

# Performance Study of Congestion Price Based Adaptive Service

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# Outline

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- Resource negotiation & RNAP
- Pricing strategy
- User adaptation
- Simulation model
- Results and discussion

# Resource Negotiation & RNAP

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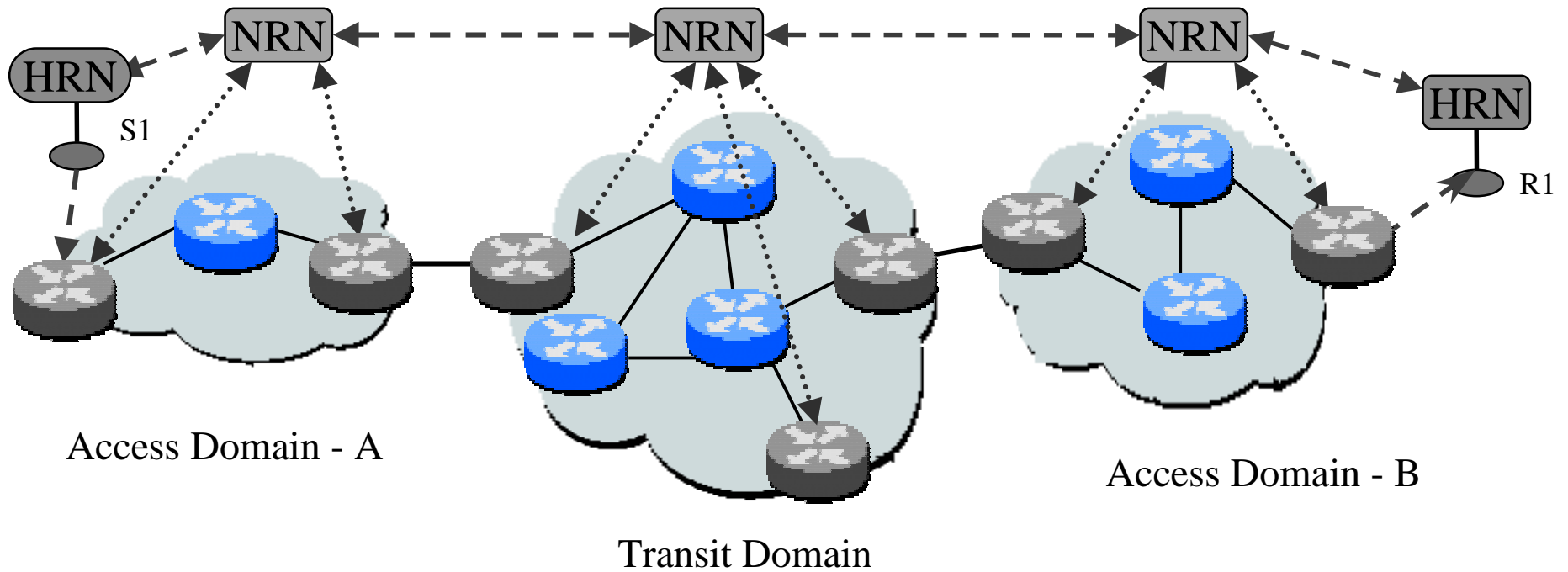
- **Assumption:** network provides a choice of delivery services to user
  - e.g. diff-serv, int-serv, best-effort, with different levels of QoS
  - with a pricing structure (may be usage-sensitive) for each.
- **RNAP:** a protocol through which the user and network (or two network domains) negotiate network delivery services.
  - *Network -> User:* communicate availability of services; price quotations and accumulated charges
  - *User -> Network:* request/re-negotiate specific services for user flows.
- **Underlying Mechanism:** combine network pricing with traffic engineering

# Resource Negotiation & RNAP (cont'd.)

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- Who can use RNAP?
  - Adaptive applications: adapt sending rate, choice of network services
  - Non-adaptive applications: take fixed price, or absorb price change

# Centralized Architecture (RNAP-C)



 Internal Router

 Edge Router

 Host

 Network Resource Negotiator

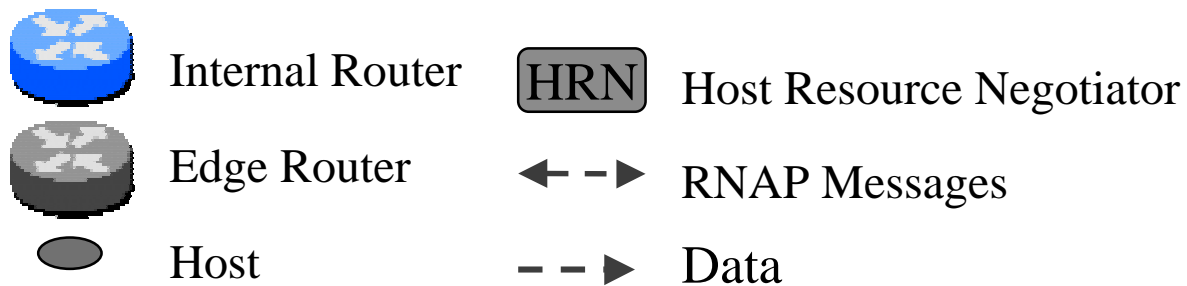
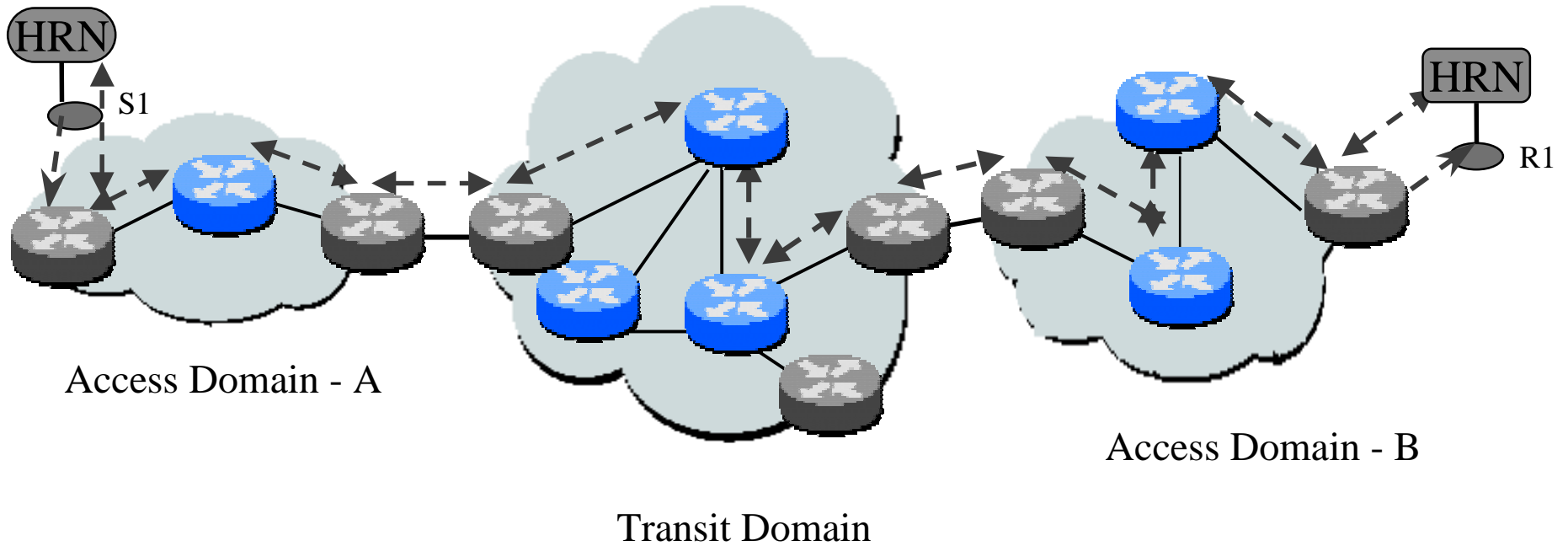
 Host Resource Negotiator

 Data

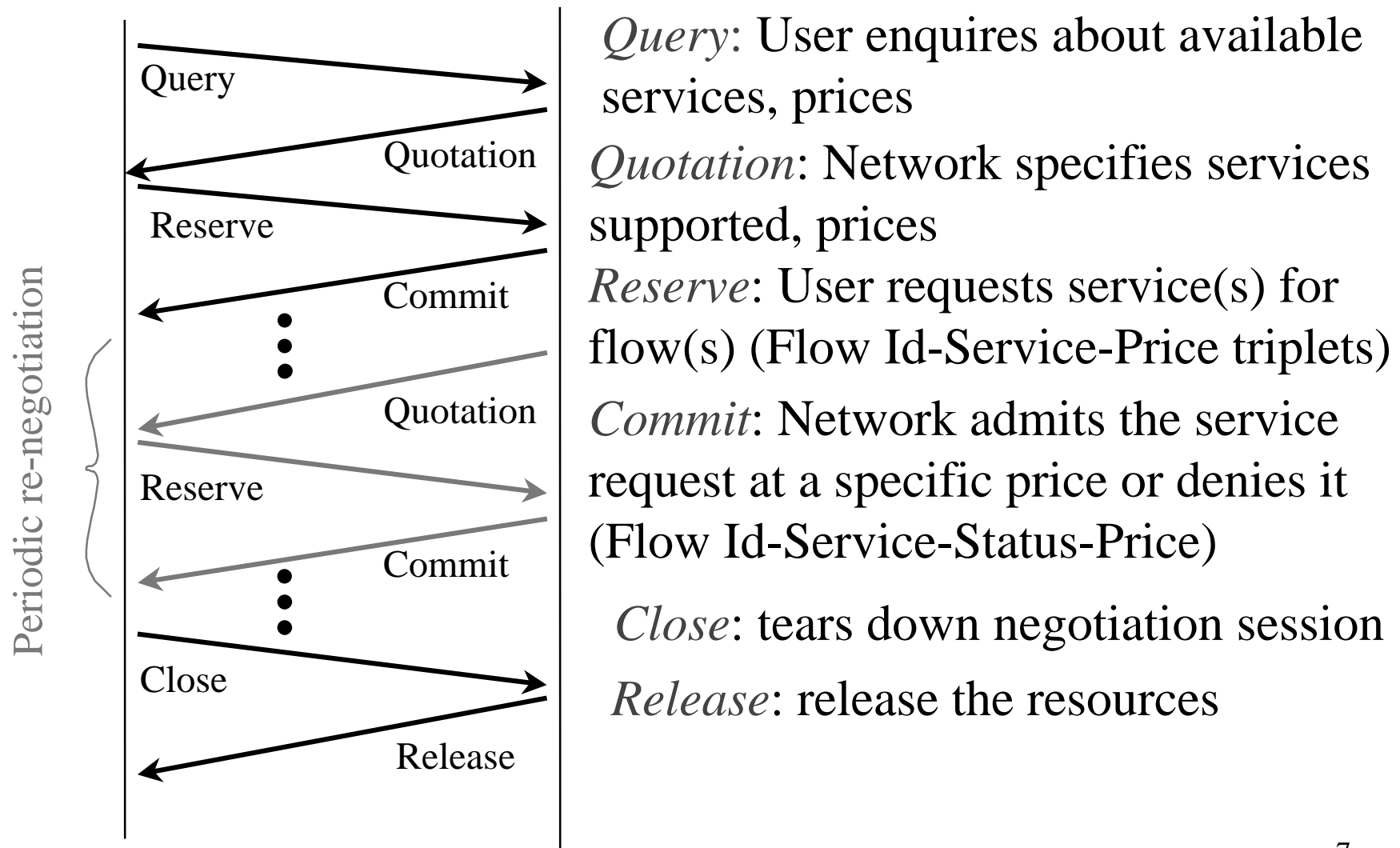
 RNAP Messages

 Intra domain messages

# Distributed Architecture (RNAP-D)



# Resource Negotiation & RNAP (cont'd.)



# Pricing Strategy

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- Current Internet:
  - Access rate dependent charge (AC)
  - Volume dependent charge (V)
  - $AC + V \longrightarrow AC-V$
  - Usage based charging: time-based, volume-based
- Fixed pricing
  - Service class independent flat pricing
  - Service class sensitive priority pricing
  - Time dependent time of day pricing
  - Time-dependent service class sensitive priority pricing



# Pricing Strategy, Cont'd

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- Congestion-based Pricing

- Usage charge:

- $p_u = f(\text{service, demand, destination, time\_of\_day, ...})$

- $c_u(n) = p_u \times V(n)$

- Holding charge:

- $P_h^i = \alpha^i \times (p_u^i - p_u^{i-1})$

- $c_h(n) = p_h \times R(n) \times \tau$

- Congestion charge:

- $p_c(n) = \min [\{p_c(n-1) + \sigma(D, S) \times (D-S)/S, 0\}^+, p_{\max}]$

- $c_c(n) = p_c(n) \times V(n)$

# Pricing Strategy (cont'd.)

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- A generic pricing structure

$$- \text{Cost} = c_{ac}(r_{ac}) + p(r_{ac}) \times (t - t_m)^+ + \sum_i \sum_n [p_h^i(n) \times r^i(n) \times \tau + (p_u^i(n) + p_c^i(n)) \times v^i(n)] \times (v^i - v_m^i)^+$$

- $c_{ac}$ : access charge;  $r_{ac}$ : *access rate*
- $p(r_{ac})$ : unit time price
- $i$ : class  $i$ ;  $n$ :  $n$ th negotiation interval;
- $\tau$ : *negotiation period*
- $t_m$ : the minimum time without charge
- $v_m$ : the volume transferred free of charge

