Saturation Throughput Analysis of the IEEE 802.11g (ERP-OFDM) Networks

Krzysztof Szczypiorski, Józef Lubacz
Warsaw University of Technology, Poland

Agenda

- Overview of existing performance models
- Assumptions
- States of the physical channel
- Saturation throughput calculations
- Model validation
- Analysis of 802.11g 54 Mbps (ERP-OFDM)
- Conclusions

Overview of existing performance models

(Markov based, saturated conditons)

Authors:

- G. Bianchi (1, 3)
- H. Wu et al. (1, 4)
- E. Ziouva and T. Antonakopoulos (1, 3, 5)
- M. Ergen and P. Varaiya (1, 3, 5)
- P. Chatzimisios et al. (2b, 4)
- Q. Ni et al. (2a, 4)

Proposed model: (2a, 4, 5)

Characteristics:

1. Error-free channel (RTS/CTS and basic method)
2. Error-prone channel (basic method only)
   - 2a. Errors in ACK
   - 2b. No Errors in ACK
3. Infinite number of retransmissions
4. Limit on the number of retransmissions
5. Freezing backoff timer

Assumptions

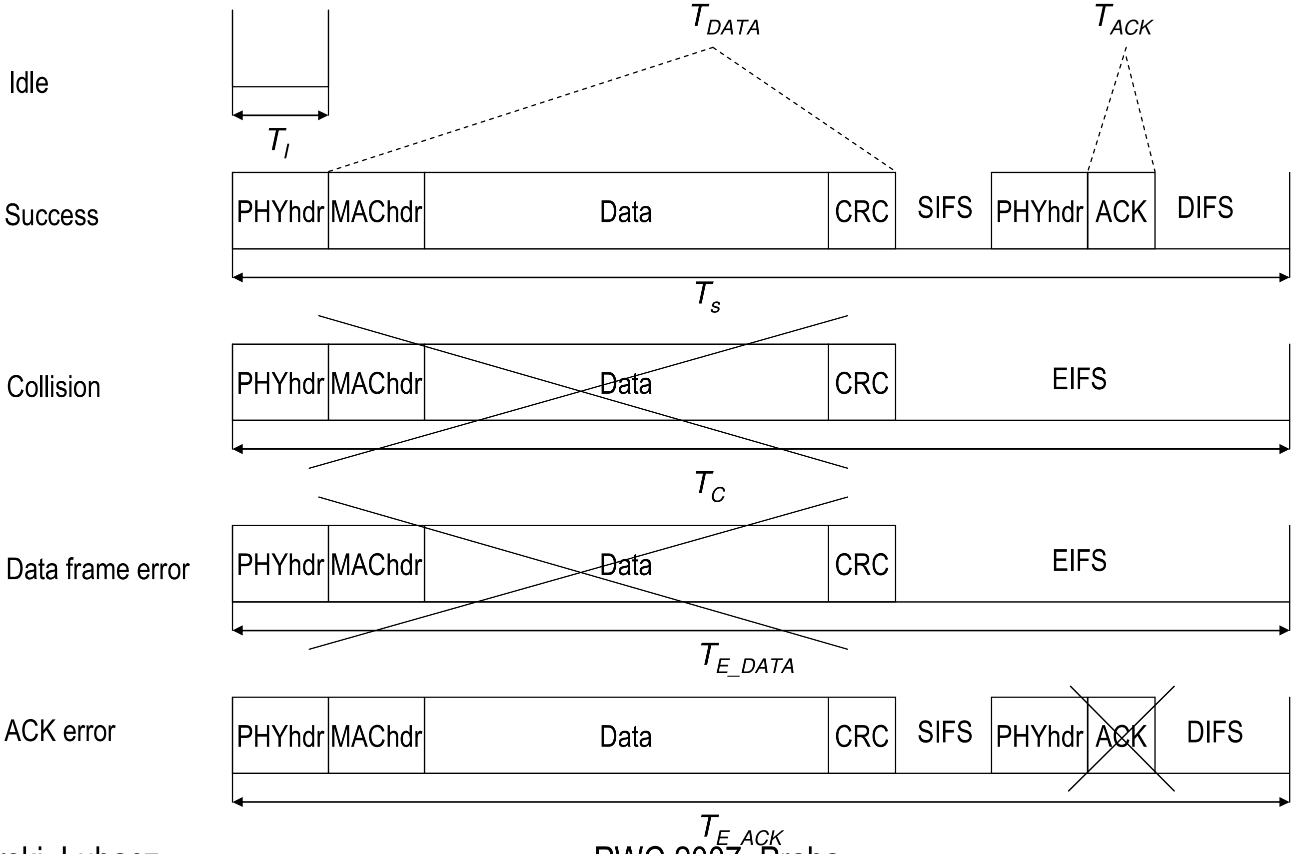
1. Saturated conditions are considered; stations have no empty queues – there is always a frame to be sent.
2. n stations compete for medium access (for n=1 only one station sends frames to other station which can only reply with ACK).
3. Errors in the transmission medium are randomly distributed; this is the worst case for the frame error rate – FER. All stations have the same bit error rate (BER).
4. All stations are in transmission range and there are no hidden terminals.
5. Stations communicate in ad hoc mode (BSS – Basic Service Set) with basic access method.
6. All stations use the same physical layer (PHY).
7. The transmission data rate R is the same and constant for all stations.
8. All frames are of constant length L.
9. Only data frames and ACK frames are exchanged.
10. Collided frames are discarded – the capture effect is not considered.

