Performance Analysis of MAC Protocols for Wireless LANs in Rayleigh and Shadow Fading Channel

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Contents

Background

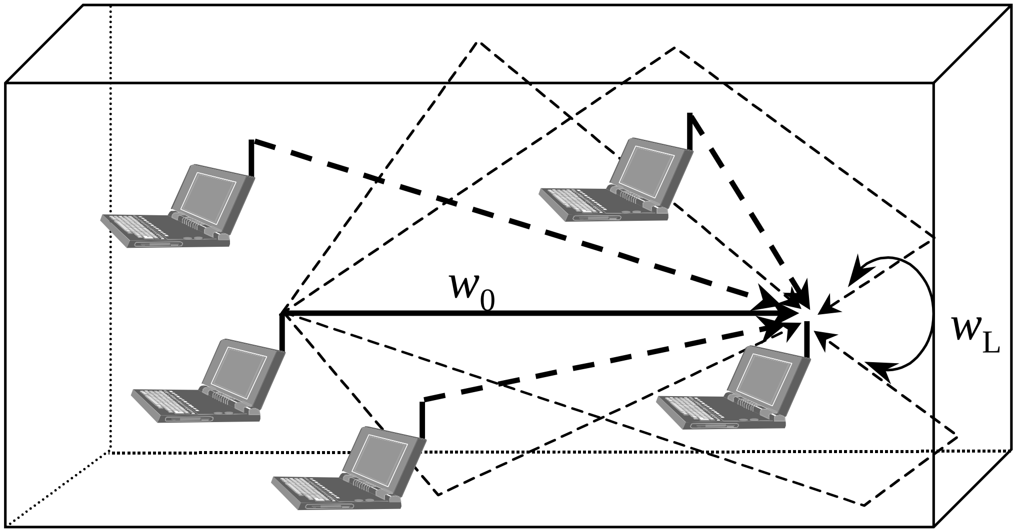
- Why Wireless LAN ?
  - Increase the wireless service.
  - Easy to change the network configuration.
  - Unlicensed Wireless Channel : ISM Band (900MHz, 2.4GHz, 5.7GHz)
  - Increasing the wireless LANs market.
- Wireless LAN Standards
  - IEEE 802.11 : ***CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol***
  - ETSI HIPERLAN Type I : EY-NPMA(Elimination Yield -Non-preemptive Priority) protocol

Previous Works

- K. C. Chen : Throughput and delay analysis of CSMA/CA (Personal, Indoor and Mobile Radio Communication: PIMRC ‘95)
  - Non-persistent CSMA => *No Backoff delay*
- S. M. Nor : Computer simulation for CSMA/CA (PIMRC ‘95)
  - *No analytical model*
- H. Chhaya and S. Gupta : CSMA/CA (PIMRC ‘95)
  - Calculate the lower bound of throughput=>*No Backoff delay*
- J. L. Sobrinho and A. Krishnakumar (GLOBECOM ‘96)
  - Consider the CSMA/CA for only real time service(voice)
  - *Delay stability analysis*
- Our Research
  - CSMA/CA : ***1-persistent + p-persistent CSMA model***
  - ***Wireless fading channel model***
  - ***Throughput & Packet delay***

Radio Channel Model

- Radio Channel (Linnartz model)
  - Multipath fading : Rayleigh Distribution
  - Shadow fading : Log-normal Distribution
  - Near-Far Effect : Uniform Distribution



Radio Channel Model

- Instantaneous power (w_0)
  - *Unconditional probability density function of the instantaneous power*

$$f_{w_0}(w_0) = \int_0^{\infty}\int_0^{\infty} \underbrace{\frac{1}{w_L}\exp\left(-\frac{w_0}{w_L}\right)}_{\text{Multipath fading}} \underbrace{\overset{\text{Near-far effect}}{\frac{f(r_i)}{\sqrt{2}\sigma_s w_L}} \exp\left\{-\frac{\ln^2\left(r_i^{\xi} w_L\right)}{2\sigma_s}\right\}}_{\text{Shadowing}} dr_i \, dw_L$$

w_0 : the instantaneous power

w_L : the local mean power

r_i : a distance between a receiver and *i*-th transmitting terminal

ξ : path loss parameter (1.79 - 6.2, urban : 4)

σ_s : the standard deviation of Shadow fading

■ Capture Model

- Capture probability : $q(n|z)$

$$q(n\,|\,z) = \frac{2}{\sqrt{\pi}} \int_0^1 \int_{-\infty}^{\infty} r_1 \exp\left(-x_1^2\right) \left[\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f\left(x_1, y_1\right) \exp\left(-y_1^2\right) dy_1 \right] dx_1\, dr_1$$

$$\cdot \frac{2}{\sqrt{\pi}} \int_0^1 \int_{-\infty}^{\infty} r_2 \exp\left(-x_2^2\right) \left[\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f\left(x_2, y_2\right) \exp\left(-y_2^2\right) dy_2 \right]^{n-1} dx_2\, dr_2$$