# User Adaptation

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- Based on perceived value
- Application adaptation
  - Maximize total utility over the total cost
  - Constraint:  
budget, min QoS & max QoS

# CPA & FP

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- CPA: congestion price based adaptive service
- FP: fixed price based service

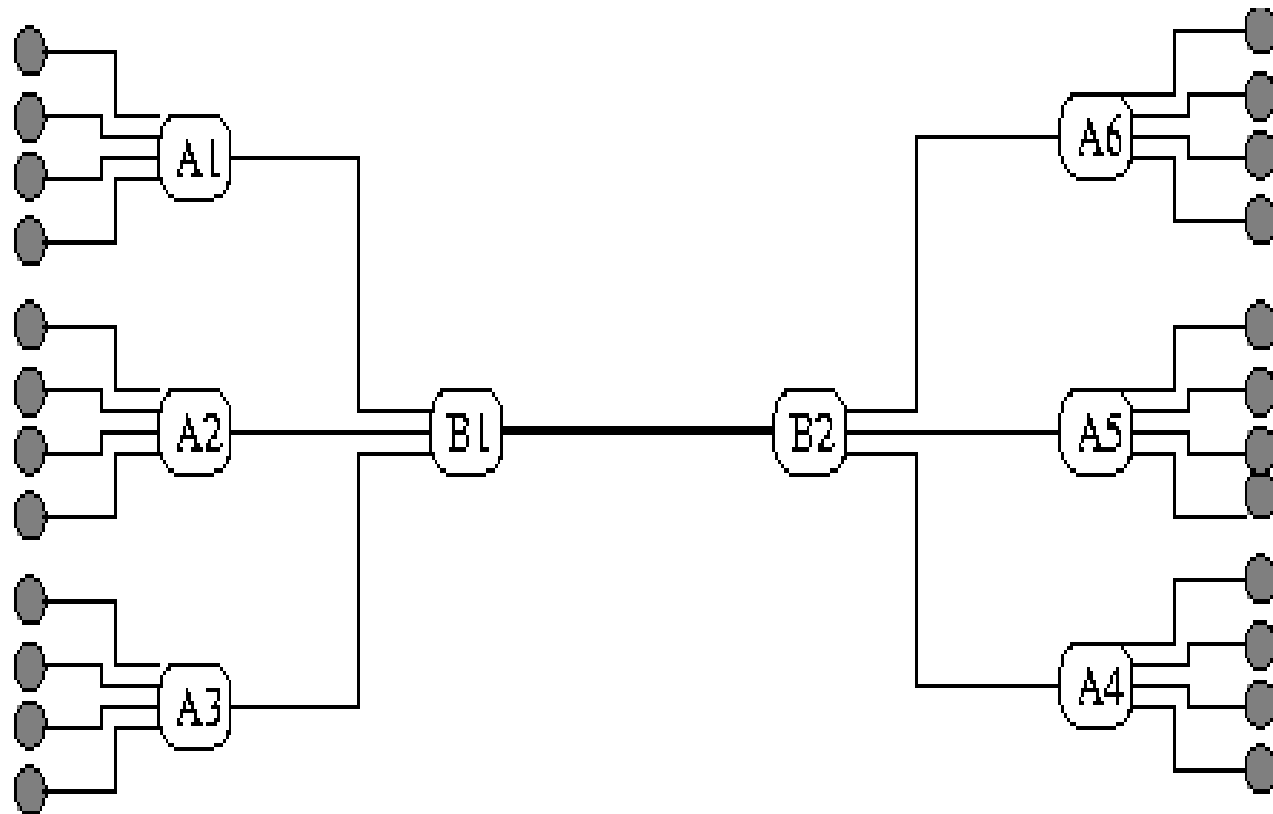
# User Adaptation (cont'd.)

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- An example utility function
  - $U(x) = U_0 + \omega \log(x / x_m)$
- Optimal user demand
  - Without budget constraint:  $x^j = \omega^j / p^j$
  - With budget constraint:  $x^j = (b \times \omega^j / \sum_l \omega^l) / p^j$ 
    - Affordable resource is distributed proportionally among applications of the system, based on the user's preference and budget for each application.

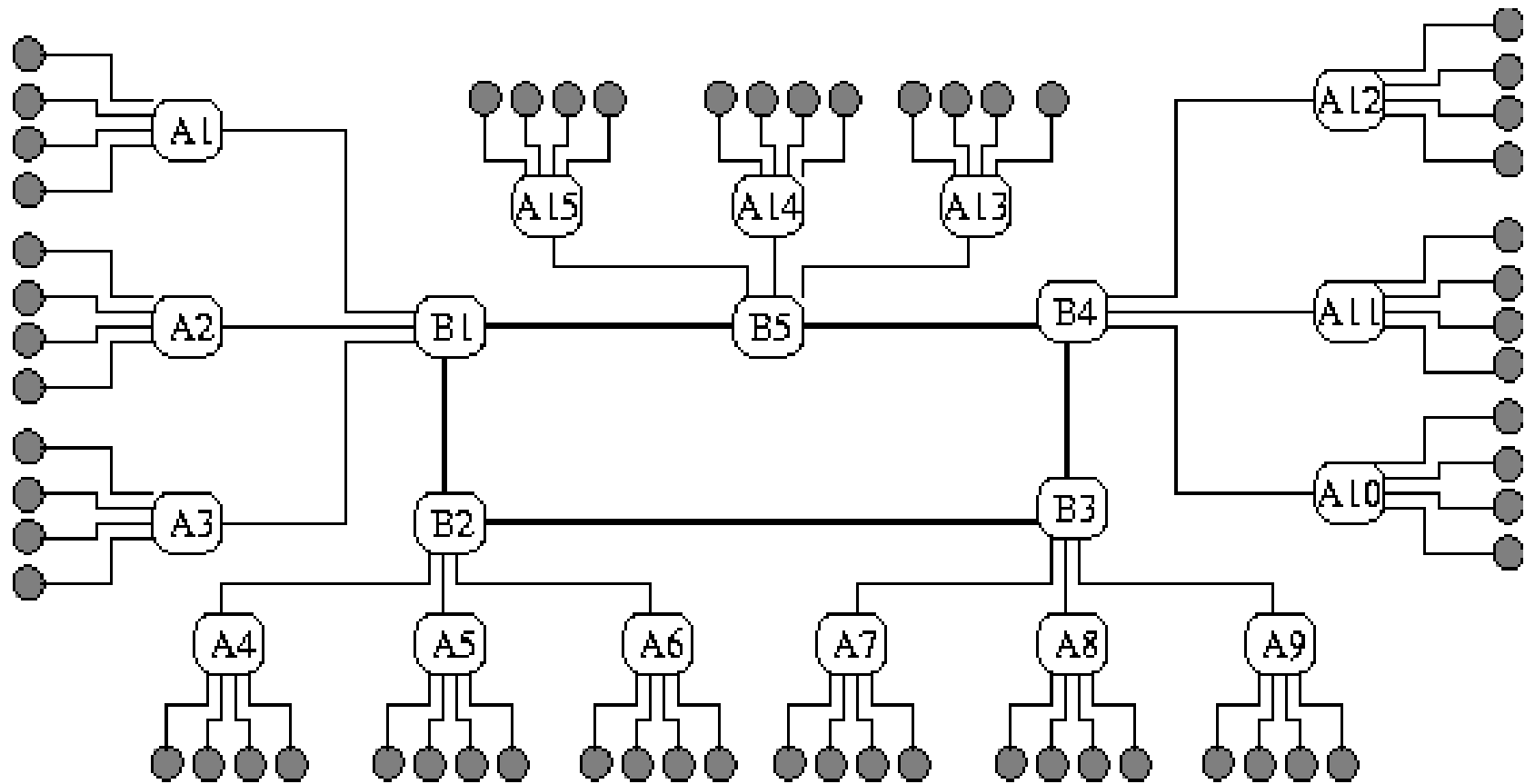
# Simulation Model

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# Simulation Model

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# Simulation Model (cont'd.)

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- Parameters Set-up
  - topology1: 48 users
  - topology 2: 360 users
  - user requests: 60 kb/s -- 160 kb/s
  - targeted reservation rate: 90%
  - price adjustment factor:  $\sigma = 0.06$
  - price update threshold:  $\theta = 0.05$
  - negotiation period: 30 seconds
  - usage price:  $p_u = 0.23$  cents/kb/min



# Simulation Model (cont'd.)

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- Performance measures
  - Bottleneck bandwidth utilization
  - User request blocking probability
  - Average and total user benefit
  - Network revenue
  - System price
  - User charge

# Design of the Experiments

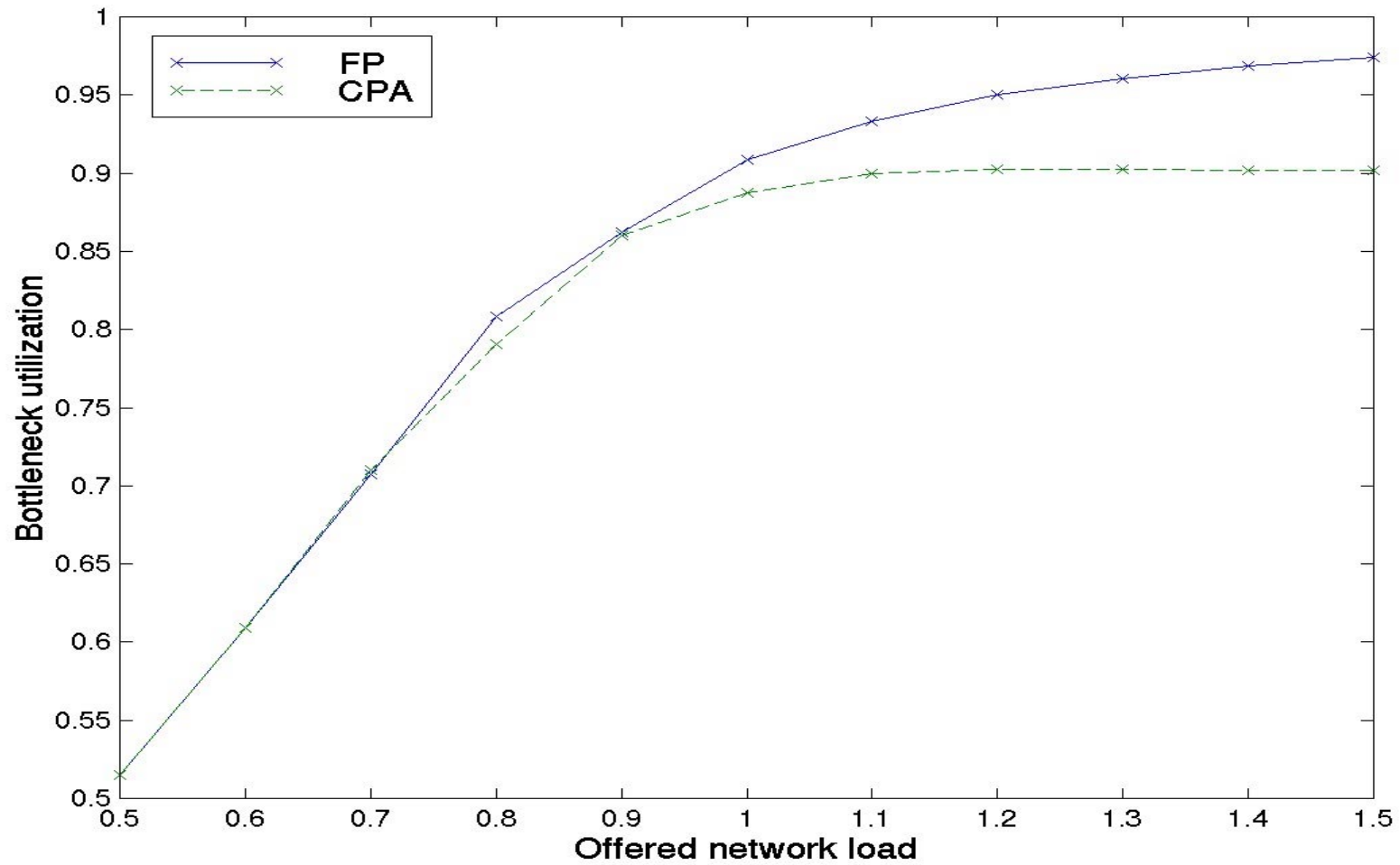
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- Performance comparison of CPA & FP
- Effect of system control parameters:
  - target reservation rate
  - price adjustment step
  - price adjustment threshold
- Effect of user demand elasticity
- Effect of session multiplexing
- Effect when part of users adapt
- Session adaptation and adaptive reservation