Saturation throughput and states of the physical channel

The saturation throughput: $S = \frac{E[DATA]}{E[T]}$

E[*DATA*] is the mean value of the successfully transmitted payload

E[*T*] is the mean value of the duration of the following *channel states*:



States of the physical channel (cont.)

$$\begin{cases} T_I = \sigma \\ T_S = 2T_{PHYhdr} + T_{DATA} + 2\delta + T_{SIFS} + T_{ACK} + T_{DIFS} \\ T_C = T_{PHYhdr} + T_{DATA} + \delta + T_{EIFS} \\ T_{E\_DATA} = T_{PHYhdr} + \delta + T_{DATA} + T_{EIFS} \\ T_{E\_ACK} = T_S \end{cases}$$

$$\begin{cases} P_I = (1-\tau)^n \\ P_S = n\tau(1-\tau)^{n-1}(1-p_{e\_data})(1-p_{e\_ACK}) \\ P_C = 1-(1-\tau)^n - n\tau(1-\tau)^{n-1} \\ P_{E\_DATA} = n\tau(1-\tau)^{n-1} p_{e\_data} \\ P_{E\_ACK} = n\tau(1-\tau)^{n-1}(1-p_{e\_data}) p_{e\_ACK} \end{cases}$$

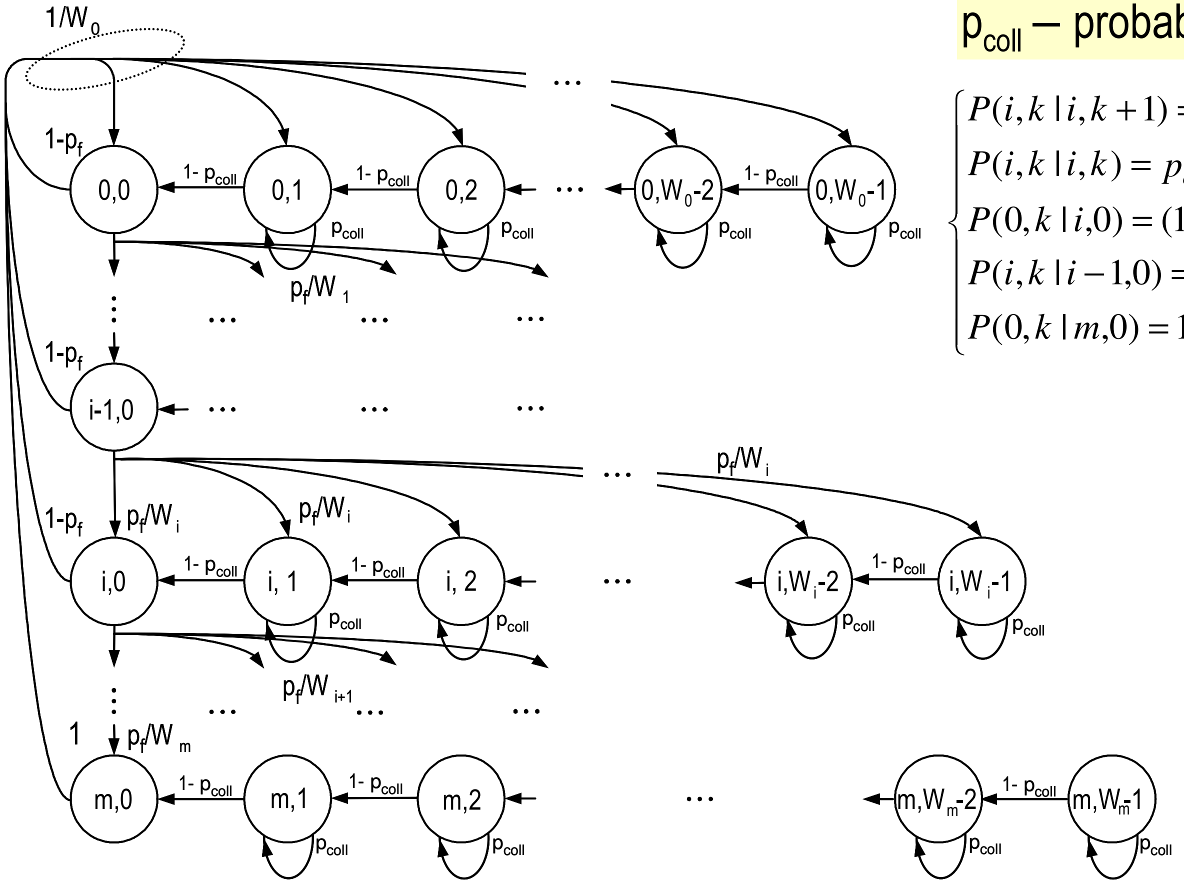
$$T_{ACK} = T_{symbol} \left\lceil \frac{L_{SER} + L_{TAIL} + L_{ACK}}{N_{BpS}} \right\rceil$$

$$T_{DATA} = T_{symbol} \left\lceil \frac{L_{SER} + L_{TAIL} + L_{DATA}}{N_{BpS}} \right\rceil$$