where,

$$f\left(x_1, y_1\right) \triangleq \Bigg[\sqrt{z} r_1^2 \exp\left\{ \frac{\sqrt{2}}{2} \sigma_s \left(x_1 - y_1\right) \right\} \Bigg] \Bigg] \cdot \Bigg[\frac{1}{z r_1^4} \exp\left\{ \frac{\sqrt{2}}{2} \sigma_s \left(x_1 - y_1\right) \right\} \Bigg]$$

$$f\left(x_2, y_2\right) \triangleq \Bigg[\sqrt{z} r_2^2 \exp\left\{ \frac{\sqrt{2}}{2} \sigma_s \left(x_2 - y_2\right) \right\} \Bigg] \Bigg] \cdot \Bigg[\frac{1}{z r_2^4} \exp\left\{ \frac{\sqrt{2}}{2} \sigma_s \left(x_2 - y_2\right) \right\} \Bigg]$$

n :the number of stations,
z : capture ratio
r : a distance between terminals,

➪ Use Hermite polynomial method for approximation

CSMA/CA Protocol

- CSMA/CA
  - Modified CSMA/CD (Carrier Sense Multiple Access/Collision Detection)
    => Can't detect collision in wireless channel
- CSMA/CA packet transmission process
  - Channel Idle : Immediately transmit
  - Channel Busy : Wait until channel Idle => Backoff delay
    => If channel is Idle => Transmit
  - Backoff delay algorithm
    - Increased exponentially according to the number of retransmission try.

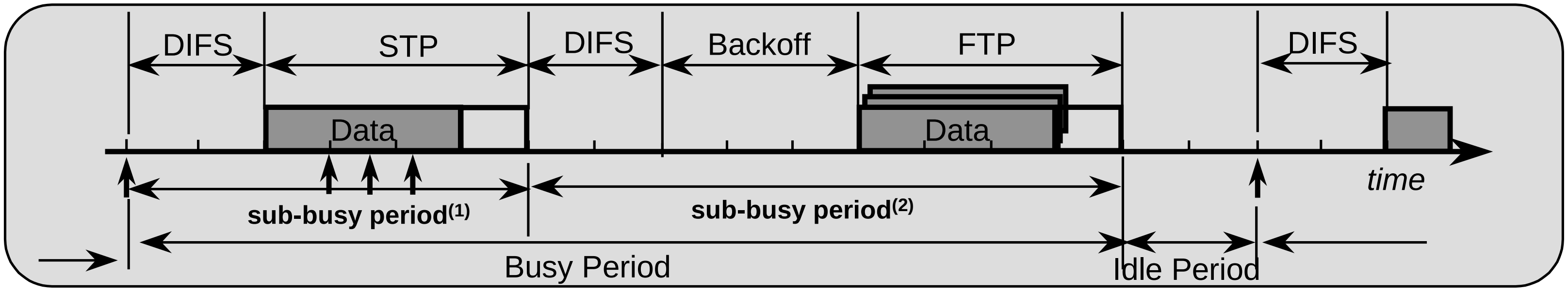
Performance Analysis

- Performance Parameters
  - Throughput analysis
  - Normalized packet delay analysis
- CSMA/CA Protocols
  - Basic CSMA/CA : Data- ...
  - Stop-and-Wait CSMA/CA : Data-ACK-...
  - 4-Way Hand Shake CSMA/CA : RTS-CTS-Data-ACK-...
    - ACK : Acknowledgement packet, RTS : Request To Send packet
      CTS : Clear To Send packet

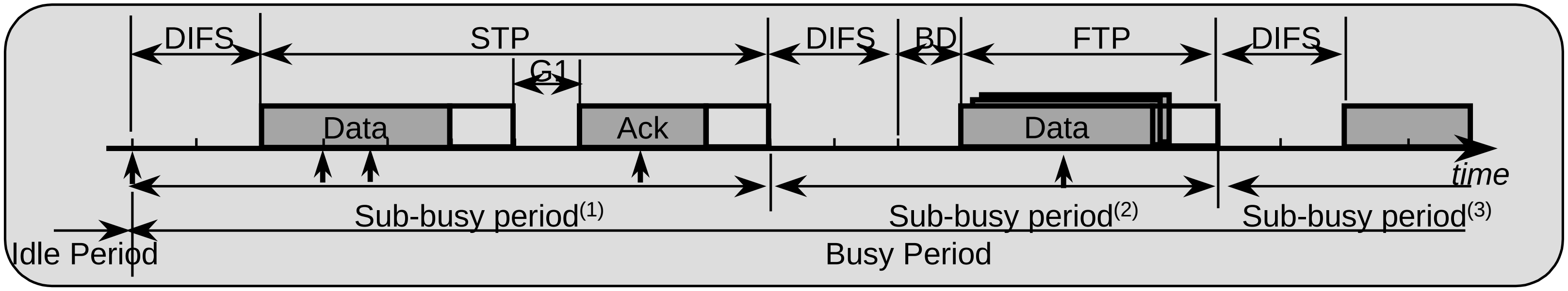
System Model

- CSMA/CA = 1-persistent CSMA + *p*-persistent CSMA
- M/G/1 Busy period analysis based on the Renewal Theory
- Finite population : The number of users (M)
- Slotted Channel: Slot size (a)
- All terminals are synchronized
- Packet arrival rate in a slot : g $(0 < g < 1)$
- Packet transmission probability : p $(0 < p \le 1)$
- Channel model with Multipath fading, Shadow fading and Near-far effect