# Performance Comparison of CPA and FP

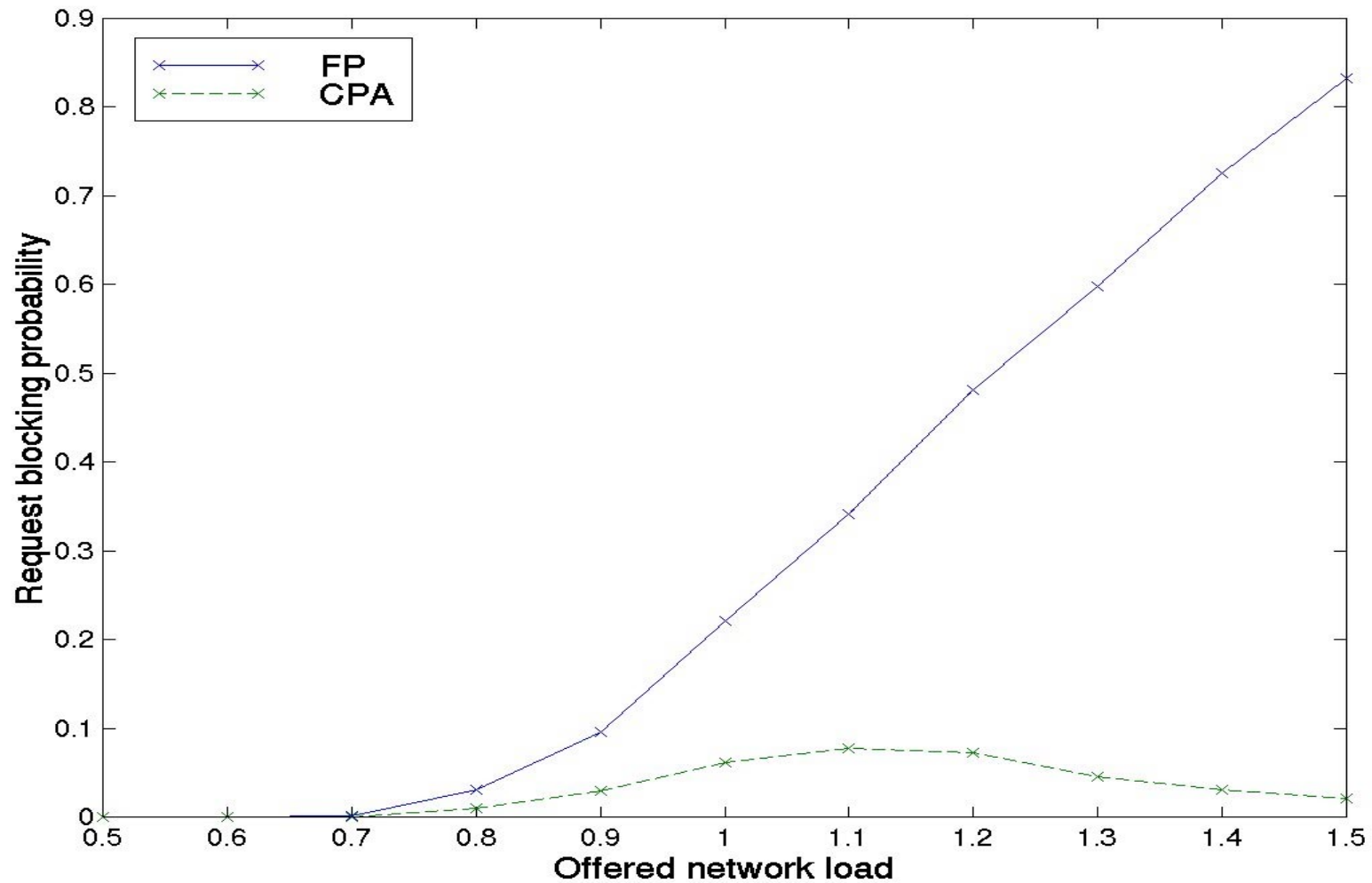
# Bottleneck Utilization

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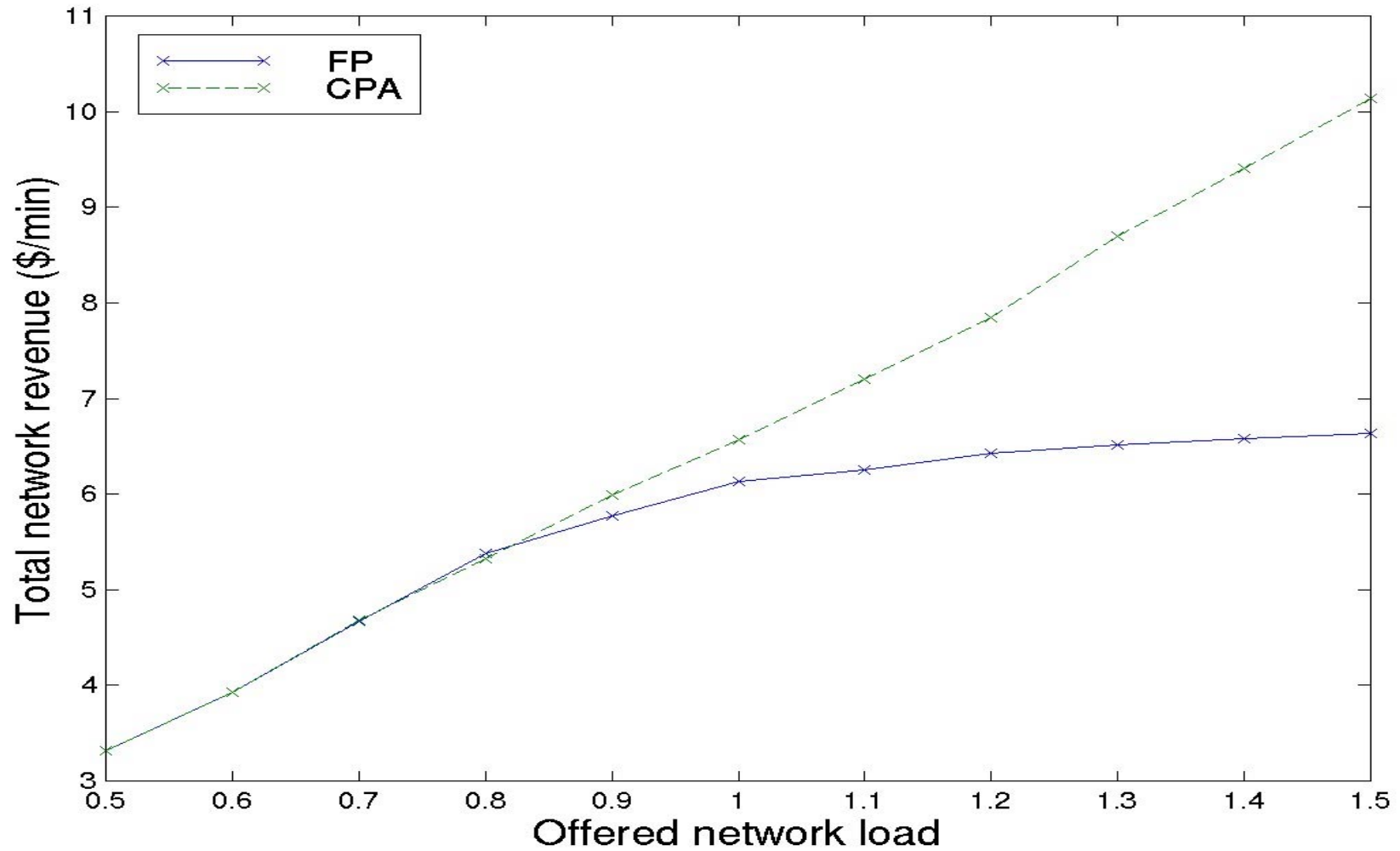
# Request blocking probability

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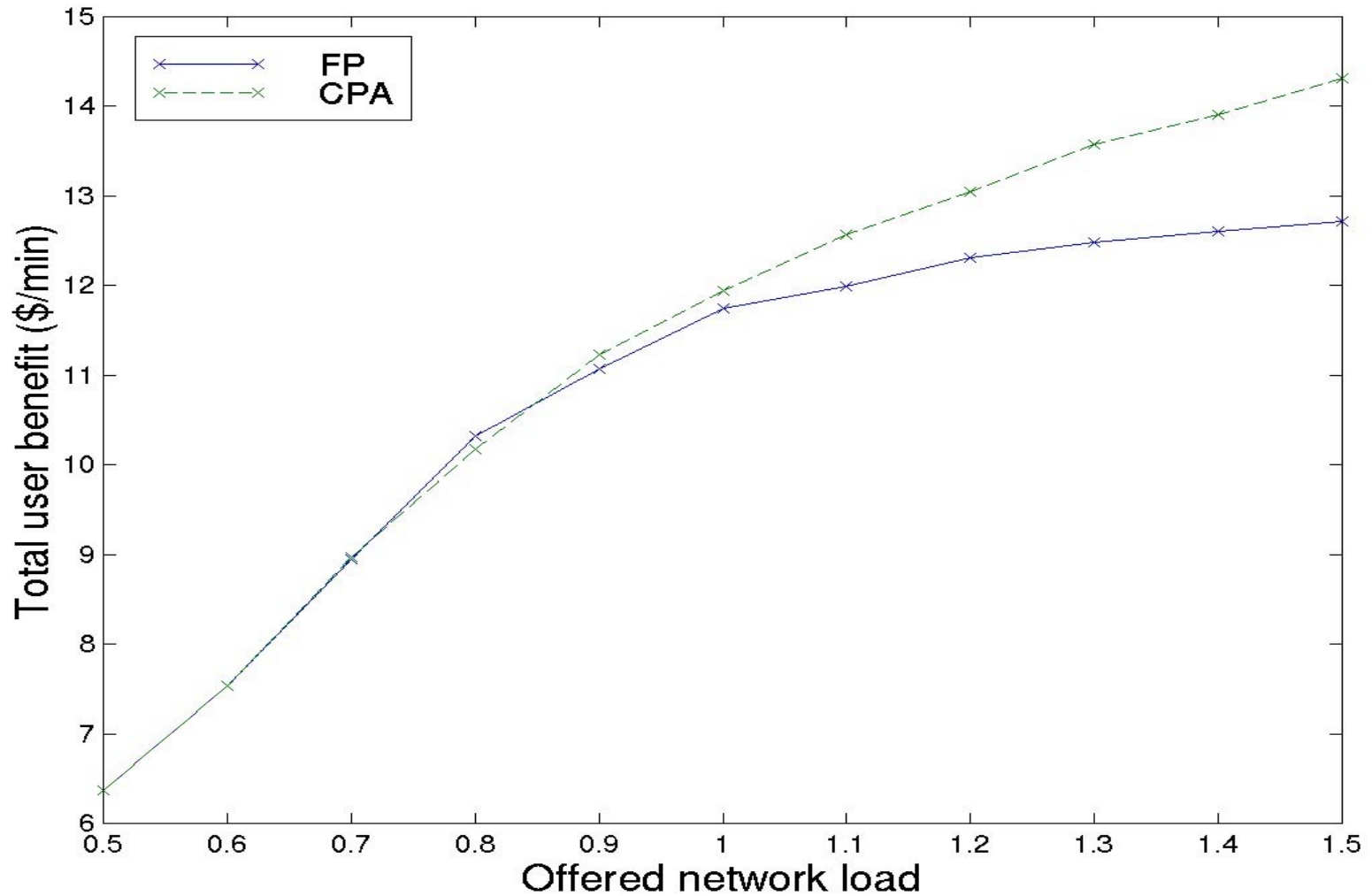
# Total network revenue (\$/min)

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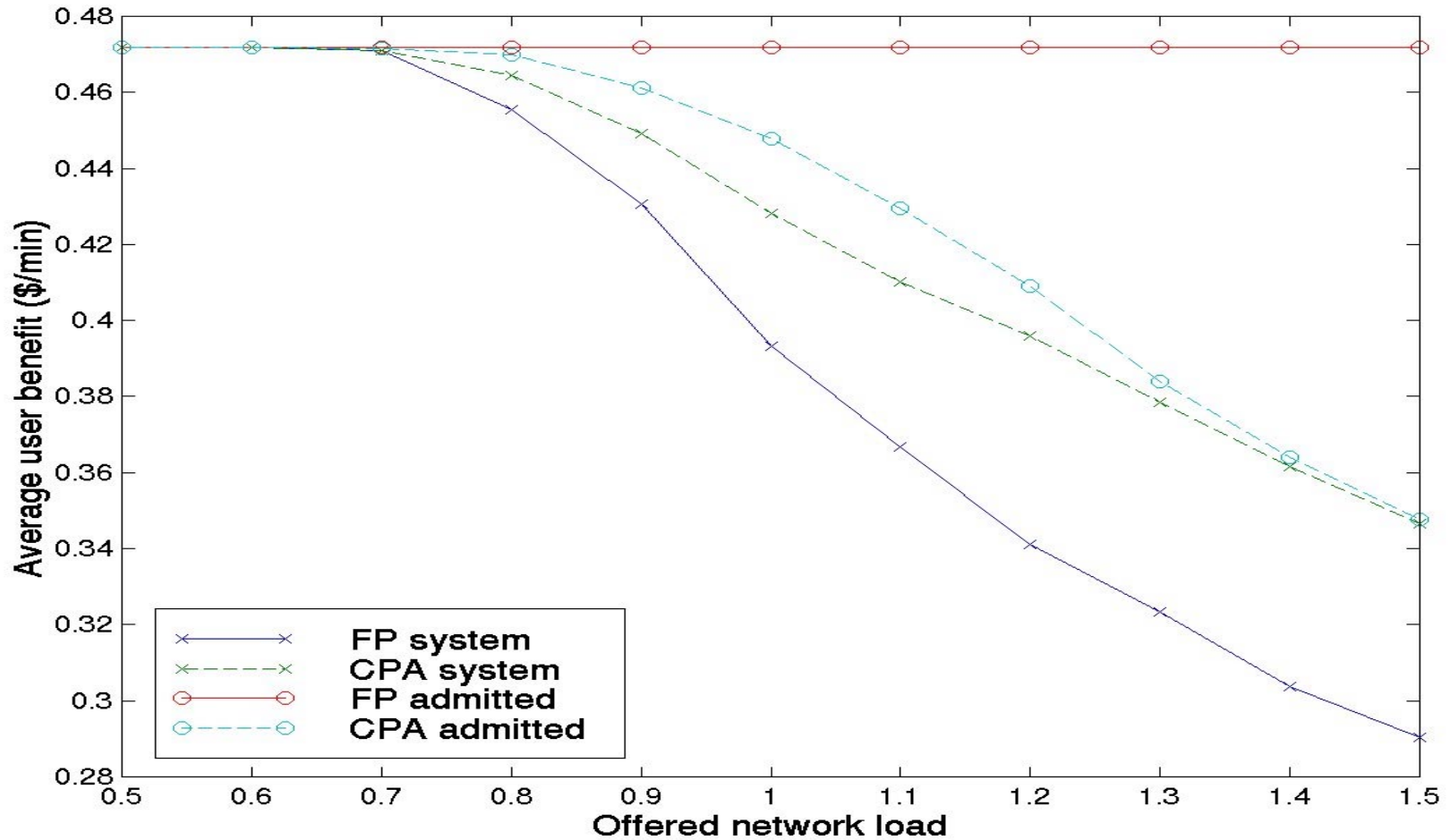


