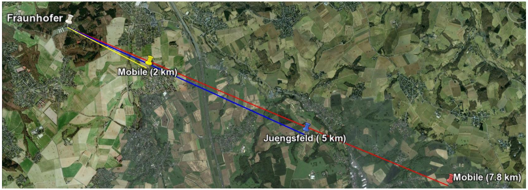
$$D = \frac{N}{S/E[P]}$$

Numerous extensions: integrated (○) or developed (●)

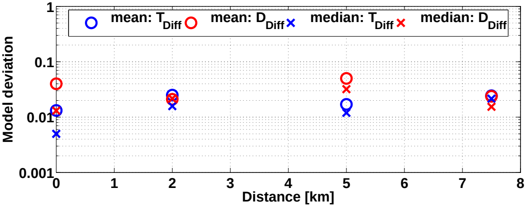
- ○ Erroneous links (BER)
- ○ Backoff-freezing and anomalous slots
- ○ The current 802.11-2012 standard specifications

- ● Long-distance point-to-point links
- ● The 802.11n standard
  - Physical Layer extension (HT-MCS and MIMO)
  - A-MPDU MAC aggregation on erroneous links
- ● Additional delay factors (System Delay)
  - Reordering Time
  - Buffer and Processing Times
- ● Finite Buffering (Throughput decrease)
- ● Peculiarities of Hardware and the Linux Soft-MAC

Validation on real-world WiLD links



- Outdoor router, modified Linux Kernel
- Developed measurement tools
- Delay correction
- Design of Experiments
- ≈ **5000 different measurements**



- Overall low deviations (≈ 0.02),...
- ... independent of the link distance.
- Deviation slightly higher for
  - The delay
  - High A-MPDU factors

What to-do with the developed modeling approach:

1. Estimation

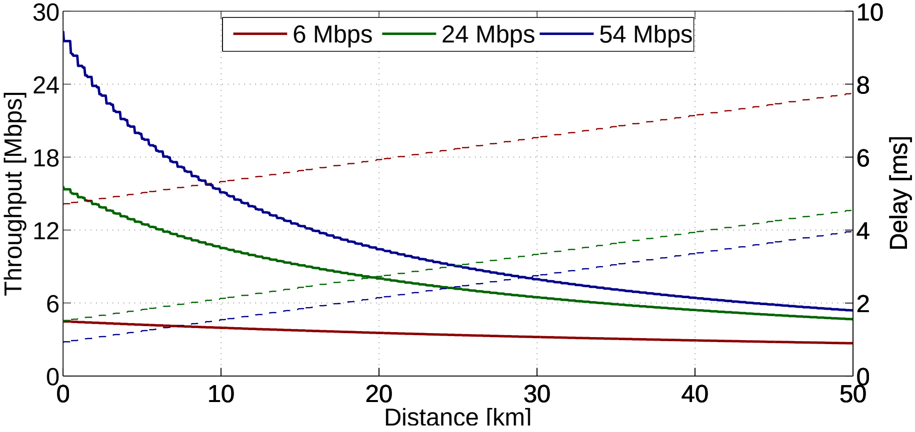
- **Influence of the distance**
- Influence of the payload size
- Influence of the aggregation factor
- Influence of the BER

} on throughput and delay

2. Optimization of the 802.11 MAC parameters

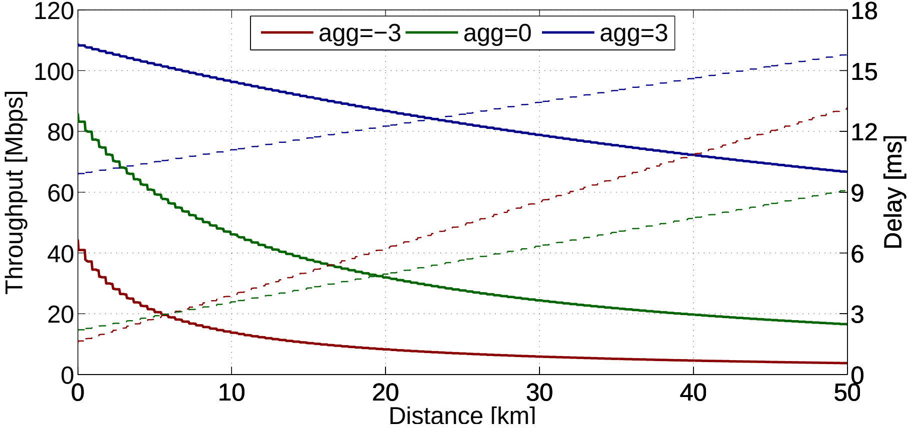
- Optimum *CW* and R to maximize throughput **and** minimize delay

