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IEEE 802.11 DCF with Capture over Rician-Fading Channel

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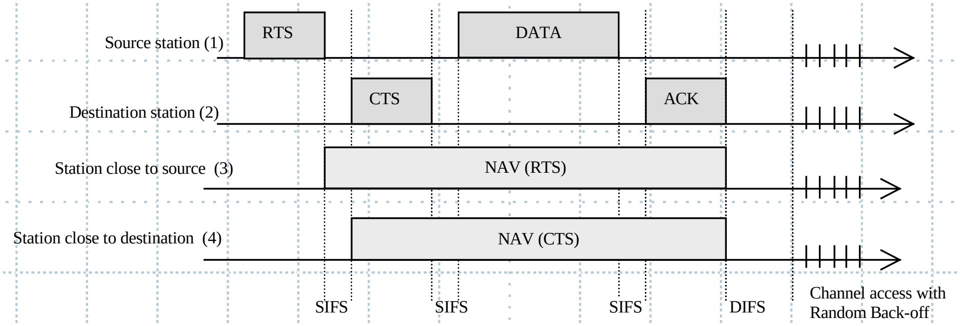
Outline

- IEEE 802.11B Distributed Coordination Function
- DCF Channel Utilization
- Capture Effect
- Capture Models of Indoor Rayleigh-fading Channel with Two Distinct Power Levels (CM1 and CM2)
- Models Verification by Simulation in Pure Rician-fading Channel
- Conclusions

IEEE 802.11B DCF

- DSSS multirate operation in the 2.4 GHz ISM band
  - 1 and 2 Mbps PSK over 11-chip Barker sequence
  - 5.5 and 11 Mbps CCK
  - Preamble and Header transmitted mandatory at Basic rate

- Asynchronous services via Distributed Coordination Function (DCF)
- RTS/CTS “handshake” access scheme



- Considerable influence of RTS/CTS “handshake” over capture (as shown forthwith)

DCF Saturation Capacity

- Saturation throughput $S_{\max}$ of IEEE 802.11 DCF in ideal channel conditions (according to Bianchi's paper) can be expressed as:

$$S_{\max} = \frac{P}{T_s - T_c + \dfrac{\sigma(1 - P_{tr})/P_{tr} + T_c}{P_{suc}}}$$

  - P average packet payload
  - σ duration of an empty slot time during contention
  - T_s average time channel is sensed busy because of a successful transmission (fixed value depending on weather Basic or RTS/CTS access is used)
  - T_c average time channel is sensed busy by each station during collision (fixed value depending on weather Basic or RTS/CTS access is used)
  - P_{tr} is the probability of at least one transmission in the observed time slot
  - P_{suc} is the probability of a successful transmission assuming at least one station is transmitting

DCF Saturation Capacity (cont'd)

- P_{suc} and P_{tr} can be expressed through probability τ of a station transmitting in a randomly chosen slot time:
  - $P_{tr} = 1 - (1 - \tau)^N$
  - $P_{\text{suc}} = N\tau(1 - \tau)^{N-1}/P_{\text{tr}}$
- Probability τ depends on:
  - Number of contending stations N
  - Initial contention window
  - Number of retries before a frame discard

Capture Effect in IEEE 802.11 PHY

- A receiver captures a frame if frame’s detected power P_s sufficiently exceeds the joint interfering power P_n of n interfering contenders
  - $P_s / P_n > z_0 \cdot g(S_f)$
  - for a duration a certain fragment t_{w} of the time slot t $(0 < t_{\mathrm{w}} < t)$
- z_0 is capture ratio
- $g(S_f)$ is S/I reduction factor due to processing gain in DSSS correlation receiver; S_f is the spreading factor
- We assume a receiver inspects posible capture during t_{w} of the preamble/header part of the frame, which is always transmitted at 1 Mbps using BPSK modulation of the Barker symbols
- Given rectangular-shaped chips, $\mathrm{g}(S_f) = 2/(3 \cdot S_f)$, where $S_{\mathrm{f}} = 11$ due to 11-chip Barker code