# Total user benefit (\$/min)

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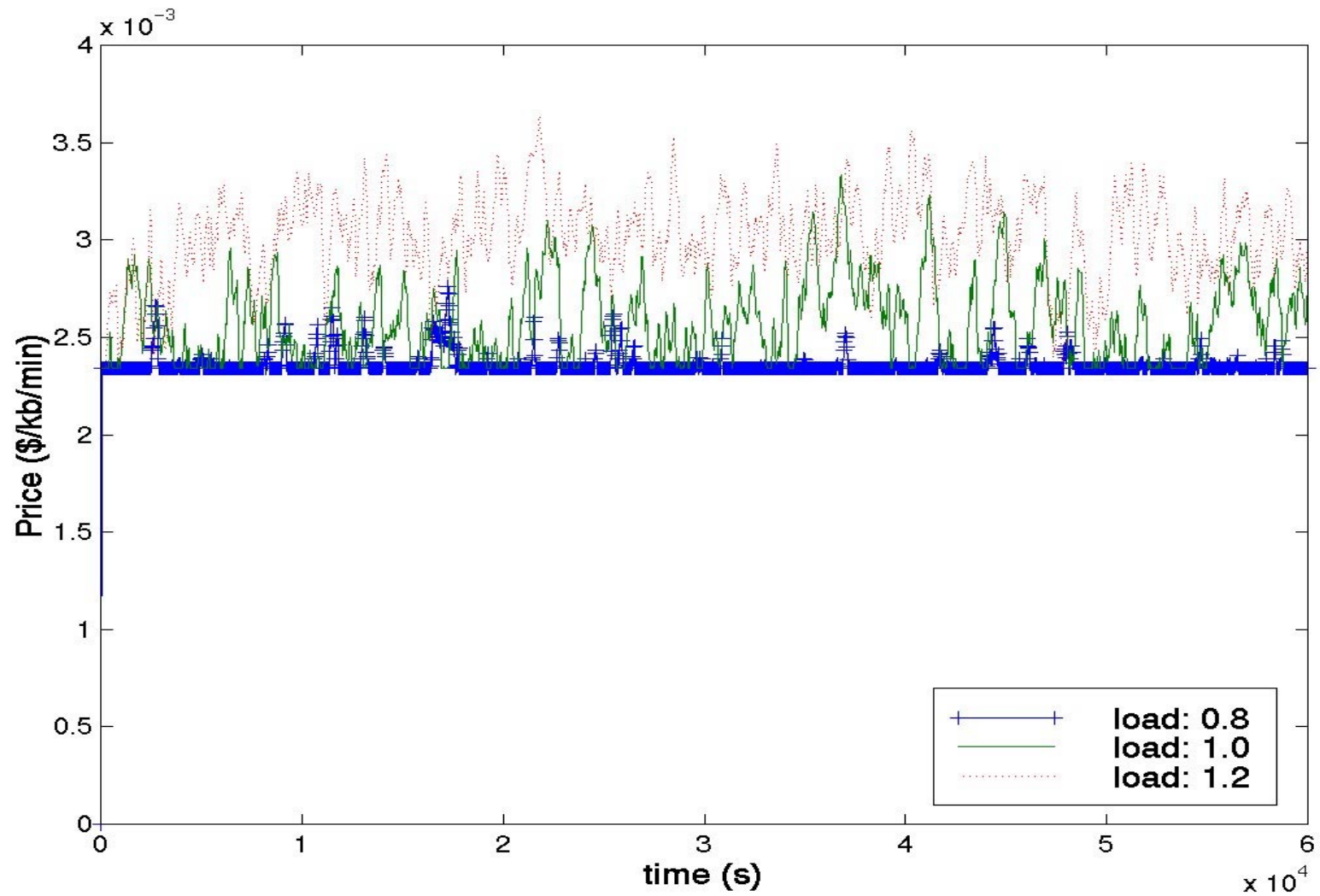


# Average user benefit (\$/min)



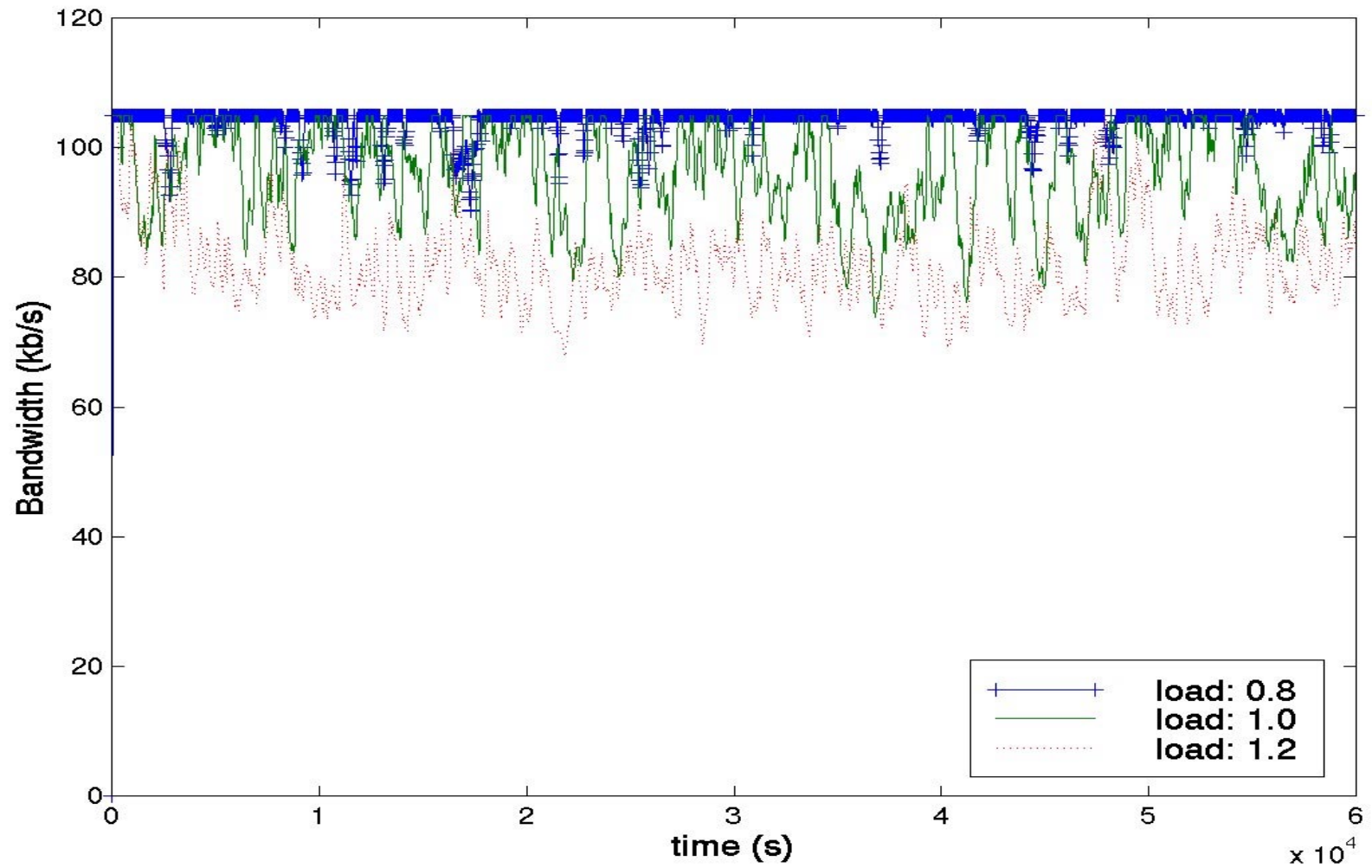


# Price (\$/kb/min)



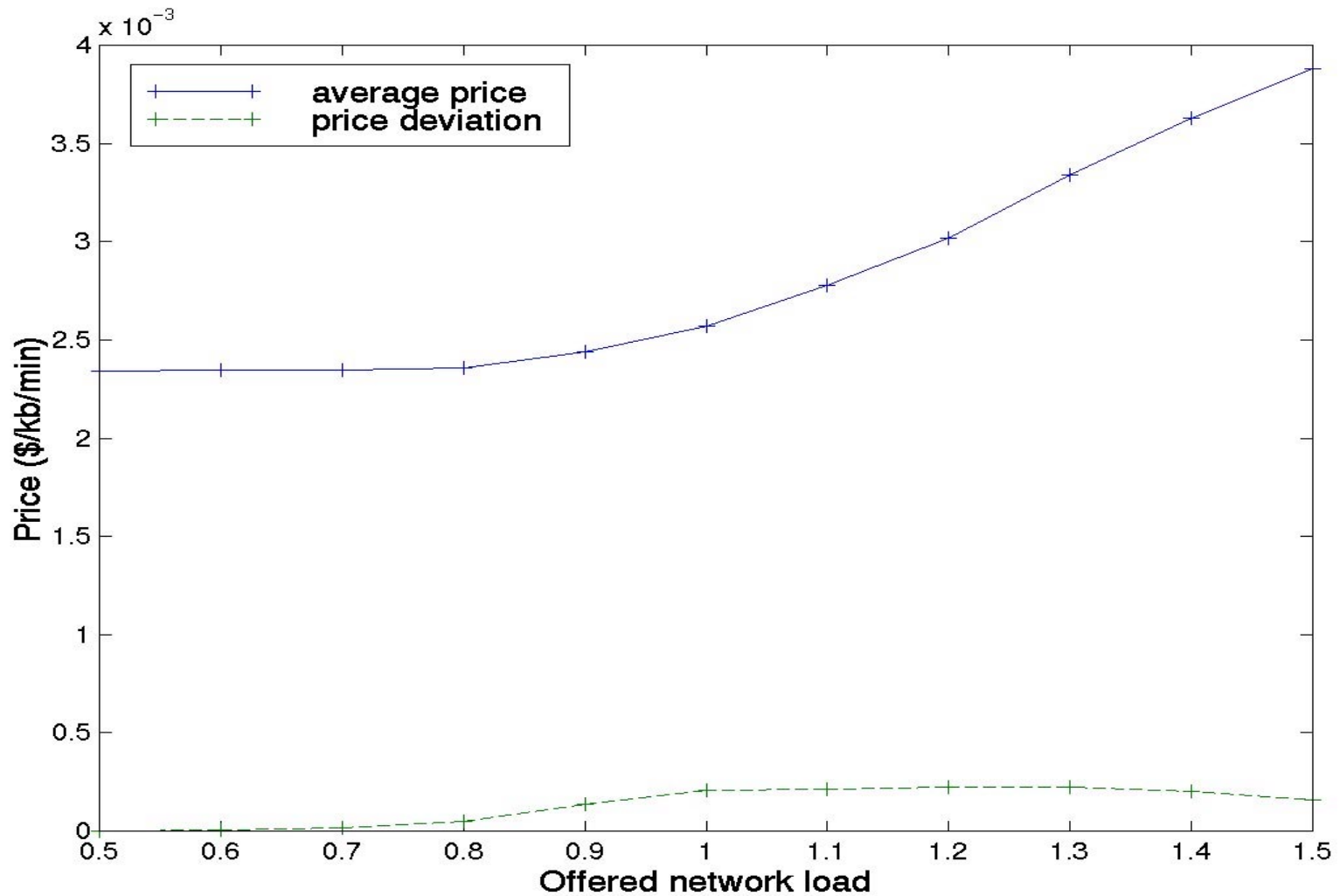
# User bandwidth (kb/s)