$$S = \frac{P_S L_{pld}}{T_I P_I + T_S P_S + T_C P_C + T_{E\_DATA} P_{E\_DATA} + T_{E\_ACK} P_{E\_ACK}}$$

T_{PHYhdr} – duration of a PLCP preamble and a PLCP header
T_{DATA} – duration to transmit a data frame
T_{ACK} – duration to transmit an ACK frame
T_{SIFS} – duration of SIFS
T_{DIFS} – duration of DIFS
T_{EIFS} – duration of EIFS
T_{symbol} – duration of a transmission symbol
L_{SER} – OFDM PHY layer SERVICE field size
L_{TAIL} – OFDM PHY layer TAIL fields size
N_{BpS} – number of encoded bits per one symbol
L_{ACK} – size of an ACK frame
L_{DATA} – size of a data frame
τ – probability of frame transmission
p_{e_data} – the probability of data frame error
p_{e_ACK} – the probability of ACK error

Markov chain



p_f – probability of transmission failure
p_{coll} – probability of collision

$$\begin{cases} P(i,k\mid i,k+1)=1-p_{coll}, & 0\le i\le m,\ 0\le k\le W_i-2 \\ P(i,k\mid i,k)=p_{coll}, & 0\le i\le m,\ 1\le k\le W_i-1 \\ P(0,k\mid i,0)=(1-p_f)/W_0, & 0\le i\le m-1,\ 0\le k\le W_0-1 \\ P(i,k\mid i-1,0)=p_f/W_i, & 1\le i\le m,\ 0\le k\le W_i-1 \\ P(0,k\mid m,0)=1/W_0, & 0\le k\le W_0-1 \end{cases}$$