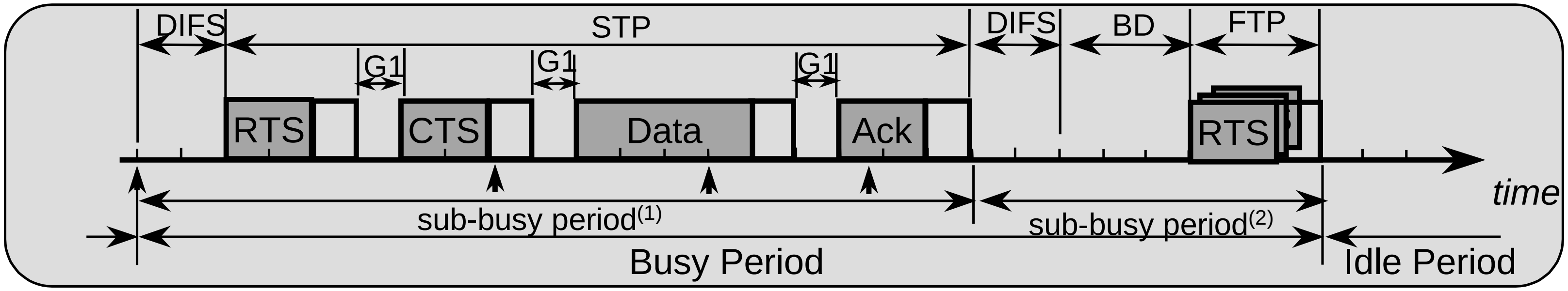
- Basic CSMA/CA Channel model



- Stop-and-Wait ARQ CSMA/CA Channel model



- 4-Way Handshake CSMA/CA Channel model



- DIFS : Distributed Inter-Frame Space
- STP : Successful Transmission Period
- RTS : Request To Send
- G1 : Short Inter-Frame Space
- FTP : Failed Transmission Period
- CTS : Clear To Send

CSMA/CA Throughput Analysis

- Basic concept

$$S = \frac{\overline{U}}{\overline{I} + \overline{B}}$$

- I : Idle period
- B: Busy period
- U : Useful transmission period

■ Throughput of Basic CSMA/CA

$$S = \frac{\overline{U}}{\overline{B} + \overline{I}}$$

$$= \frac{\begin{gathered} \Bigg[\sum_{i=1}^{M} \left\{ \frac{\binom{M}{i}\left[1-(1-g)\right]^{i}(1-g)^{M-i}}{1-(1-g)^{M}} \right\} \boxed{q(i,z)} + \frac{1}{1-(1-g)^{((1/a)+1)M}} \sum_{n=1}^{M} \Bigg[\Bigg\{ \sum_{i=1}^{n} \binom{n}{i} p^{i}(1-p)^{n-i} \\ \cdot \sum_{l=1}^{n} \binom{M-n}{l} g^{l}(1-g)^{M-n-l} + (M-n)(1-p)^{(k+1)n} g(1-g)^{(k+1)(M-n)-1} \boxed{(i+l)q(i+l,z)} \Bigg\} \\ \cdot \frac{(1-p)^{n}(1-g)^{M-n}}{1-(1-p)^{n}(1-g)^{M-n}} + \sum_{i=1}^{n} \binom{n}{i} p^{i}(1-p)^{n-i} \boxed{iq(i,z)} \Bigg] \\ \cdot \left\{ \frac{\binom{M}{n}\left[1-(1-g)^{(TP_S/a)}\right]^{n}(1-g)^{(TP_S/a)(M-n)}}{1-(1-g)^{(TP_S/a)M}} \right\} \Bigg] \end{gathered}}{\begin{gathered} \Bigg[f[1-(1-g)^{M}]+1+a+\frac{a}{1-(1-g)^{((1/a)+1)M}} \Bigg(-(f+1+a)[1-(1-g)^{((1/a)+1)M}]+ \\ a\sum_{k=1}^{\infty}\{(1-p)^{k}-(1-g)^{((1/a)+1)}[(1-p)^{k}-(1-g)^{k}]\}^{M} - a(1-g)^{((1/a)+a)M}\sum_{k=1}^{\infty}(1-g)^{kM} \Bigg) \\ + \frac{a}{1-(1-g)^{M}} \Bigg] \end{gathered}}$$

$TP_S = 1+a+f$: Average period of successful transmission $\boxed{}$ **capture probability**