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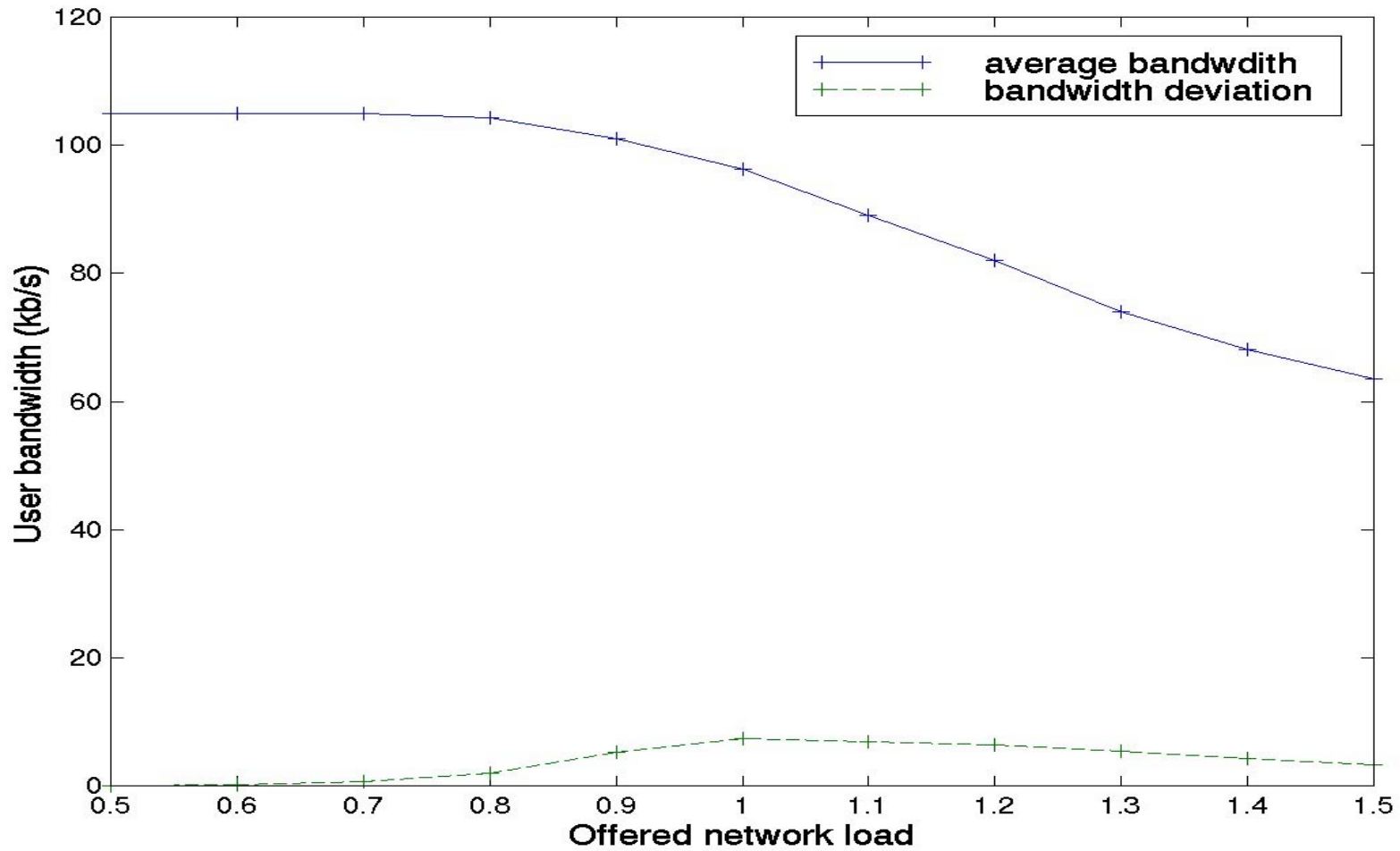
# Average price (\$/kb/min)

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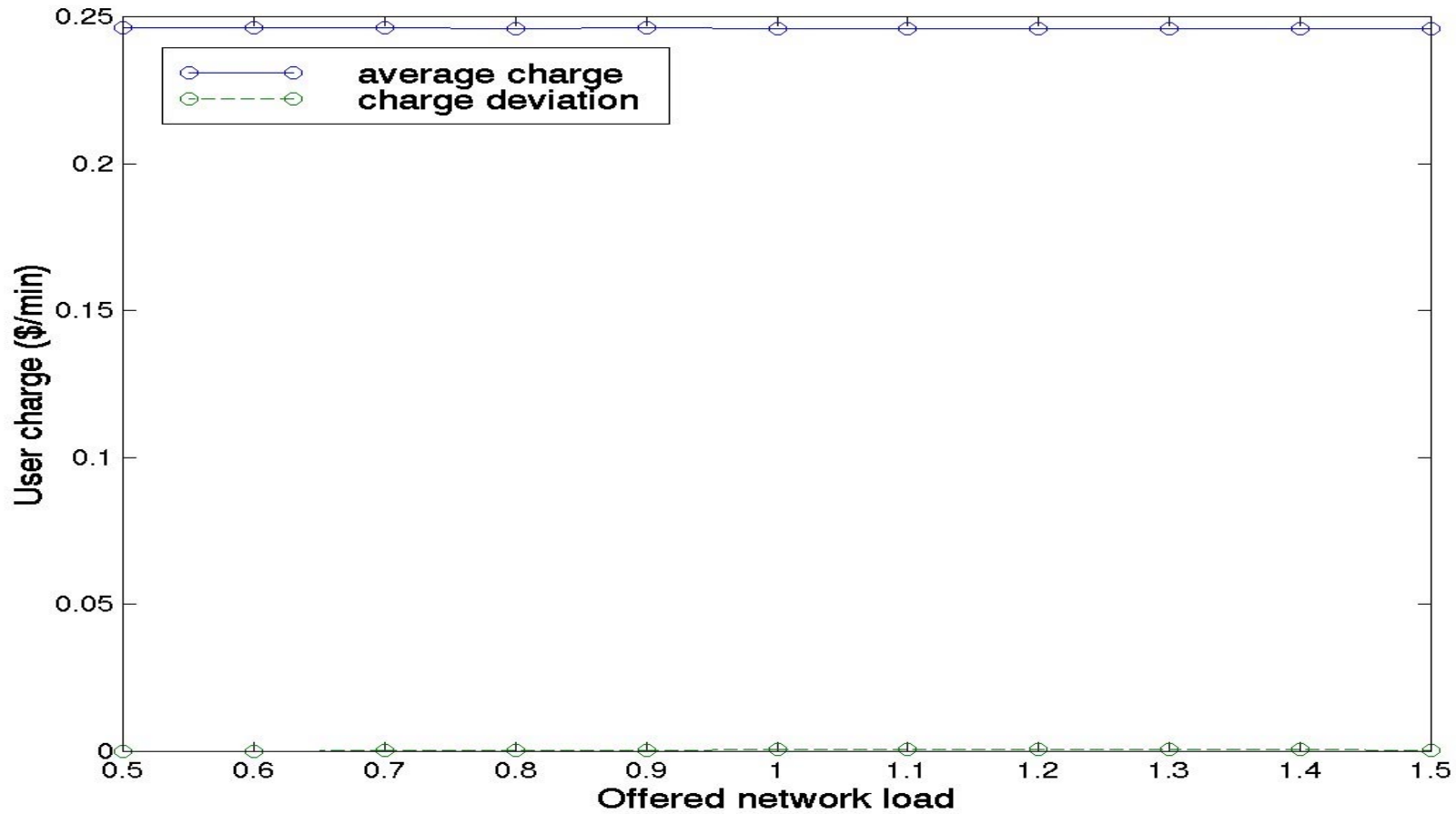
# Average user bandwidth (kb/s)

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# Average user charge (\$/min)

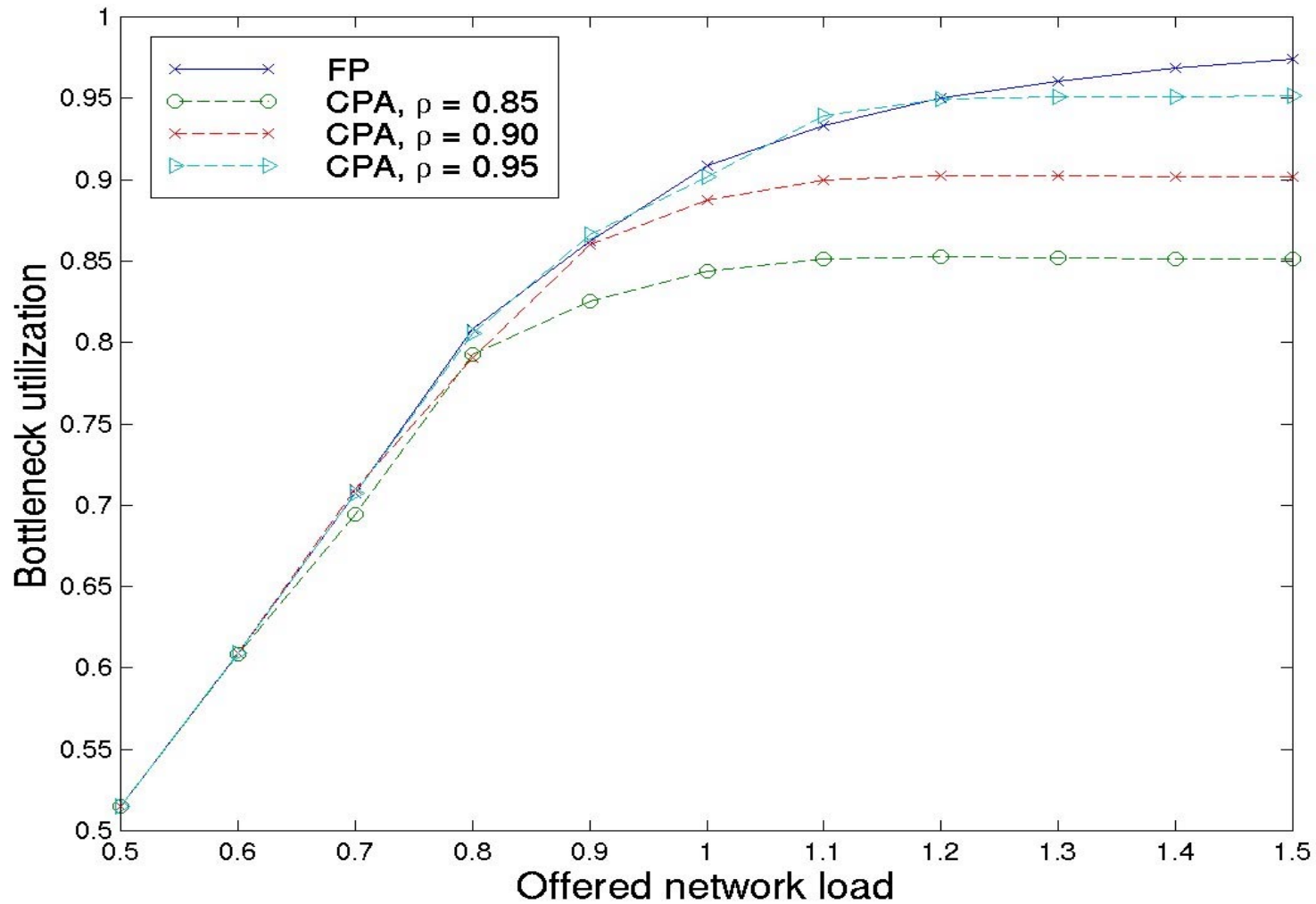
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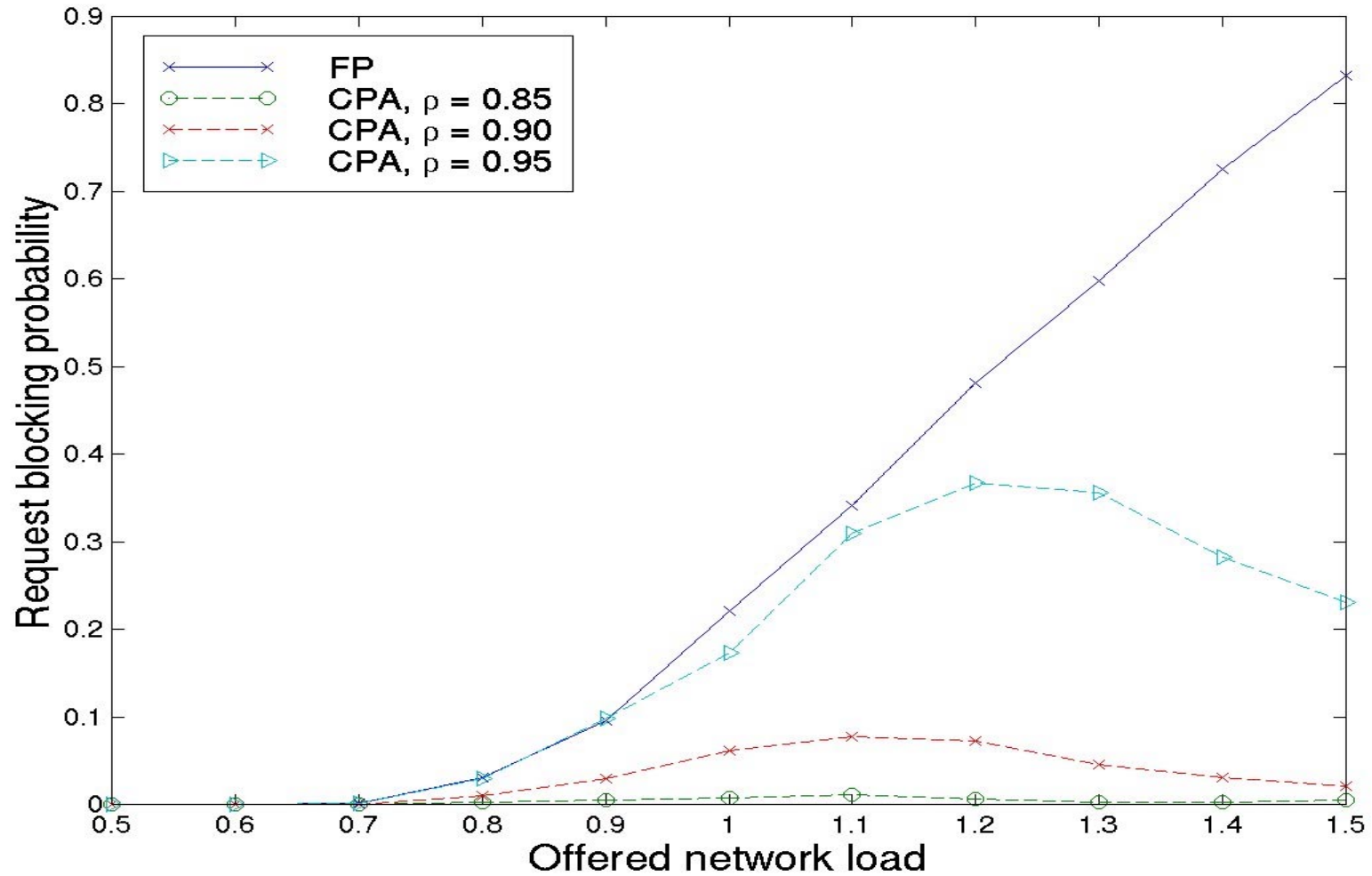
# Effect of target reservation rate