$$W_i=\begin{cases} 2^i W_0, & i\le m' \\ 2^{m'}W_0=W_m, & i>m' \end{cases}$$

$$W_0=CW_{\min}+1$$

$$W_{m'}=CW_{\max}+1=2^{m'}W_0$$

Probability of frame transmission τ

$$b_{i,0} = p_f \cdot b_{i-1,0}, \quad b_{i,0} = p_f{}^{i} \cdot b_{0,0}$$

$$b_{i,k} = \begin{cases} \dfrac{W_i - k}{W_i(1-p_{coll})} p_f{}^{i} \cdot b_{0,0}, & 0 < k \le W_i - 1 \\ p_f{}^{i} \cdot b_{0,0}, & k = 0 \end{cases}$$

$$\sum_{i=0}^{m} \sum_{k=0}^{W_i - 1} b_{i,k} = 1, \quad \sum_{i=0}^{m} b_{i,0} = b_{0,0} \frac{1-p_f{}^{m+1}}{1-p_f}$$

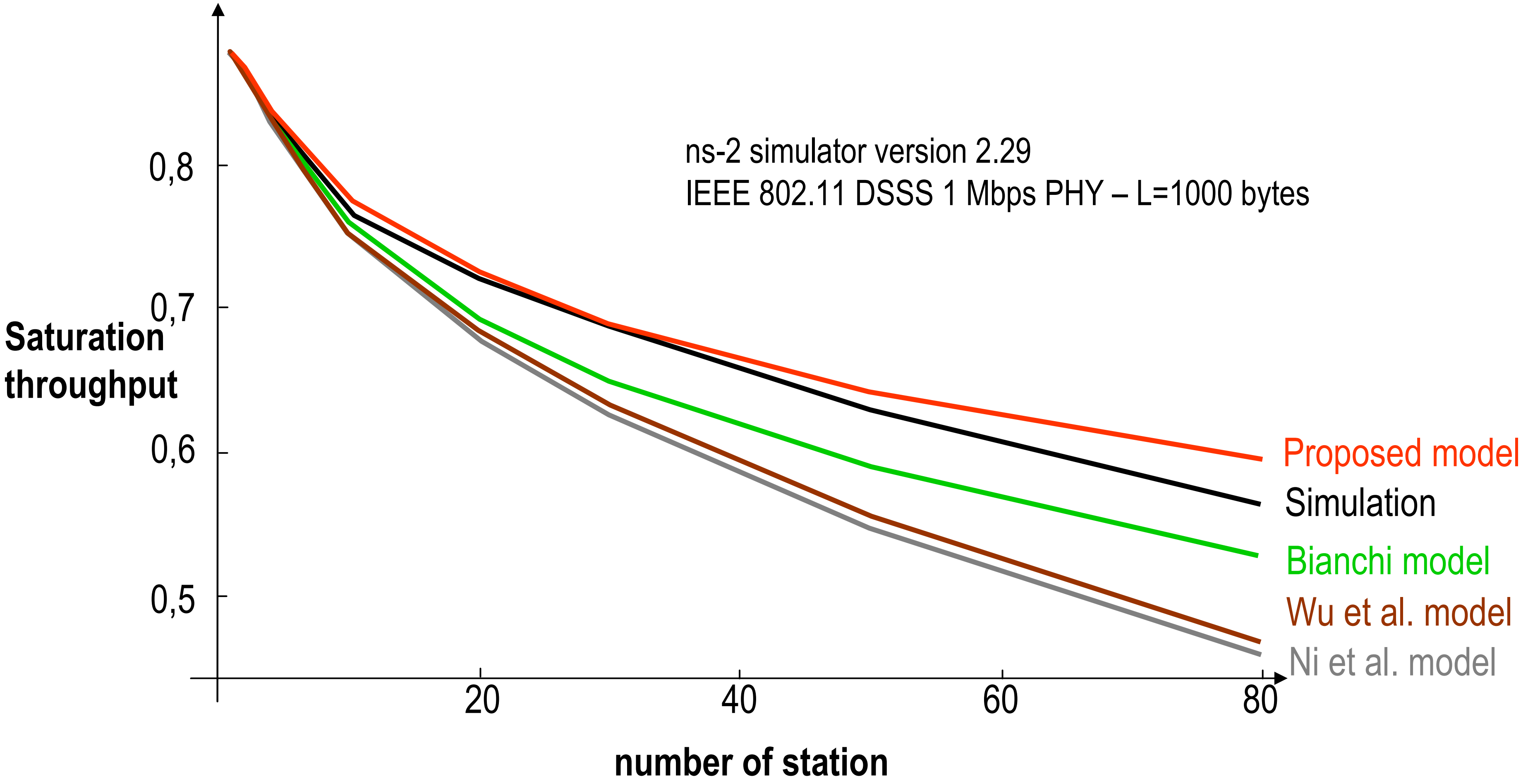
$$\tau = \sum_{i=0}^{m} b_{i,0} = \begin{cases} \left(\dfrac{(1-p_f)W_0(1-(2p_f)^{m+1}) - (1-2p_f)(1-p_f{}^{m+1})}{2(1-2p_f)(1-p_f)(1-p_{coll})} + \dfrac{1-p_f{}^{m+1}}{1-p_f} \right)^{-1} \dfrac{1-p_f{}^{m+1}}{1-p_f}, & m \le m' \\ \left(\dfrac{\Psi}{2(1-2p_f)(1-p_f)(1-p_{coll})} + \dfrac{1-p_f{}^{m+1}}{1-p_f} \right)^{-1} \dfrac{1-p_f{}^{m+1}}{1-p_f}, & m > m' \end{cases}$$