Estimation: 802.11a WiLD links



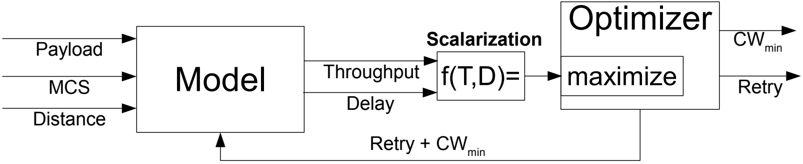
Throughput (fixed) and delay (dotted) for 802.11a
20 MHz, 1450 Bytes, IP/UDP bi-directional saturation

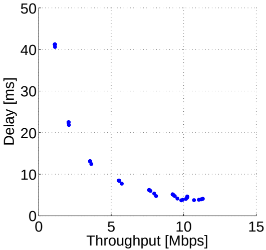
Estimation: 802.11n WiLD links

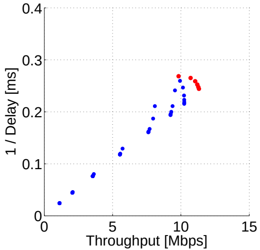


Throughput (fixed) and delay (dotted) for 802.11n
20 MHz, 1450 Bytes, MIMO, MCS 15, IP/UDP bi-directional saturation
A-MPDU=2^{13+agg} Bytes

Optimization - A ~~multi~~ single-objective problem







$\forall\ CW_{min}$ *and* R

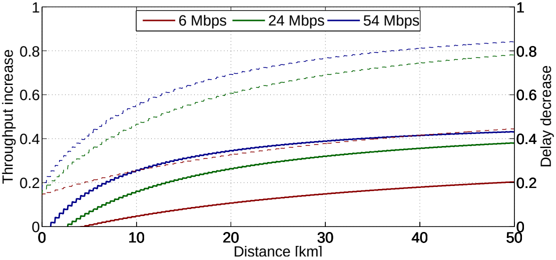
maximize

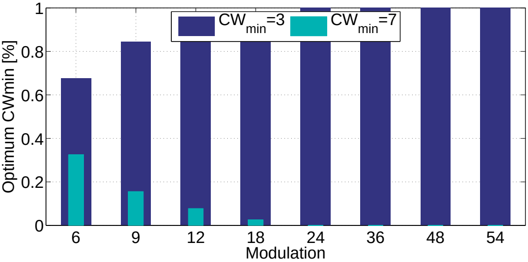
$$\left(\sqrt{\left(\frac{F}{\frac{D_i}{D_{max}}}\right)^2 + \left(\frac{S_i}{S_{max}}\right)^2}\right)$$

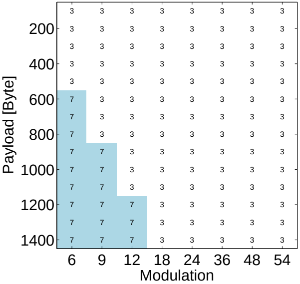
Optimization - 802.11a

Parameter:

- Distances (1-50 km)
- Payload (50-1450 Byte)
- Modulations (all)







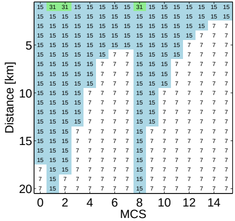
Optimization - 802.11n

Parameter:

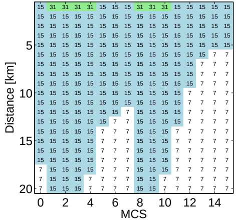
- Bandwidth (20/40 MHz)
- A-MPDU factor
- Payload (50-1450 Byte)
- MCS (0-15)
- Distance (1-20 km)

- Higher variation of optimum
- $CW_{min} = 15$ is the default

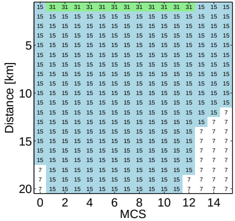
$\Rightarrow$ Less throughput gain



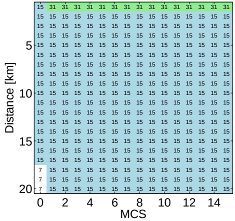
(a) 8 KBytes



(b) 16 KBytes



(c) 32 KBytes



(d) 64 KBytes

Conclusion and Contribution

- A unified model for 802.11a/802.11n long-distance point-to-point links
- Extension to the well-known DCF model by Bianchi
- Extensive verification on real hardware

∃ An optimum value for CW_{min} and R

- The range of this optimum values is less than expected beforehand
- A QoS gain especially for 802.11a

- Designer of WiLD can use this model to estimate and optimize the links beforehand, thus enabling a more accurate network planning.