# Bottleneck utilization

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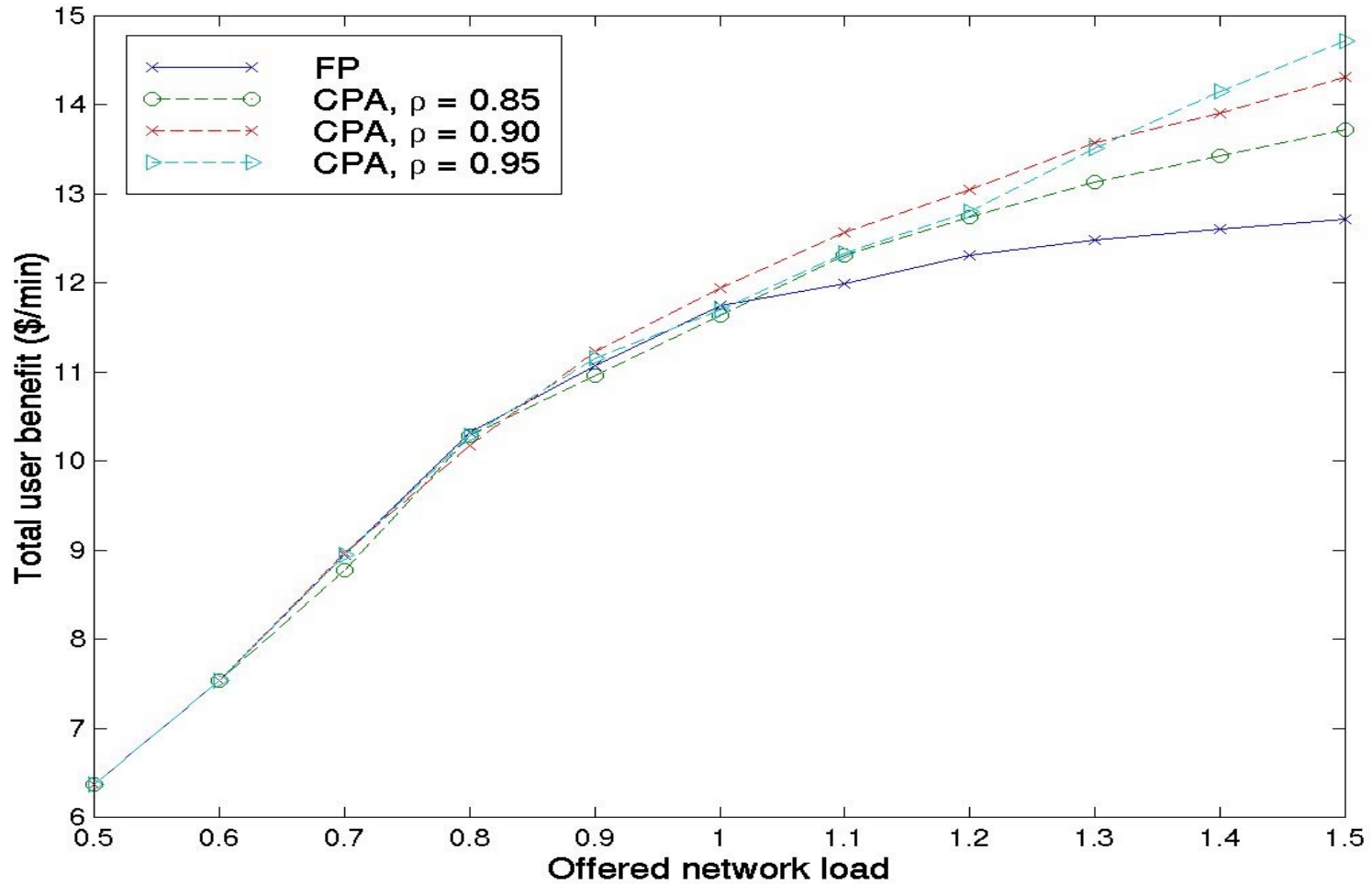