$$\Psi = (1-p_f)W_0(1-(2p_f)^{m'+1}) - (1-2p_f)(1-p_f{}^{m+1}) + W_0 2^{m'} p_f^{m'+1}(1-2p_f)(1-p_f{}^{m-m'})$$

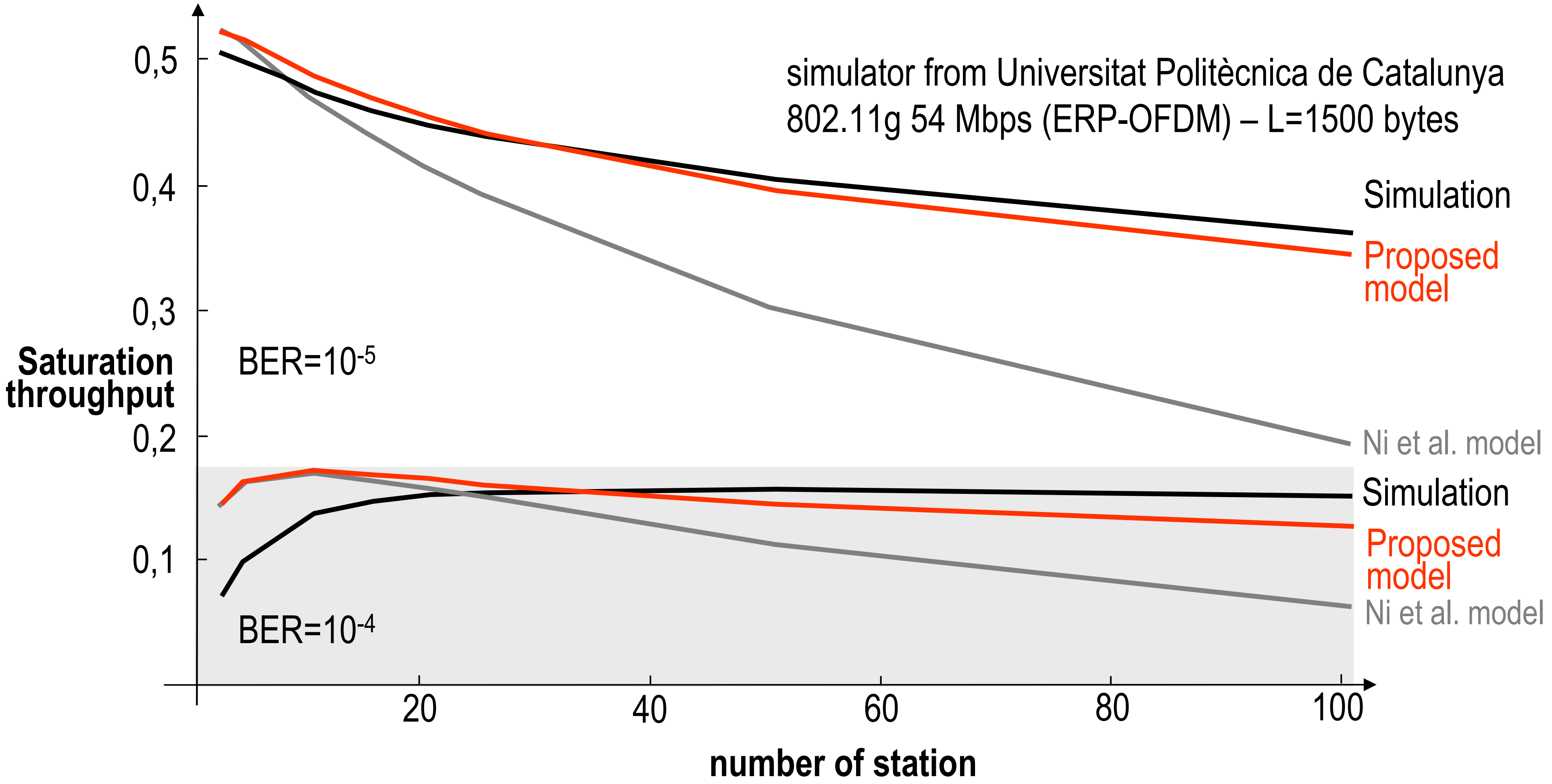
$$p_e = 1-(1-p_{e\_data})(1-p_{e\_ACK}), \quad p_{coll} = 1-(1-\tau)^{n-1}$$