Capture Probability

- Conditional capture probability given *i* interfering frames, $Prob(\gamma > z_0 \cdot g(S_f) | i)$, is the probability of S/I ($\gamma = P_s/P_n$) exceeding value of $z_0 \cdot g(S_f)$
- Probability of frame capture P_{capure}

$$P_{capture} = \sum_{i=1}^{N-1} R_i \cdot \Pr ob(\gamma > z_o \cdot g(S_f) | i)$$

- R_{i} is probability of *i* interfering frames being generated in an observed time slot:

$$R_i = \binom{N}{i+1} \tau^{i+1} (1-\tau)^{N-i-1}$$

- $$P_{suc} = \frac{N\tau(1-\tau)^{N-1} + P_{capture}}{P_{tr}} = \frac{N\tau(1-\tau)^{N-1} + \sum_{i=1}^{N-1} R_i \cdot \Pr ob(\gamma > z_o \cdot g(S_f) | i)}{1-(1-\tau)^N}$$

Capture Model 1 (CM1)

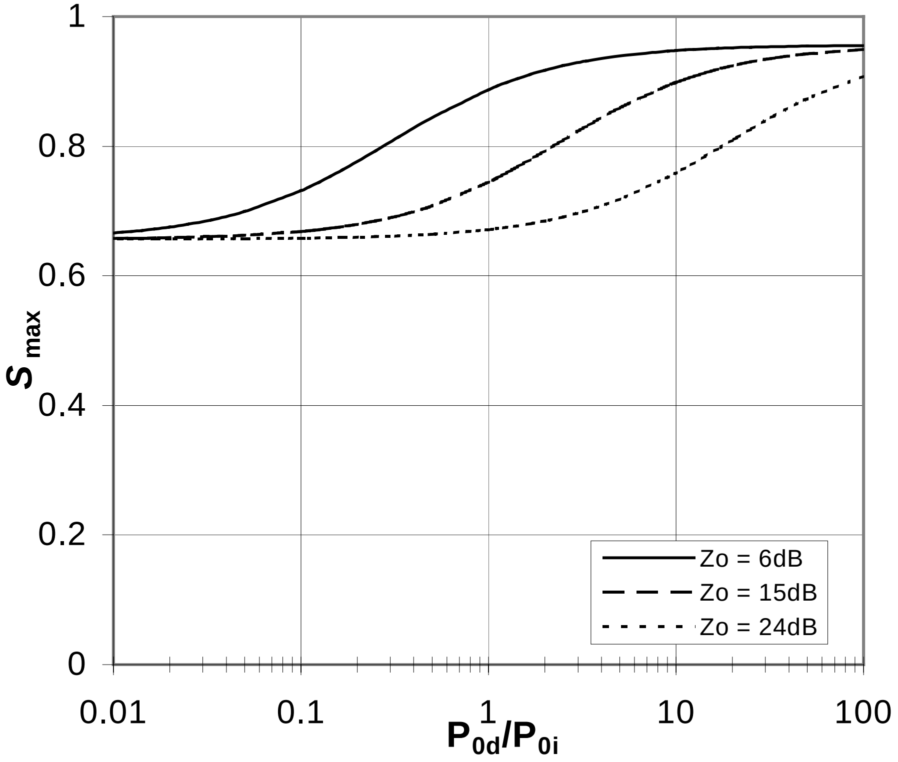
- Rayleigh-distributed envelopes of both useful and interfering frames
  - mean power p_{0d} of the useful signal at the receiver
  - mean power p_{0i} of n interfering frames at the receiver
- Conditional capture probability

$$\Pr ob(\gamma > z_o \cdot g(S_f) \mid n) = 1/[1 + g(S_f) \cdot z_o \cdot p_{0i} / p_{0d}]^n$$

- Attained closed-form solution of capture probability P_{capture} and saturation throughput $S_{\max}$ of the IEEE 802.11 DCF

Basic Access with CM1

- Theoretical max. capacity S_{max} as function of mean power ratio p_{0d}/p_{0i} given 10 stations
- Capture ratio z_0 appear as parameter



Capture Model 2 (CM2)