# Request blocking probability





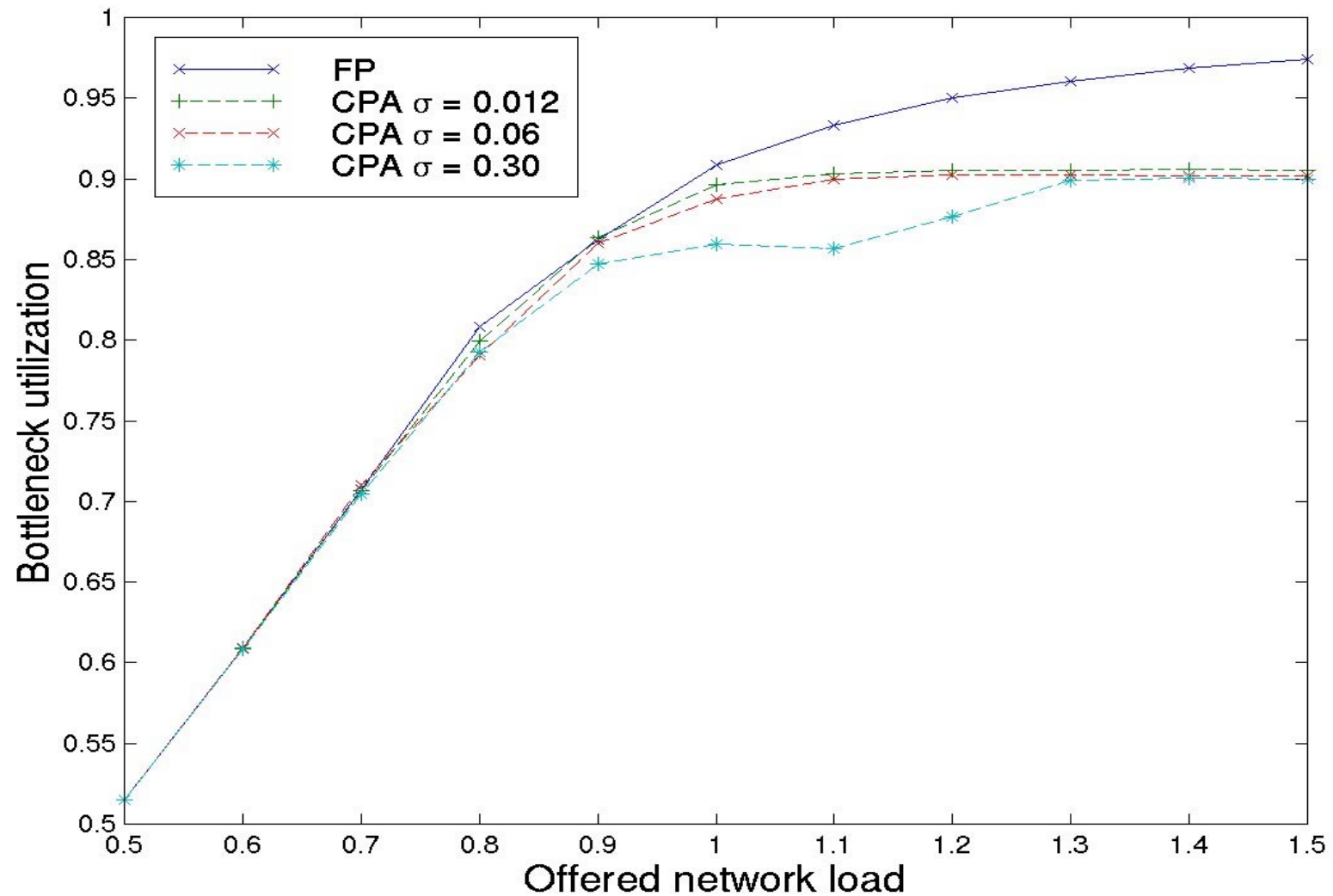
# Total user benefit



# Effect of Price Adjustment Step

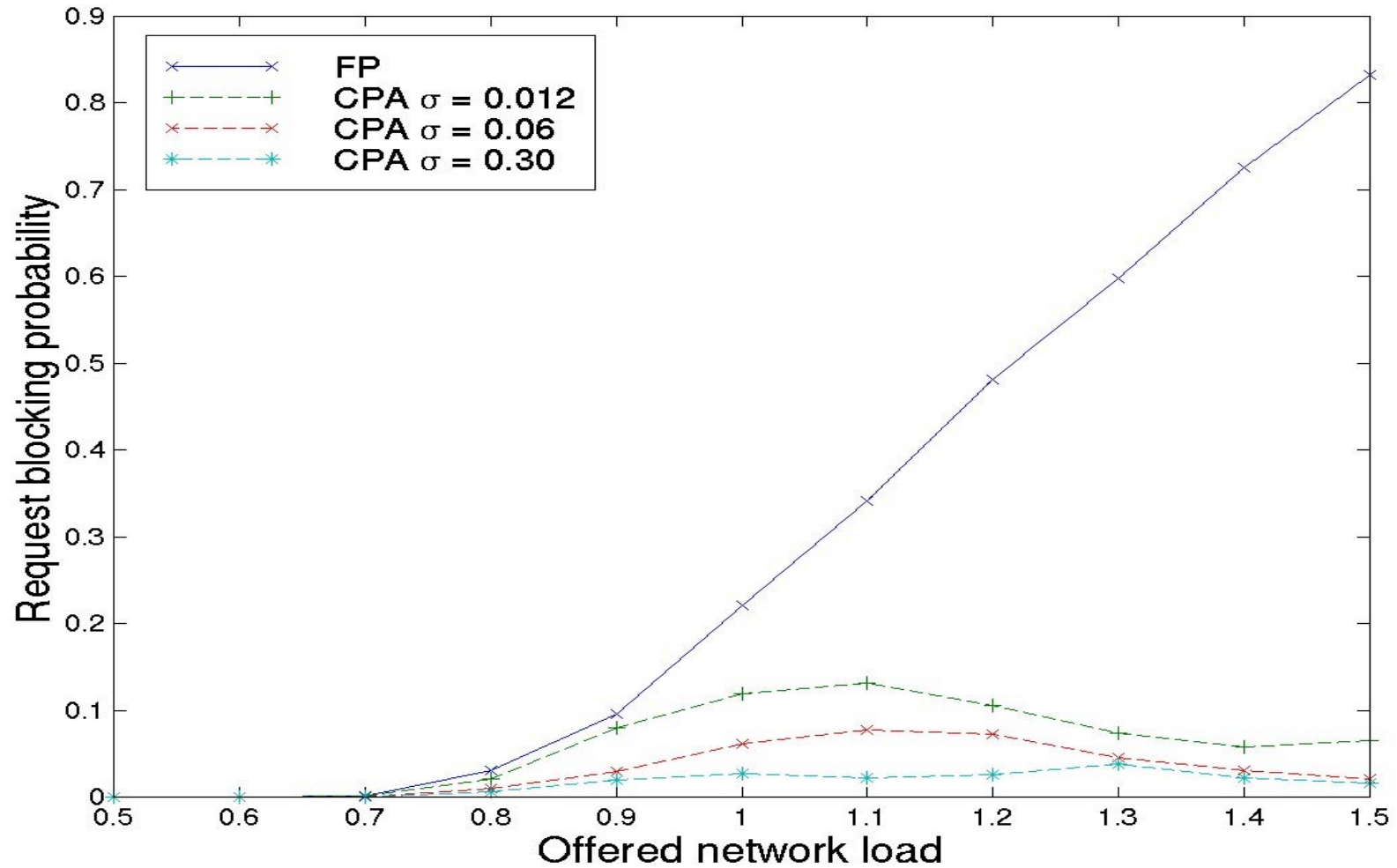
# Bottleneck utilization

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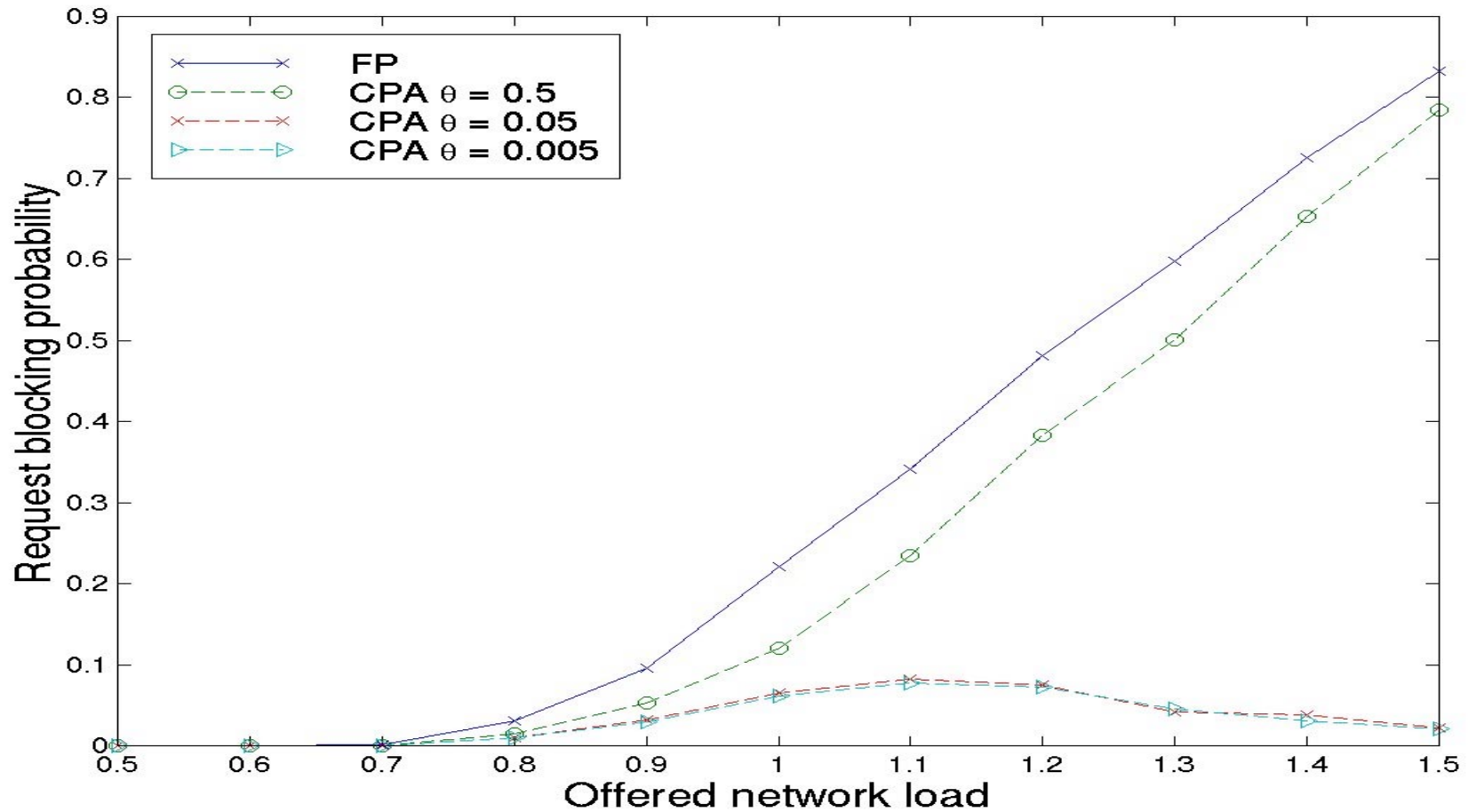
# Request blocking probability

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# Effect of Price Adjustment Threshold

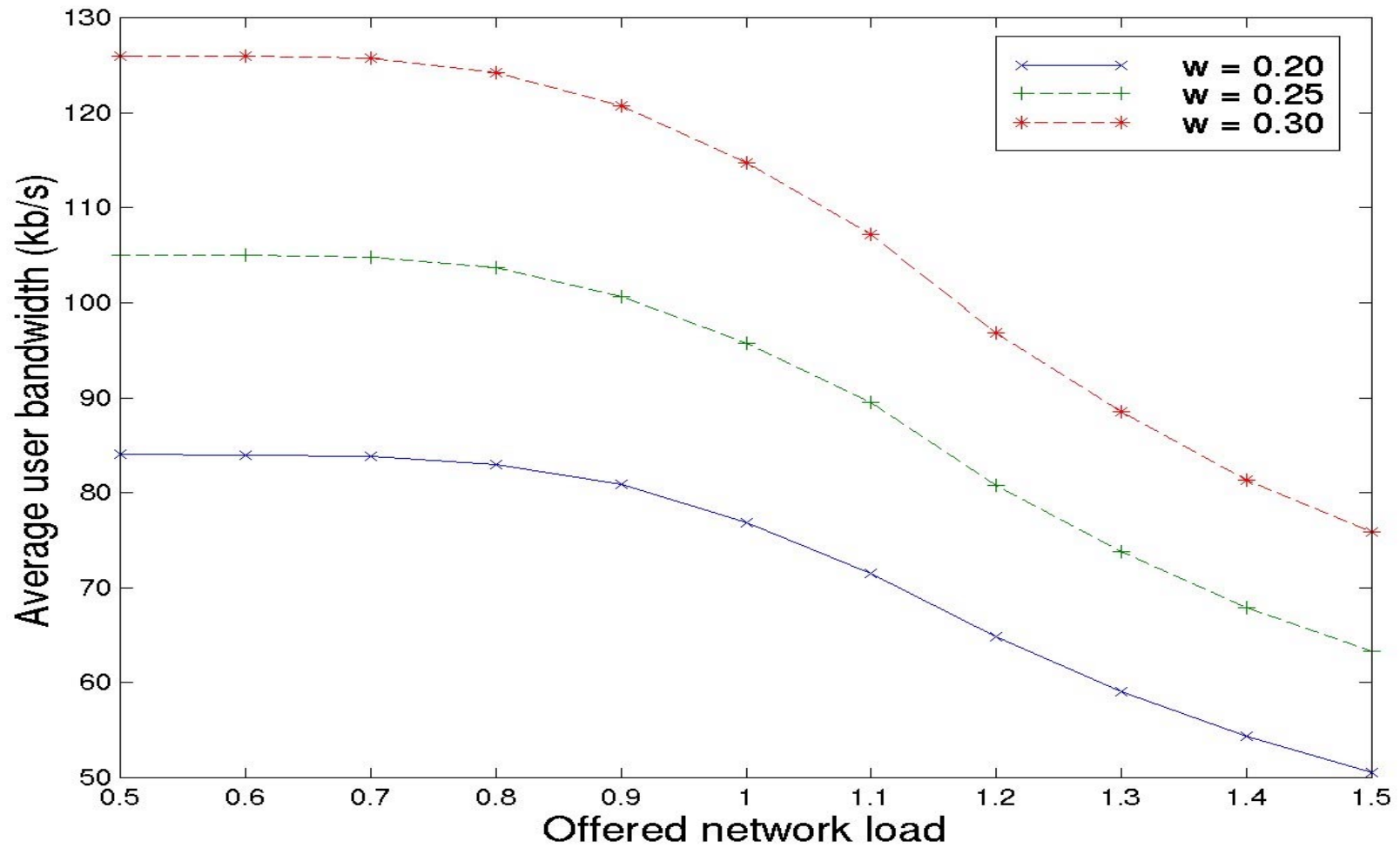
# Request blocking probability



# Effect of User Demand Elasticity

# Average user bandwidth

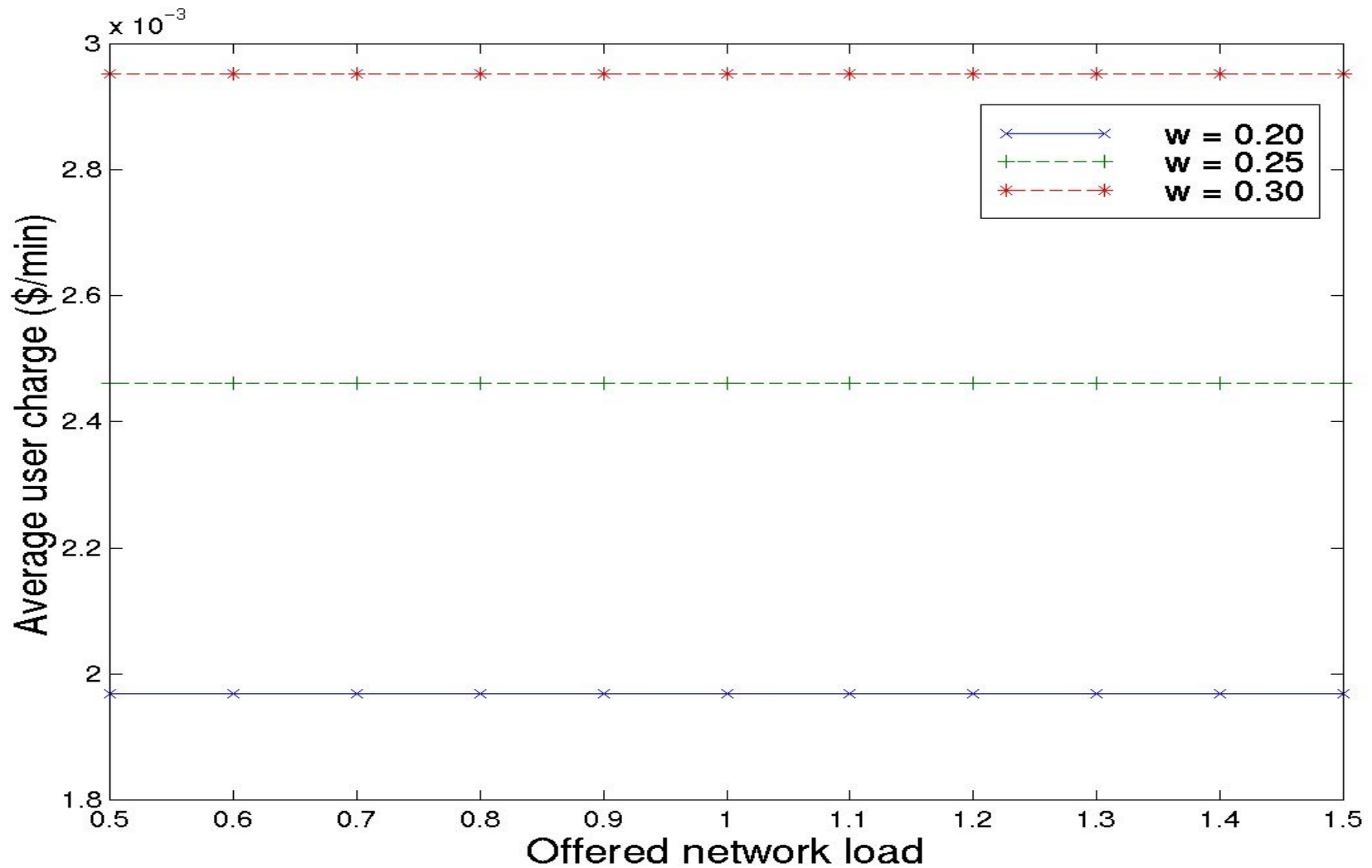
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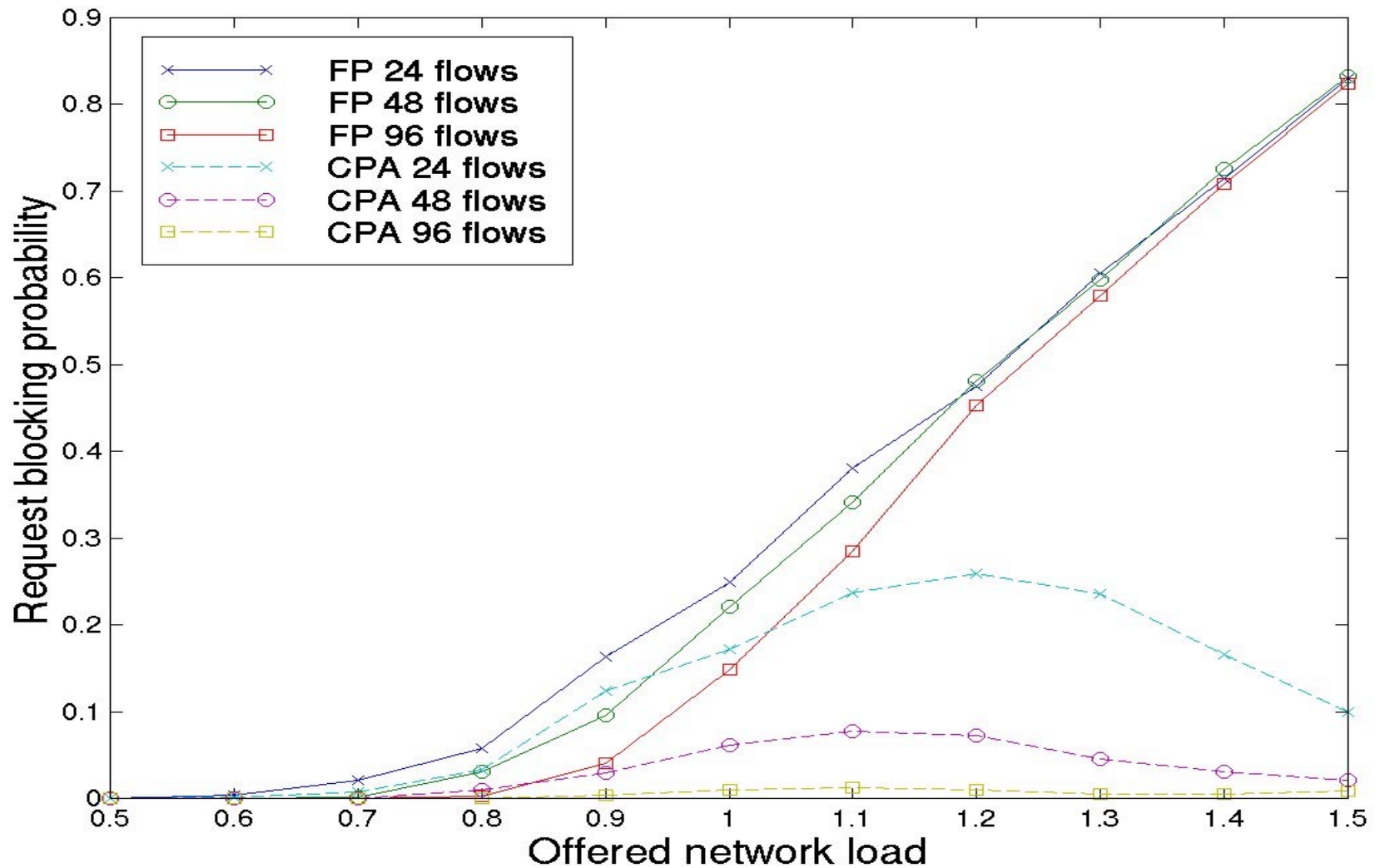
# Average user charge