■ Throughput of SW ARQ & 4-WH CSMA/CA

$$S = \frac{\overline{U}}{\overline{B} + \overline{I}}$$

where

$$\overline{I} = \frac{a}{1-(1-g)^{M}}$$

$$\begin{aligned}\overline{B} &= f\left[1-(1-g)^{M}\right] \\ &+ \{TP_{Succ} + [1-(1-g)^{(TP_{Succ}/a)}]\boxed{B(TP_{Succ}/a)}\}\overline{u} \\ &+ \{TP_{Fail} + [1-(1-g)^{(TP_{Fail}/a)}]\boxed{B(TP_{Fail}/a)}\}[1-\overline{u}]\end{aligned}$$

$$\begin{aligned}\overline{U} &= \{1+[1-(1-g)^{(TP_{Succ}/a)}]\boxed{U(TP_{Succ}/a)}\}\overline{u} \\ &+ \{[1-(1-g)^{(TP_{Fail}/a)}]\boxed{U(TP_{Fail}/a)}\}[1-\overline{u}]\end{aligned}$$

$$\text{SW ARQ CSMA/CA} : \begin{cases} TP_{Succ} = 1+2a+\beta+\delta+f & \text{(average period of successful transmiss ion)} \\ TP_{Fail} = 1+a+f & \text{(average period of failed transmiss ion)} \end{cases}$$

$$4-\text{WH CSMA/CA} : \begin{cases} TP_{Succ} = 1+\gamma+\theta+3\beta+\delta+4a+f \\ TP_{Fail} = \gamma+a+f \end{cases}$$

$\overline{u} = [U^{(j)}]$

CSMA/CA Delay Analysis

- Use channel throughput calculations
- Average number of retransmission for a packet

$$\left(\frac{G}{S}-1\right)$$

- Average delay for a packet from arrival time to successful transmission starting time ($\overline{R}$)
  - probability with arriving in Idle period : $\frac{\overline{I}}{\overline{B}+\overline{I}}$
  - probability with arriving in Delay period : $\frac{\overline{D}}{\overline{B}+\overline{I}}$
  - probability with arriving in Transmitting period : $\frac{\overline{T}}{\overline{B}+\overline{I}}$
  - For Basic CSMA/CA

$$\overline{R}=\frac{\overline{I}}{\overline{B}+\overline{I}}f+\frac{\overline{D}}{\overline{B}+\overline{I}}f+\frac{\overline{T}}{\overline{B}+\overline{I}}\left[\frac{\overline{(1+a+f+E[D^{(2)}])}^{2}}{\overline{2(1+a+f+E[D^{(2)}])}}\right]$$

- $\overline{Y}$: Average Random delay by Backoff algorithm

- Normalized packet delay for Basic CSMA/CA

$$L = \left(\frac{G}{S} - 1\right)[1 + a + \overline{Y} + \overline{R}] + [\overline{R} + 1 + a]$$

- Normalized packet delay for Stop-and-Wait CSMA/CA

$$L = \left(\frac{G}{S} - 1\right)[1 + a + \overline{Y} + \overline{R}] + [\overline{R} + 1 + 2a + \beta + \delta]$$

- Normalized packet delay for 4-Way Handshake CSMA/CA

$$L = \left(\frac{G}{S} - 1\right)[\gamma + a + \overline{Y} + \overline{R}] + [\overline{R} + 1 + \gamma + \theta + \delta + 3\beta + 4a]$$