- Rayleigh-distributed envelopes of both useful and interfering frames
- Two distinct levels of frame's mean power at the receiver:
  - mean power *A* of *i* interfering frames (also the useful one)
  - mean power *B* of *j* interfering frames
  - conditional capture probability

$$\mathrm{Prob}(\gamma > z_0 \cdot g(S_f) \mid n) = \frac{1}{[1+z_0 \cdot g(S_f)]^i \cdot [1+(B/A)z_0 \cdot g(S_f)]^j}$$

- Given N_0 of interferers with power levels *A* and *B* are binomial distributed, with probabilities *p* and 1-*p*, respectively:

$$\overline{\Pr ob(\gamma > z_o \cdot g(S_f) \mid n)} = p\sum_{i=0}^{n}\binom{n}{i}p^i(1-p)^{n-i}\frac{1}{[1+z_o \cdot g(S_f)]^i}\,\frac{1}{(1+z_o \cdot g(S_f)\,B/A)^{n-i}}$$

$$+(1-p)\sum_{i=0}^{n}\binom{n}{i}p^i(1-p)^{n-i}\frac{1}{[1+z_o \cdot g(S_f)\,A/B]^i}\,\frac{1}{[1+z_o \cdot g(S_f)]^{n-i}}$$

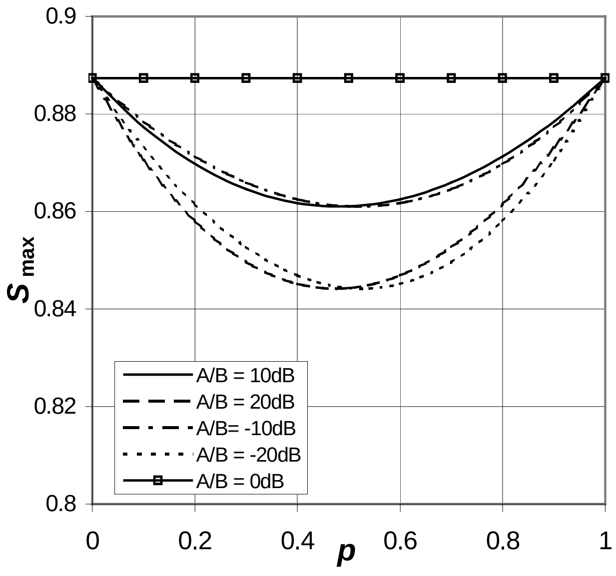
$$= p\left(\frac{p}{1+g(S_f)\cdot z_o}+\frac{1-p}{1+g(S_f)\cdot z_o\,B/A}\right)^n+(1-p)\left(\frac{p}{1+A/B\,z_o \cdot g(S_f)}+\frac{1-p}{1+g(S_f)\cdot z_o}\right)^n$$

- Attained closed-form solution of capture probability P_{capture} and saturation throughput of $S_{\max}$ of the IEEE 802.11 DCF

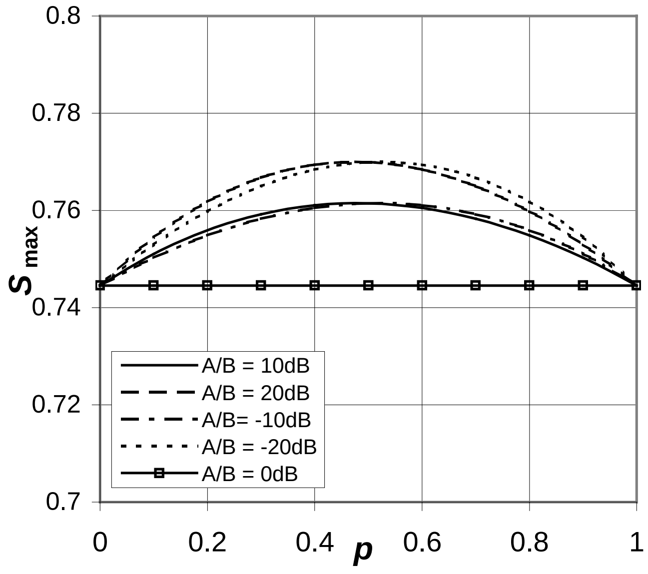
Basic Access with CM2

- Theoretical max. capacity $S_{\max}$ as function of probability p, given 10 stations
- Mean power ratio A/B appear as parameter
- Equal local mean power of all contending frames at receiver, i.e. $A/B = 1$

