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

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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 conditions)

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.)

\[
\begin{aligned}
T_I &= \sigma \\
T_S &= 2T_{PHYhdr} + T_{DATA} + 2\delta + T_{SIFS} + T_{ACK} + T_{DIFS} \\
T_C &= T_{PHYhdr} + T_{DATA} + \delta + T_{EIFS} \\
T_{E_DATA} &= T_{PHYhdr} + \delta + T_{DATA} + T_{EIFS} \\
T_{E_ACK} &= T_S \\
\end{aligned}
\]

\[
\begin{aligned}
P_I &= (1 - \tau)^n \\
P_S &= n\tau(1 - \tau)^{n-1}(1 - p_{e_{data}})(1 - p_{e_{ACK}}) \\
P_C &= 1 - (1 - \tau)^n - n\tau(1 - \tau)^{n-1} \\
P_{E_DATA} &= n\tau(1 - \tau)^{n-1}p_{e_{data}} \\
P_{E_ACK} &= n\tau(1 - \tau)^{n-1}(1 - p_{e_{data}})p_{e_{ACK}} \\
\end{aligned}
\]

- $T_{PHYhdr}$ – 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
- $\tau$ – probability of frame transmission
- $p_{e_{data}}$ – the probability of data frame error
- $p_{e_{ACK}}$ – the probability of ACK error

\[
S = \frac{P_S L_{p_{ld}}}{T_I P_I + T_S P_S + T_C P_C + T_{E_DATA} P_{E_DATA} + T_{E_ACK} P_{E_ACK}}
\]
Markov chain

\( p_f \) – probability of transmission failure

\( p_{\text{coll}} \) – probability of collision

\[
P(i, k | i, k + 1) = 1 - p_{\text{coll}}, \quad 0 \leq i \leq m, 0 \leq k \leq W_i - 2
\]

\[
P(i, k | i, k) = p_{\text{coll}}, \quad 0 \leq i \leq m, 1 \leq k \leq W_i - 1
\]

\[
P(0, k | i, 0) = (1 - p_f)/W_0, \quad 0 \leq i \leq m - 1, 0 \leq k \leq W_0 - 1
\]

\[
P(i, k | i - 1, 0) = p_f/W_i, \quad 1 \leq i \leq m, 0 \leq k \leq W_i - 1
\]

\[
P(0, k | m, 0) = 1/W_0, \quad 0 \leq k \leq W_0 - 1
\]

\[
W_i = \begin{cases} 
2^i W_0, & i \leq m' \\
2^{m'} W_0 = W_m, & i > m'
\end{cases}
\]

\[
W_0 = CW_{\text{min}} + 1
\]

\[
W_{m'} = CW_{\text{max}} + 1 = 2^{m'} W_0
\]

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Probability of frame transmission $\tau$

\[ b_{i,0} = p_f \cdot b_{i-1,0}, \quad b_{i,0} = p_f \cdot b_{0,0} \]

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

\[ b_{i,k} = \begin{cases} \frac{W_i-k}{W_i(1-p_{coll})} p_f^i \cdot b_{0,0}, & 0 < k \leq W_i - 1 \\ p_f^i \cdot b_{0,0}, & k = 0 \end{cases} \]

\[ \tau = \sum_{i=0}^{m} b_{i,0} = \begin{cases} \frac{(1-p_f)W_0(1-(2p_f)^{m+1})-(1-2p_f)(1-p_f^{m+1})}{2(1-2p_f)(1-p_f)(1-p_{coll})} + \frac{1-p_f^{m+1}}{1-p_f} \right)^{-1} \frac{1-p_f^{m+1}}{1-p_f}, & m \leq m' \\ \frac{\Psi}{2(1-2p_f)(1-p_f)(1-p_{coll})} + \frac{1-p_f^{m+1}}{1-p_f} \\ \frac{1-p_f^{m+1}}{1-p_f}, & m > m' \end{cases} \]

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

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

\[ p_f = 1 - (1-p_{coll})(1-p_e) = 1 - (1-\tau)^{n-1} (1-p_e) \]
Validation – error-free channel

ns-2 simulator version 2.29
IEEE 802.11 DSSS 1 Mbps PHY – L=1000 bytes

Saturation throughput

number of station

Proposed model
Simulation
Bianchi model
Wu et al. model
Ni et al. model

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Validation – error-prone channel

simulator from Universitat Politècnica de Catalunya
802.11g 54 Mbps (ERP-OFDM) – L=1500 bytes

Saturation throughput

BER=10^{-5}

BER=10^{-4}

number of station

Simulation
Proposed model
Ni et al. model

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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}

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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!
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[15] Private communication with Prof. Andrzej Duda


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