L = Normalized packet delay

G = Offered load

S = Throughput

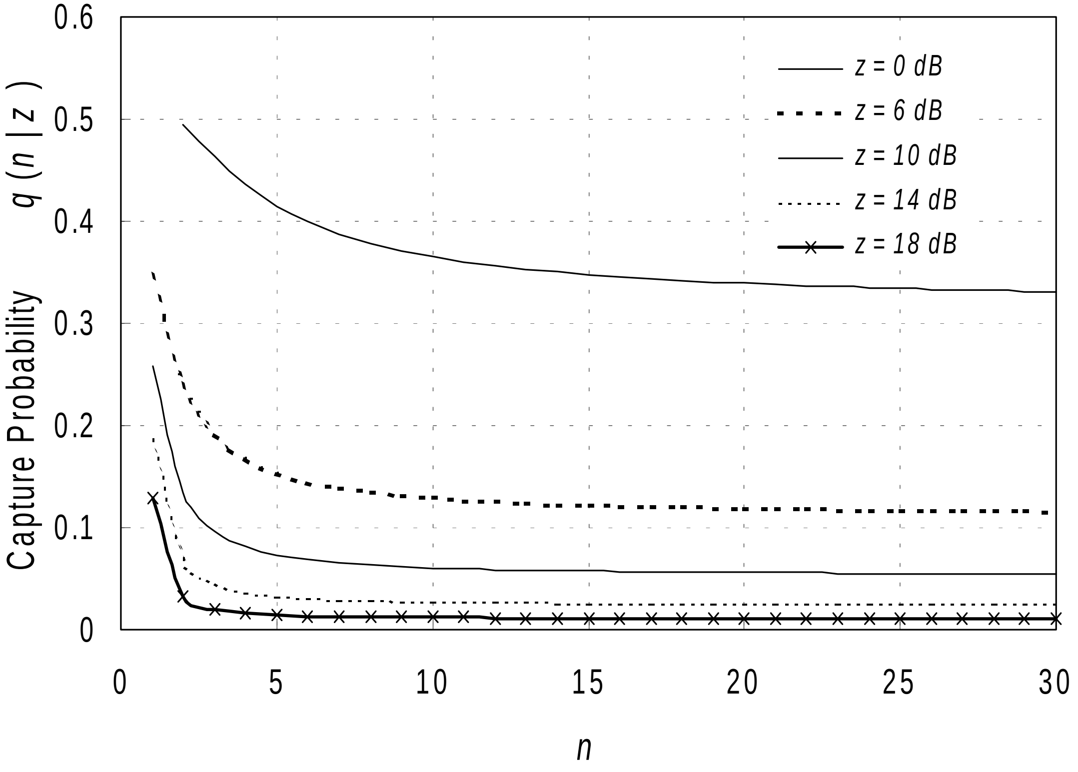
a = propagation delay,

β = SIFS,

δ = ACK packet, γ = RTS packet , θ = CTS packet

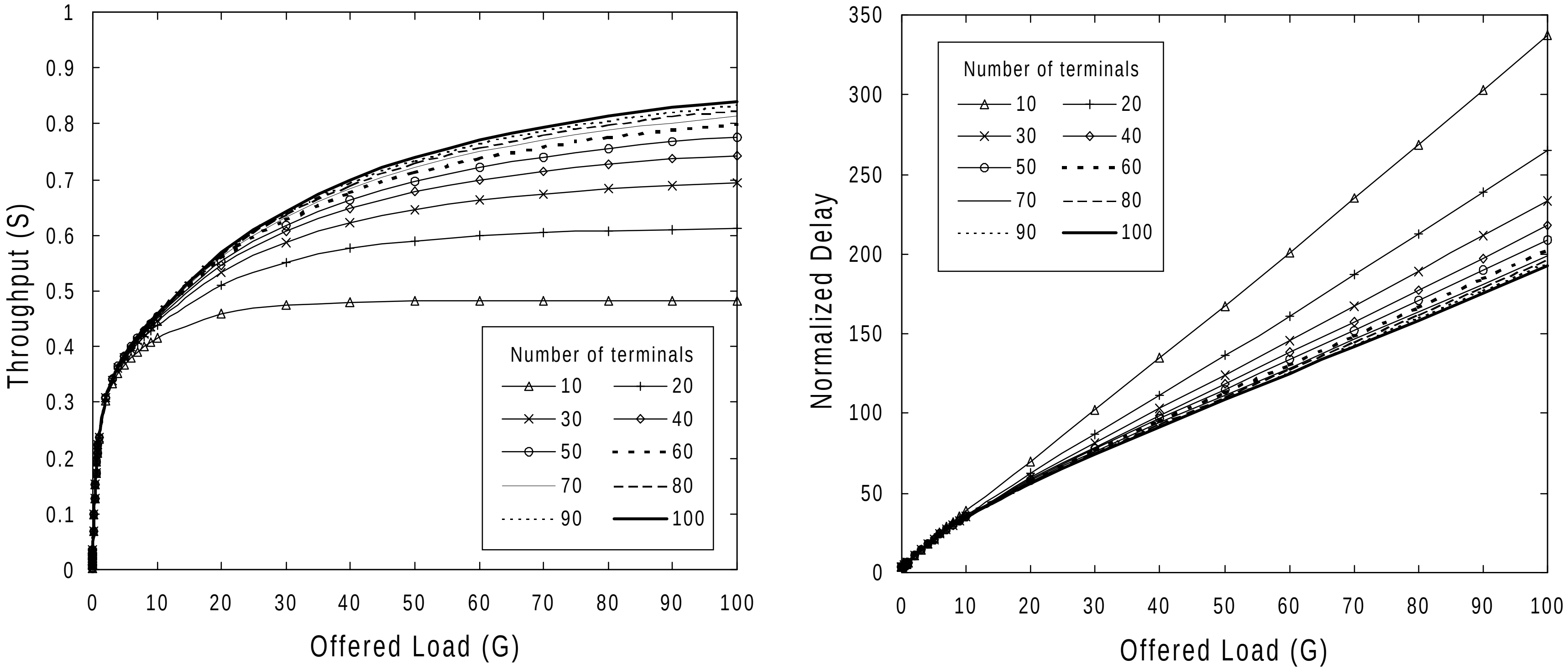
Numerical Results and Simulations

- Capture probability for the number of colliding pack



- standard deviation for Shadowing (σ_s)= 6dB
- attenuation factor for the distance (ξ) = 4

- Throughput and Packet delay vs. offered load of Basic CSMA/CA for varying of the number of terminals