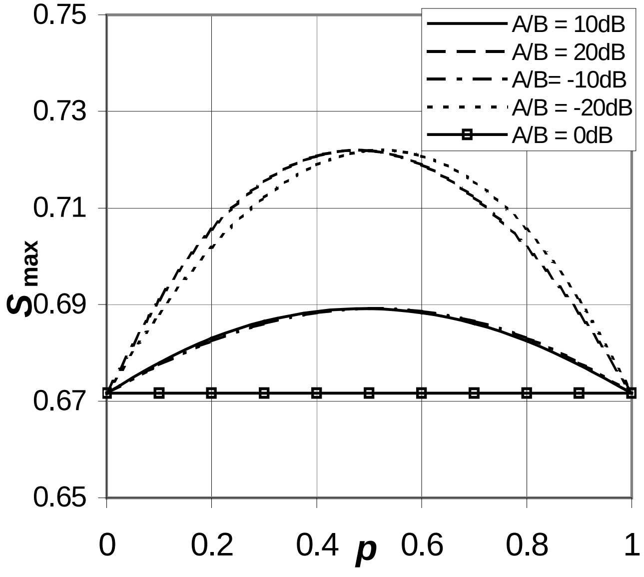
(a) $z_0 = 6\text{dB}$



(b) $z_0 = 15\text{dB}$



(c) $z_0 = 24\text{dB}$



CM1 and CM2

- If Basic access scheme is employed:
  - Capture effect generates significant throughput increase
- If RTS/CTS “handshake” access scheme is employed:
  - Minor throughput increase of a few percent for both models
- Two power level models are more suitable to study capture effects as compared to the single power level model of a Rayleigh-faded channel

IEEE 802.11 System Setup

- 10 stations within a single ad-hoc Basic Service Area
- Rician-faded envelope of all signals
- Rician factor *K* in range between 3 and 12.5 (i.e. 6.8 dB and 11 dB)
- Neglected propagation delay
- Results referring to signaling rate of 1 Mbps, $g(S_f) = 2/(3 \cdot S_f)$, and $S_f = 11$
- For rates of 2, 5.5, and 11 Mbps, corresponding system parameters must be used according to IEEE 802.11B specification

- System model parameters for both analysis and simulation

Parameter	**Default value**
Channel Rate	1 Mbit/s
PHY Preamble	144 symbols
PHY Header	48 symbols
MAC header	34 octets
ACK	14 octets
RTS	20 octets
CTS	14 octets
SIFS	20 μs
DIFS	50 μs
Slot_Time σ	20 μs
RTS_Threshold	200 octets
Retry_Limit	5
Transmit power	50 mW

Analysis vs. Simulation:Measures of Comparison

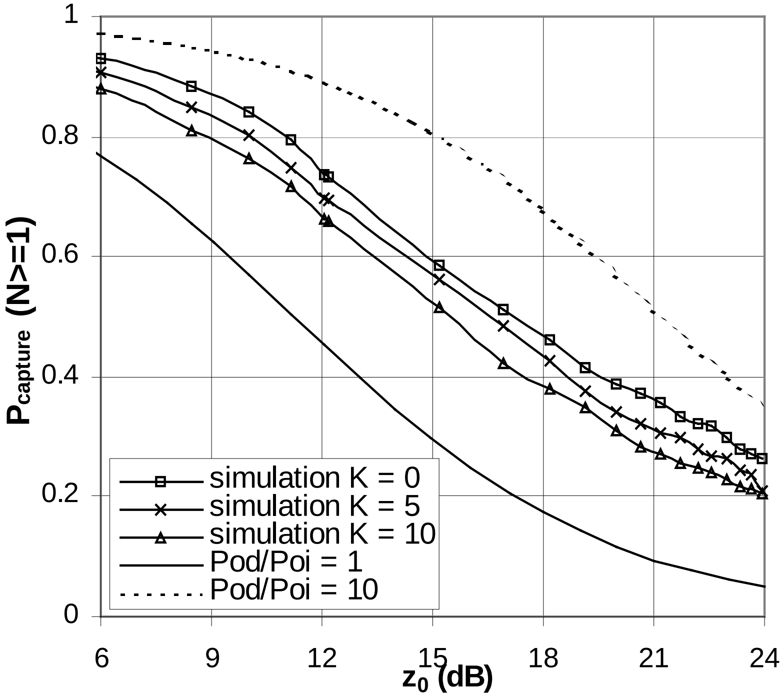
- Probability of frame capture $P_{capure}(N \geq 1)$, assuming at least one interferer $(N \geq 1)$