Future work

- Include loss in optimization function (important for TCP)
- Shift up- and downlink capacities using MAC parameter
- Machine Learning of the current traffic situation
- Evaluate a new MAC layer for WiLD links
  - Frequency Division Multiplexing (FDD)
  - Token based approach

- TVWS integration using off-the-shelf WiFi cards
- Access technologies for WiLDs

Q&A

Thank your for your attention.

Are there any questions?

References I

[1] Bianchi, G.
Performance analysis of the IEEE 802.11 distributed coordination function.
IEEE Journal on Selected Areas in Communications 18, 3 (1998), 535–547.

[2] Bianchi, G., and Tinnirello, I.
Remarks on IEEE 802.11 dcf performance analysis.
Communications Letters, IEEE 9, 8 (2005), 765–767.

[3] Bing, B.
Emerging Technologies in Wireless LANs - Theory, Design, and Deployment, 1. ed.
Cambridge University Press, Cambridge, 2008.

[4] Cali, F., Conti, M., and Gregori, E.
IEEE 802.11 wireless lan: capacity analysis and protocol enhancement.
In Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies (1998), pp. 142–149.

[5] Foh, C. H., and Tantra, J.
Comments on ieee 802.11 saturation throughput analysis with freezing of backoff counters.
Communications Letters, IEEE 9, 2 (2005), 130–132.

[6] Ieee standard for information technology - telecommunications and information exchange between systems - local and metropolitan area networks - specific requirements - part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications.
IEEE Std 802.11-2007 (Revision of IEEE Std 802.11-1999) (Dec 2007), 1–1076.

References II

[7] Ieee standard for information technology-telecommunications and information exchange between systems local and metropolitan area networks-specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications.
IEEE Std 802.11-2012 (Revision of IEEE Std 802.11-2007) (Feb 2012), 1–2793.

[8] Rademacher, M., Kretschmer, M., and Jonas, K.
Exploiting ieee802.11n mimo technology for cost-effective broadband back-hauling.
In Fifth International IEEE EAI Conference on e-Infrastructure and eServices for Developing Countries (Oct 2013).

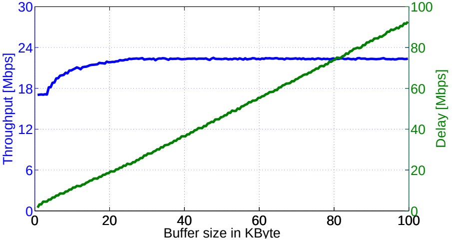
[9] S Salmerón-Ntutumu, J Simó-Reigadas, R. P.
Comparison of mac protocols for 802.11-based long distance networks.
In Proceedings of the 1st Workshop Wireless For Development (Aug 2008).

[10] Simo-Reigadas, J., Martinez-Fernandez, A., Ramos-Lopez, J., and Seoane-Pascual, J.
Modeling and optimizing ieee 802.11 dcf for long-distance links.
IEEE Transactions on Mobile Computing 9, 6 (2010), 881–896.

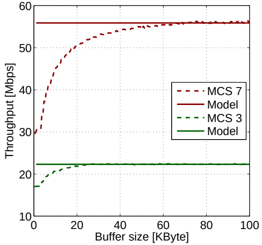
[11] Ziouva, E., Antonakopoulos, T., Ziouva, E., and Antonakopoulos, T.
Reprint csma/ca performance under high traffic conditions: Throughput and delay analysis, Feb 2002.