(a) Throughput

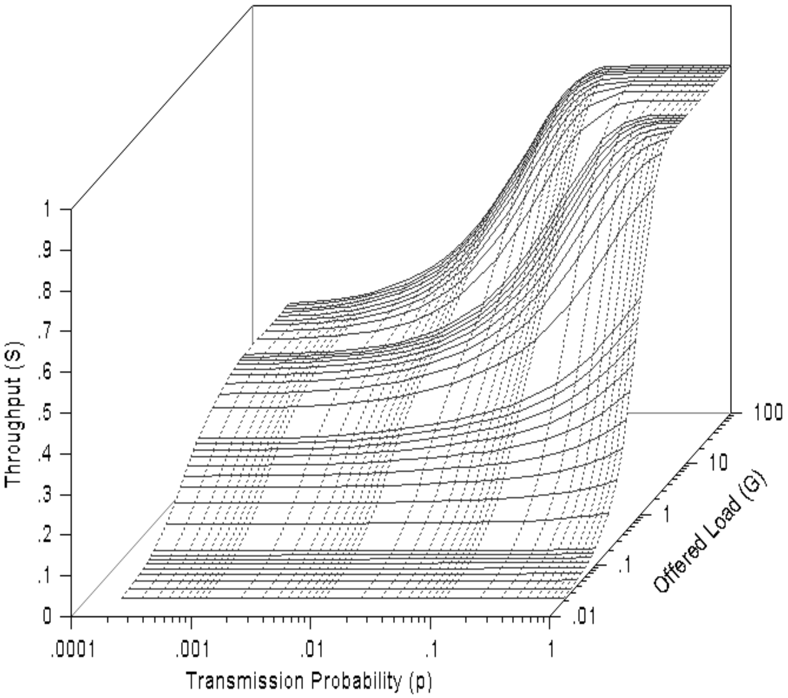
(b) Packet delay

- propagation delay (a) = 0.01
- packet transmission probability(p) = 0.03,
- standard deviation for shadowing(σ_s)= 6 dB
- attenuation factor for distance (ξ) = 4

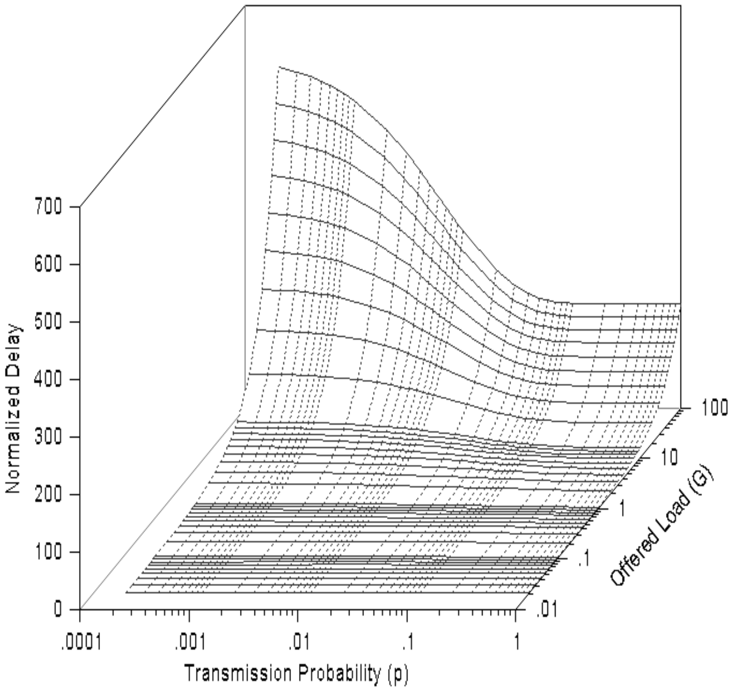
- DIFS length(f) = 0.06
- random delay(E(Y))=0.06
- capture ratio(z) = 4)

- Throughput and Packet delay vs. transmission probability *p* of SW ARQ CSMA/CA for varying of the offered load