$$P_{capture}(N \geq 1) = \frac{\sum_{i=1}^{N-1} R_i \cdot \Pr ob(\gamma > z_o \cdot g(S_f)\,|\,i)}{1-(1-\tau)^N - N\tau(1-\tau)^{N-1}}$$

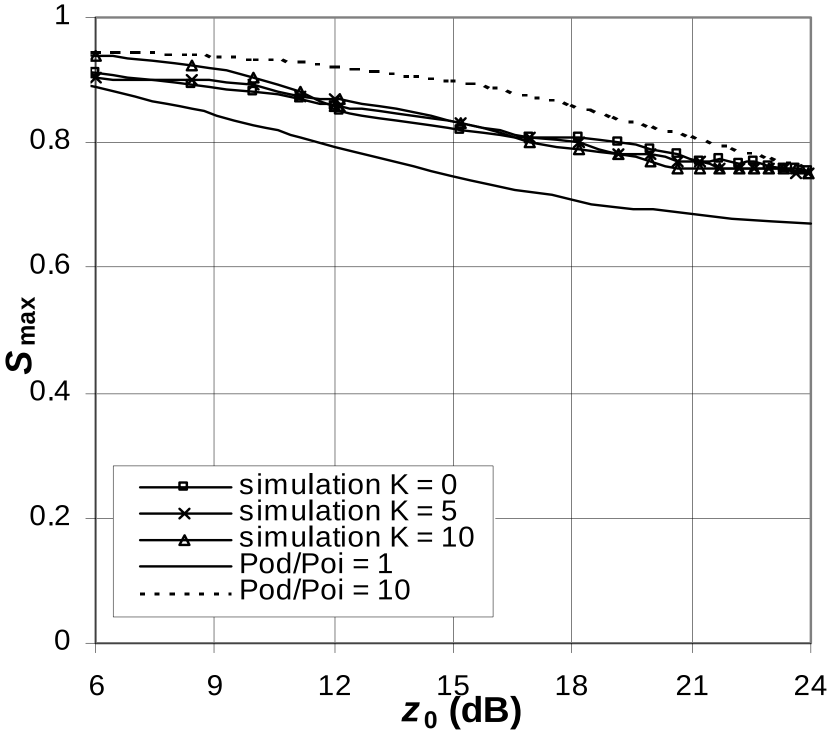
- Channel utilization $S_{\max}$
- Comparison of probability of frame capture $P_{capure}(N \geq 1)$ and channel utilization $S_{\max}$ obtained analytically and via simulation