$$p_f = 1-(1-p_{coll})(1-p_e) = 1-(1-\tau)^{n-1}(1-p_e)$$

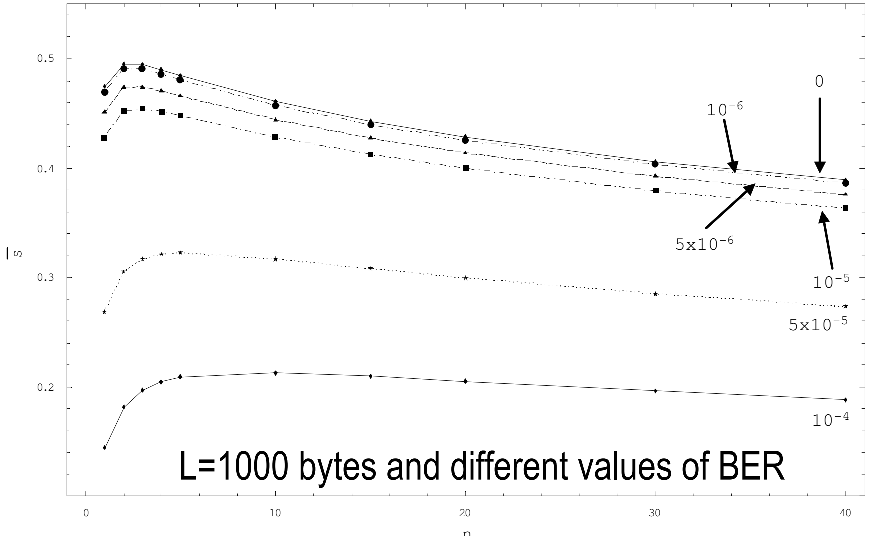
Validation – error-free channel

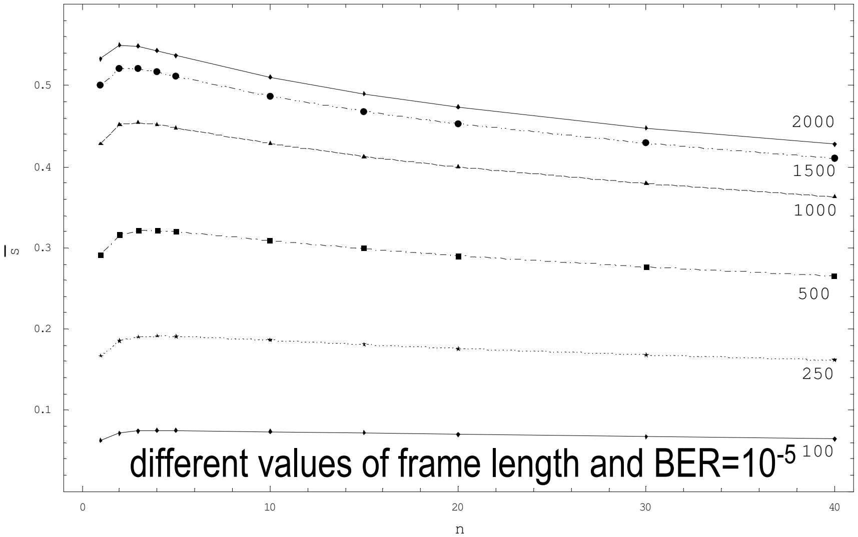


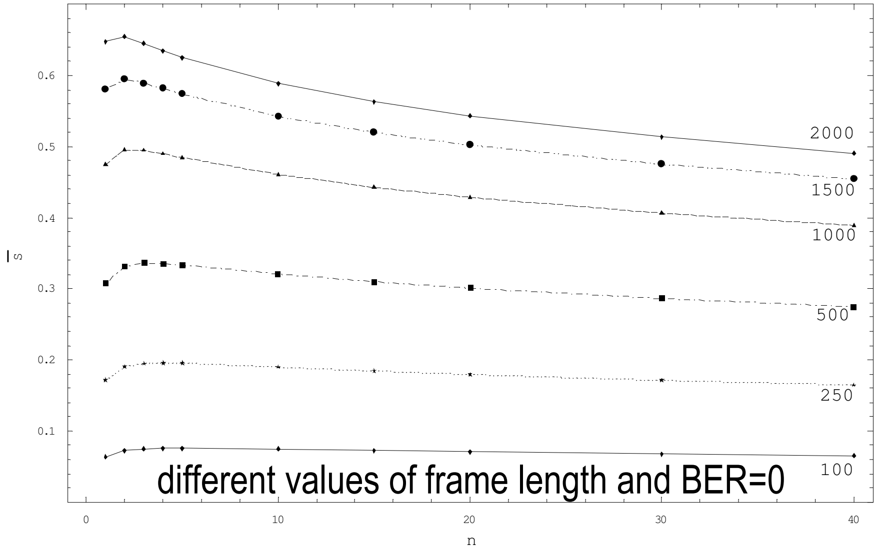
Validation – error-prone channel

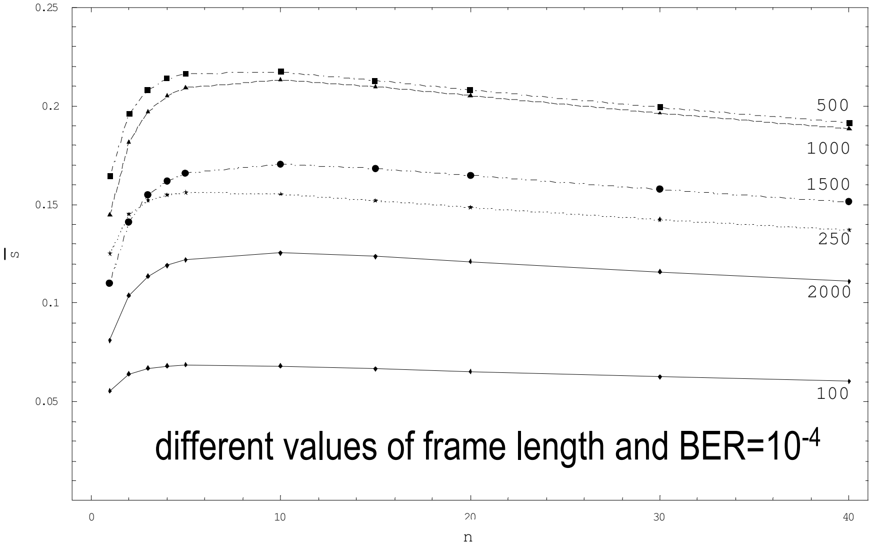


Analysis of 802.11g 54 Mbps (ERP-OFDM)


L=1000 bytes and different values of BER


different values of frame length and BER=10^{-5}


different values of frame length and BER=0


different values of frame length and BER=10^{-4}

Conclusions

- the proposed model has good accuracy both in the case of error-free and error-prone channels
- for error-free conditions the model yields some overestimation while other models known from literature tend to underestimate the saturation throughput
- for both error-free and error-prone cases the proposed model shows better accuracy than the literature models with which it was compared, especially for large number of stations
- future work could be focused on taking into account such features of the IEEE 802.11 protocol as the RTS/CTS and EDCA (Enhanced Distributed Channel Access)

Thanks!