(a) Throughput



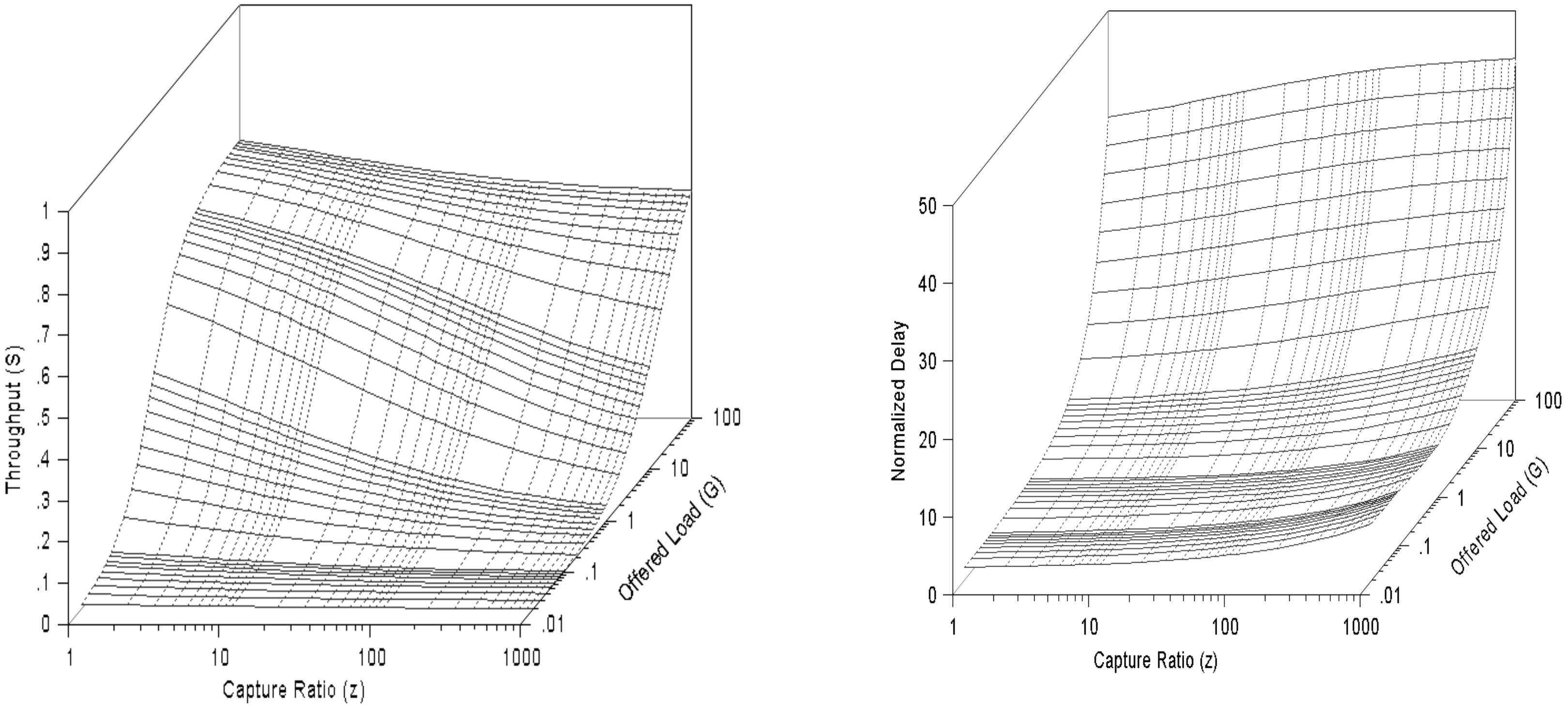
(b) Packet delay



- propagation delay (*a*) = 0.01
- standard deviation for shadowing(σ_s)= 6 dB
- attenuation factor for distance (ξ) = 4
- number of terminals = 50
- short Inter-Frame Space = 0.03

- DIFS length(*f*) = 0.06
- random delay(E(Y))=0.06
- capture ratio(*z*) = 4
- length of Ack packet = 0.06

- Throughput and Packet delay vs. capture ratio *z* of 4-WH CSMA/CA for varying of the offered load