Simulated Rician-faded channel and CM1

- ❑ $P_{capure}(N \geq 1)$ vs. z_0



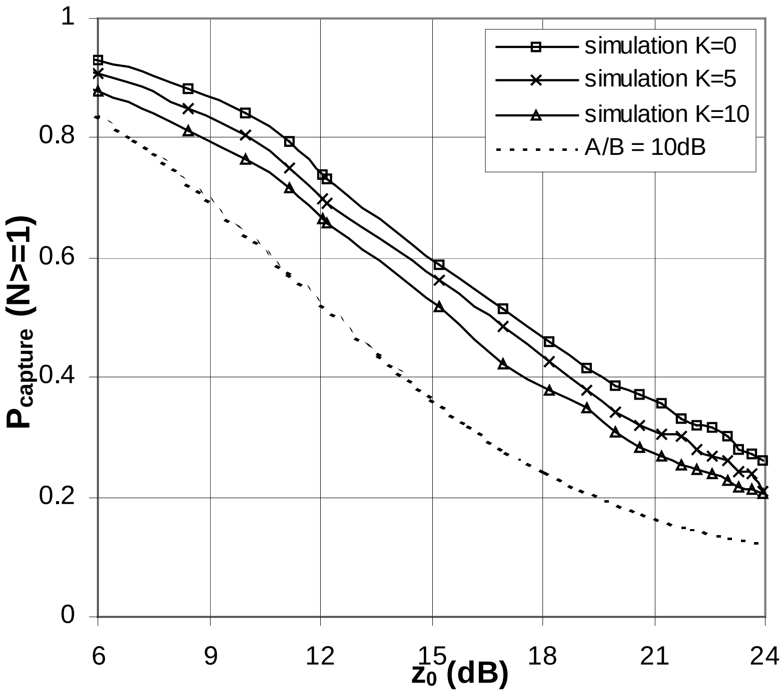
- ❑ $S_{\max}$ vs. z_0



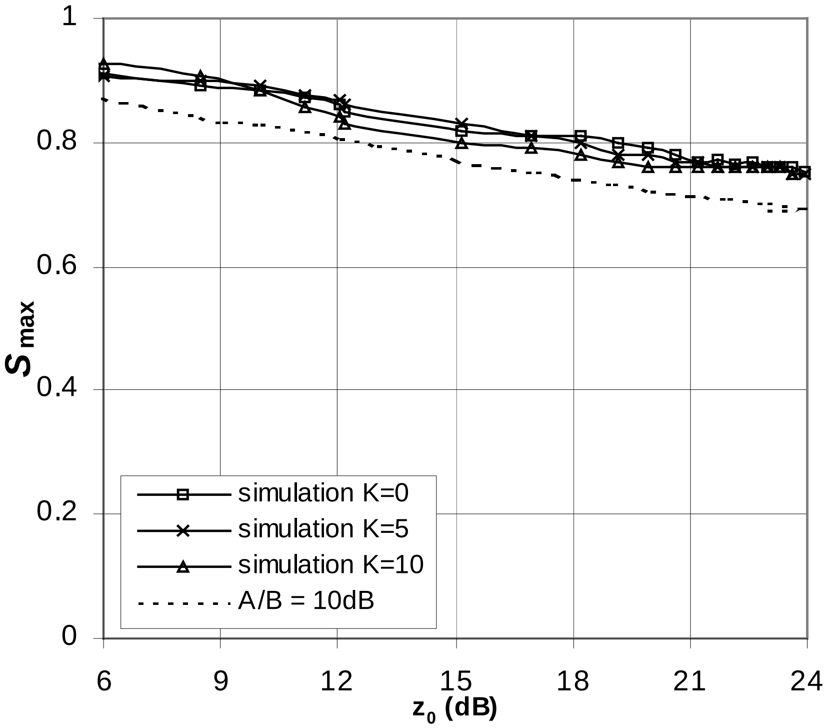
- ❑ Simulations match analytical results most closely given $1 \leq P_{0d}/P_{0i} \leq 10$

Simulated Rician-faded channel and CM2

- $P_{capure}(N \geq 1)$ vs. z_0



- S_{max} vs. z_0



- Simulations match analytical results most closely given $A/B \geq 10$ and $p = ½$ (equal occurrence probability of both power levels)

Conclusions

- 2 capture models of indoor Rayleigh-fading channel with different power scenarios to explore the influence of capture effect over IEEE 802.11 DCF
- Simulations of IEEE 802.11 DCF in a pure Rician-fading channel prove the analytical results of saturation throughput and capture probability of the two capture models
- CM 1 at Basic Access: closest correspondence between analytical and simulation results is established given mean-power ratio of the useful and each of interfering signals is in the range of 0 and 10 dB
- CM 2 at Basic Access: closest correspondence between analytical and simulation results is established given mean-power ratio of equally distributed numbers of interferers is higher then 10 dB
- Capture effect produces only minor throughput increase of a few percent given RTS/CTS “handshake” access mechanism
- Impact of capture and selection of the proper capture model depends primarily on the receiver design of an IEEE 802.11 system

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