Saturation Throughput Analysis of the IEEE 802.11g (ERP-OFDM) Networks

Krzysztof Szczypiorski, Józef Lubacz
Warsaw University of Technology, Poland

[1] Bianchi, G., Tinnirello, I.: Remarks on IEEE 802.11 DCF Performance Analysis. IEEE Communications Letters, Vol. 9 (2005) 765-767

[2] Bianchi, G.: Performance Analysis of the IEEE 802.11 Distributed Coordination Function. IEEE Journal on Selected Areas in Communications, Vol. 18, No. 3 (2000) 535-547

[3] Cali, F., Conti, M., Gregori, E.: Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Theoretical Throughput Limit. IEEE/ACM Trans. Networking, Vol. 8, No. 6 (2000) 785-799

[4] Chatzimisios, P., Boucouvalas, A., Vitsas, V.: Influence of Channel BER on IEEE 802.11 DCF. IEE Electronics Letters, Vol. 39, No. 23 (2003)

[5] Ergen, M., Varaiya, P.: Throughput Analysis and Admission Control in IEEE 802.11a. Springer Mobile Networks and Applications, Vol. 10, No. 5 (2005) 705-706

[6] Heusse, M., Rousseau, F., Guillier, R., Duda, A.: Idle Sense: An Optimal Access Method for High Throughput and Fairness in Rate Diverse Wireless LANs. In: SIGCOMM'05 Conference on Applications, Technologies, Architectures and Protocols for Computer Communications, Philadelphia (2005) 121-132

[7] IEEE 802.11, 1999 Edition (ISO/IEC 8802-11: 1999) IEEE Standards for Information Technology – Telecommunications and Information Exchange between Systems – Local and Metropolitan Area Network – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (1999)

[8] IEEE 802.11a-1999 (8802-11:1999/Amd 1:2000(E)), 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 – Amendment 1: High-speed Physical Layer in the 5 GHz band (1999)

[9] IEEE 802.11b-1999 Supplement to 802.11-1999, Wireless LAN MAC and PHY specifications: Higher speed Physical Layer (PHY) extension in the 2.4 GHz band (1999)

[10] IEEE 802.11e-2005, 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: Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements (2005)

[11] IEEE 802.11g-2003 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 – Amendment 4: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band (2003)

[12] Kochut, A., Vasan, A., Shankar, A., Agrawala, A.: Sniffing Out the Correct Physical Layer Capture Model in 802.11b. In: 12th IEEE International Conference on Network Protocols (ICNP 2004), Berlin (2004)

[13] Lopez-Aguilera, E., Heusse, M., Rousseau, F., Duda, A., Casademont, J.: Evaluating Wireless LAN Access Methods in Presence of Transmission Errors. In: IEEE INFOCOM. Barcelona (2006)

[14] Ni, Q., Li, T., Turletti, T., Xiao, Y.: Saturation Throughput Analysis of Error-Prone 802.11 Wireless Networks. Wiley Journal of Wireless Communications and Mobile Computing (JWCMC), Vol. 5, Issue 8 (2005) 945-956

[15] Private communication with Prof. Andrzej Duda

[16] Tay, Y., Chua, K.: A Capacity Analysis for the IEEE 802.11 MAC Protocol. Wireless Networks, Vol. 7, No. 2 (2001) 159-171

[17] The Network Simulator – *ns-2*. URL: http://nsnam.isi.edu/nsnam/index.php/Main_Page

[18] Wu, H., Peng, Y., Long, K., Cheng, S., Ma, J.: Performance of Reliable Transport Protocol over IEEE 802.11 Wireless LAN: Analysis and Enhancement. In: IEEE INFOCOM`02 (2002)

[19] Ziouva, E., Antonakopoulos, T.: CSMA/CA Performance under High Traffic Conditions: Throughput and Delay Analysis. Computer Communications, Vol. 25 (2002) 313-321