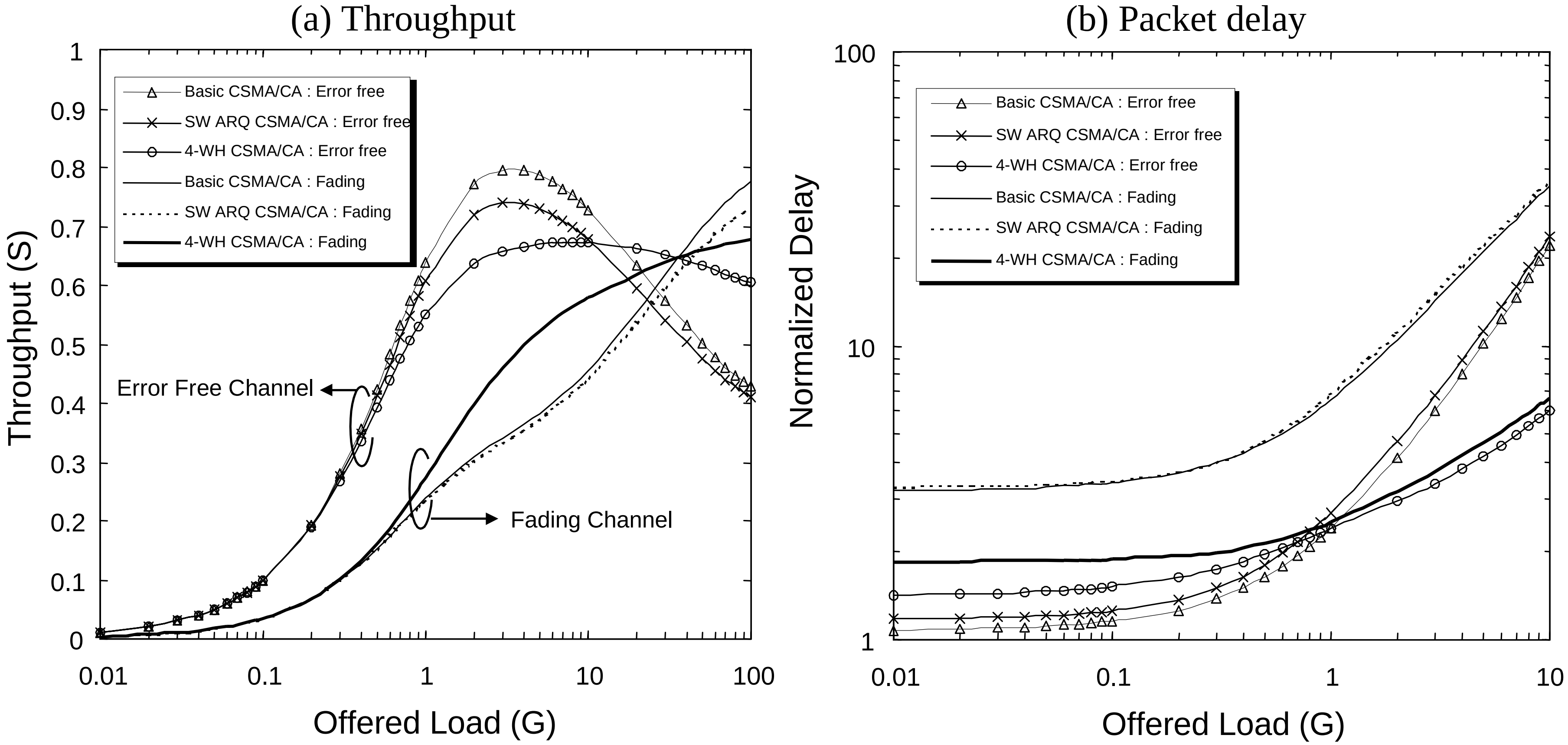
(a) Throughput

(b) Packet delay

- propagation delay (a) = 0.01
- packet transmission probability (p) = 0.03
- standard deviation for shadowing(σ_s)= 6 dB
- attenuation factor for distance (ξ) = 4
- number of terminals = 20
- random delay(E(Y))=0.06

- length of DIFS(f) = 0.06
- length of Ack packet = 0.06
- length of SIFS = 0.03
- length of RTS = 0.06
- length of CTS = 0.03

- Performance comparison of three types of CSMA/CA protocols for error free channel model and fading channel model



- propagation delay (a) = 0.01
- packet transmission probability (p) = 0.03
- standard deviation for shadowing(σ_s)= 6 dB
- attenuation factor for distance (ξ) = 4
- capture ratio = 4
- number of terminals = 50

- length of DIFS(f) = 0.06
- length of Ack packet = 0.06
- length of SIFS = 0.03
- length of RTS = 0.06
- length of CTS = 0.03
- random delay(E(Y))=0.06

Conclusions

- Propose a new analytical approach for CSMA/CA protocols in *Multipath fading, Shadow fading and Near-far Effect* environments
- Throughput and packet delay analysis
- Performance comparison of three type CSMA/CA protocols with and without *radio channel model*
- Performance prediction for various parameters
- Further Study
  - Integration of PCF(Point Coordination Function)
  - HIPERLAN : EY-NPMA protocol

- Probability of successful transmission for SW ARQ & 4-WH CSMA/CA

$$E[U^{(j)}] = \begin{cases} u(1) & ;\ j = 1 \\ u(\mathrm{STP}/a) & ;\ \text{if } (j-1)\text{th transmission is success},\ j = 2,3,\cdots \\ u(\mathrm{FTP}/a) & ;\ \text{if } (j-1)\text{th transmission is unsuccess},\ j = 2,3,\cdots \end{cases}$$

where

$$u(1) = \sum_{i=1}^{M} \boxed{\left\{ \frac{\binom{M}{i}\left[1-(1-g)\right]^{i}(1-g)^{M-i}}{1-(1-g)^{M}} \right\} q(i-1,z)}$$

$$u(\mathrm{STP}/a) = \sum_{n=0}^{M}\left[\left\{ \sum_{i=1}^{n}\binom{n}{i}p^{i}(1-p)^{n-i}\sum_{l=1}^{n}\binom{M-n}{l}g^{l}(1-g)^{M-n-l}\boxed{(i+l)q(i+l,z)} \right\} \cdot \frac{(1-p)^{n}(1-g)^{M-n}}{1-(1-p)^{n}(1-g)^{M-n}} + \sum_{i=1}^{n}\binom{n}{i}p^{i}(1-p)^{n-i}\boxed{i\,q(i-1)} \right] \cdot \left\{ \frac{\binom{M}{n}[1-(1-g)^{(\mathrm{STP}/a)}]^{n}(1-g)^{(\mathrm{STP}/a)(M-n)}}{1-(1-g)^{(\mathrm{STP}/a)M}} \right\}$$

$$u(\mathrm{FTP}/a) = \sum_{n=0}^{M}\left[\left\{ \sum_{i=1}^{n}\binom{n}{i}p^{i}(1-p)^{n-i}\sum_{l=1}^{n}\binom{M-n}{l}g^{l}(1-g)^{M-n-l}\boxed{(i+l)q(i+l,z)} \right. \frac{(1-p)^{n}(1-g)^{M-n}}{1-(1-p)^{n}(1-g)^{M-n}} + \sum_{i=1}^{n}\binom{n}{i}p^{i}(1-p)^{n-i}\boxed{i\,q(i-1)} \right] \cdot \left\{ \frac{\binom{M}{n}[1-(1-g)^{(\mathrm{FTP}/a)}]^{n}(1-g)^{(\mathrm{FTP}/a)(M-n)}}{1-(1-g)^{(\mathrm{FTP}/a)M}} \right\}$$

STP : Successful Transmission period, FTP : Failed Transmission period ⬚ **capture probability**