Backup

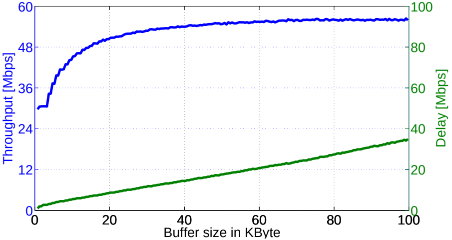
Validation - Influence of different buffer-sizes 802.11n



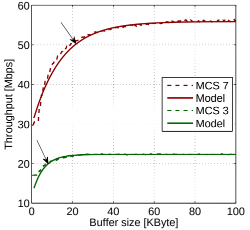
(a) MCS 3



(b) Without buffer modeling

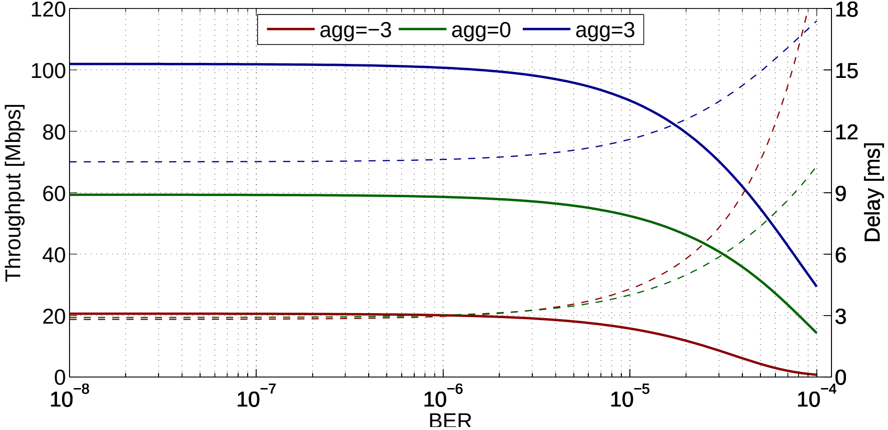


(c) MCS 7



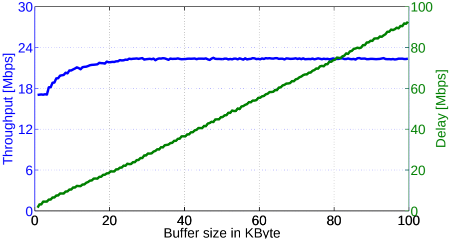
(d) With buffer modeling

Estimation: Influence of the BER for 802.11n WiLD links

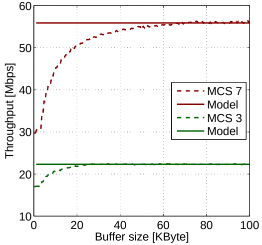


Throughput (fixed) and delay (dotted) for 802.11a
20 MHz, 1450 Bytes, 5 km, MIMO, MCS 15

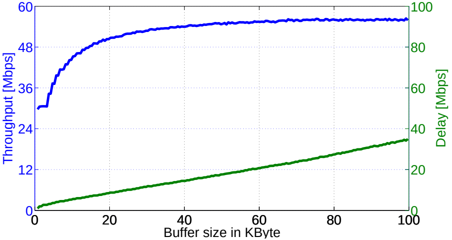
Validation - Influence of different buffer-sizes 802.11n



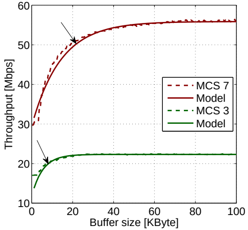
(a) MCS 3



(b) Without buffer modeling

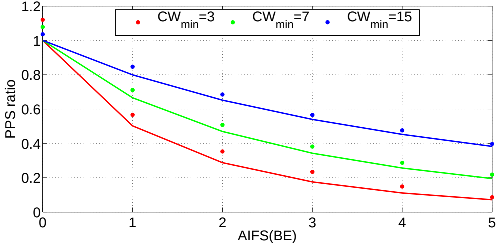


(c) MCS 7



(d) With buffer modeling

Traffic Class seperation

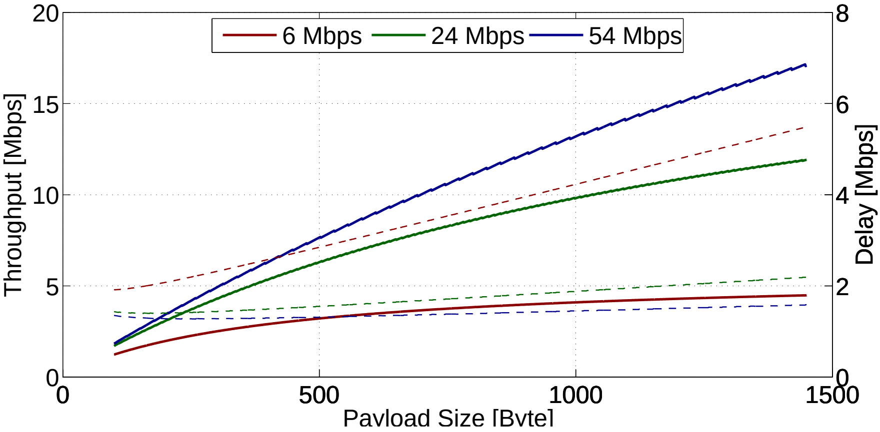


$$\frac{PPS_j}{PPS_k} \approx \frac{0.5(1-\tau)^{2\delta_j}}{1-0.5(1-\tau)^{2\delta_j}}$$

Two different techniques can be applied to protect traffic classes:

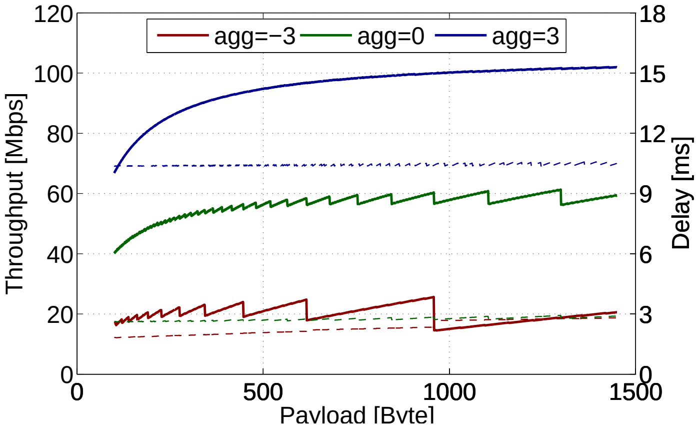
- CW_{min} differentiation
- **AIFS differentiation**
  - Even small values for AIFS => high traffic class separation
  - Amount of separation depend on CW_{min} as well

Influence of the payload size 802.11a and 802.11n



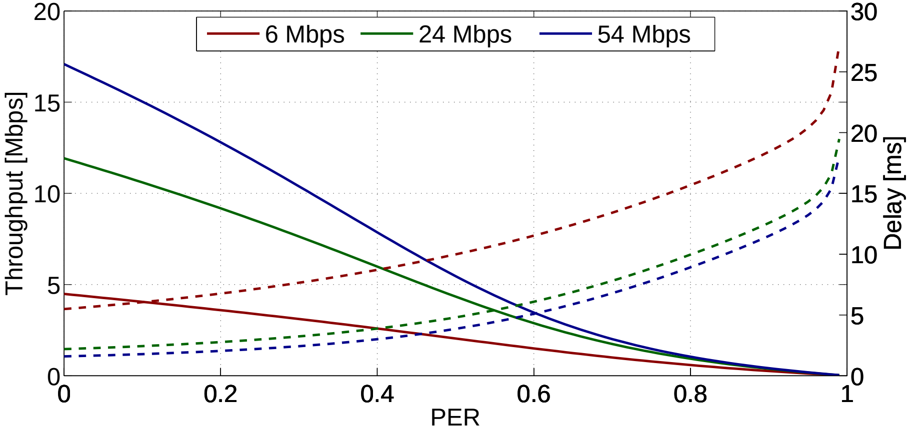
Influence of the Payload for 802.11a

Influence of the payload size 802.11a and 802.11n



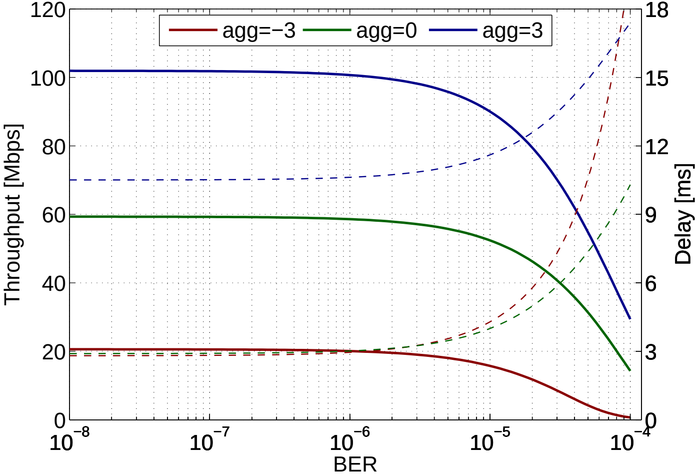
Influence of the Payload for 802.11n A-MPDU aggregation 20MHz MCS 15

Influence of the errounous links 802.11a and 802.11n



Influence of the PER for 802.11a

Influence of the errounous links 802.11a and 802.11n



Influence of the BER for 802.11n A-MPDU aggregation 20MHz MCS 15