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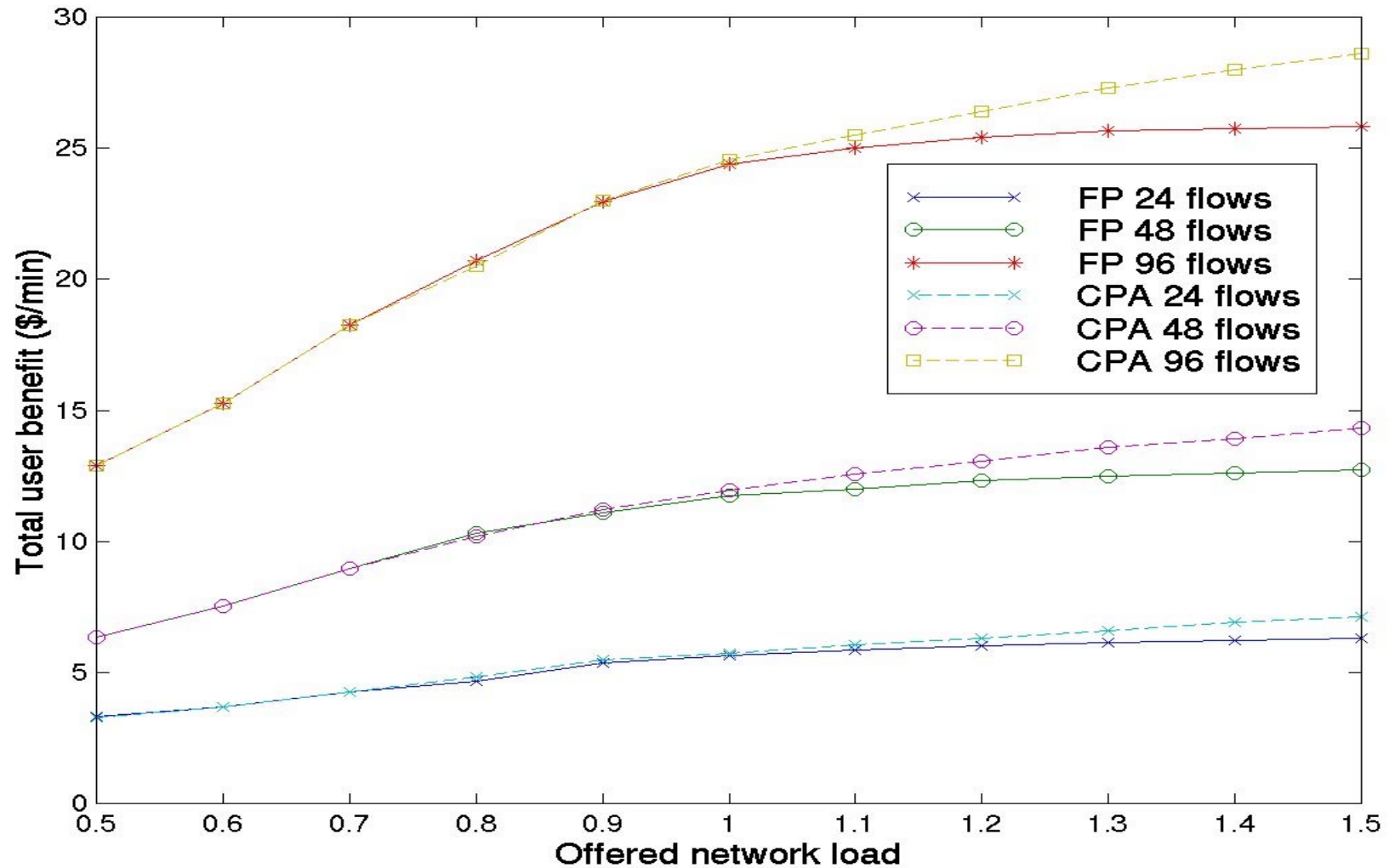


# Effect of Session Multiplexing

# Request blocking probability

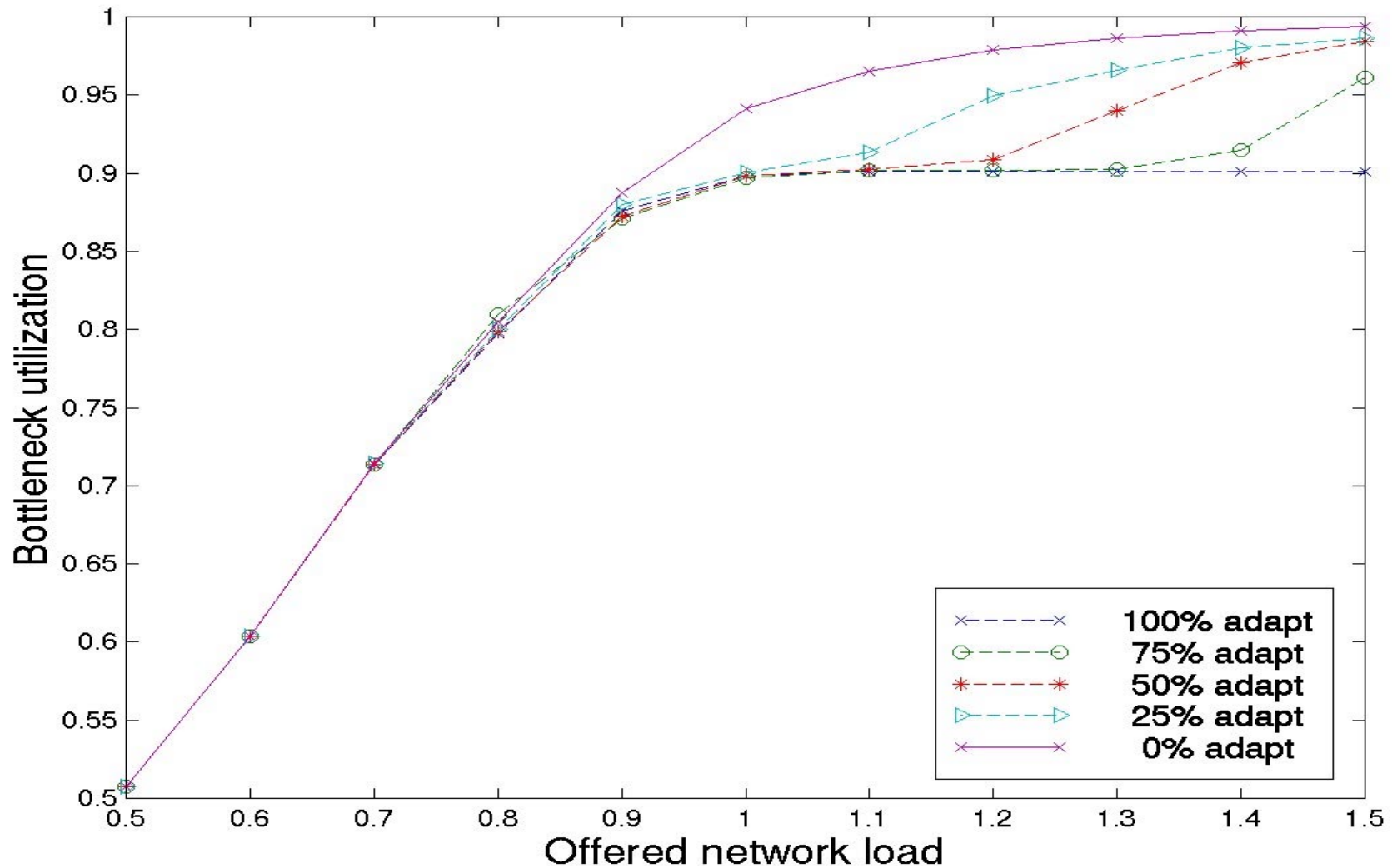


# Total user benefit

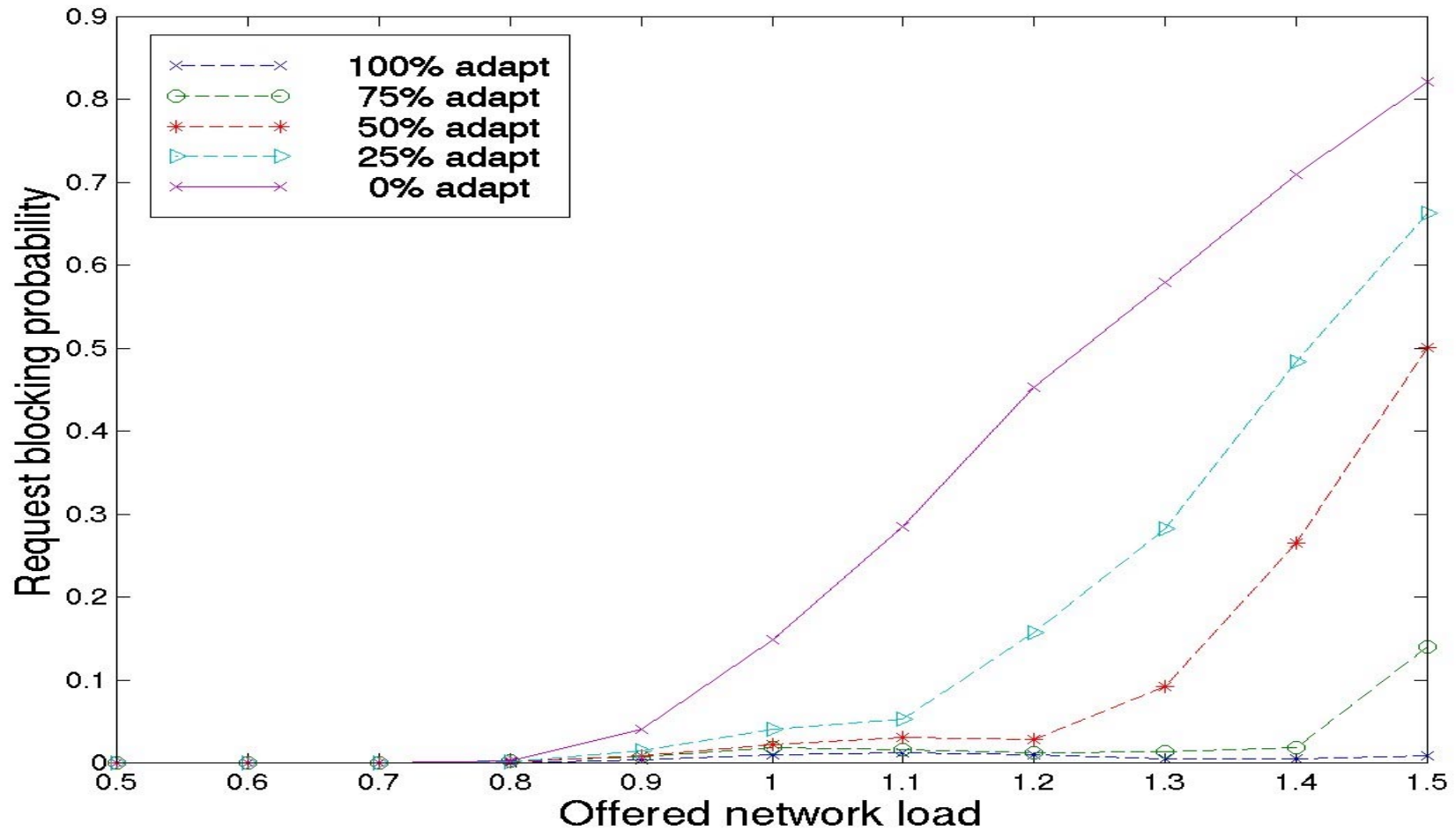


# Effect When Part of Users Adapt

# Bandwidth utilization



# Request blocking probability

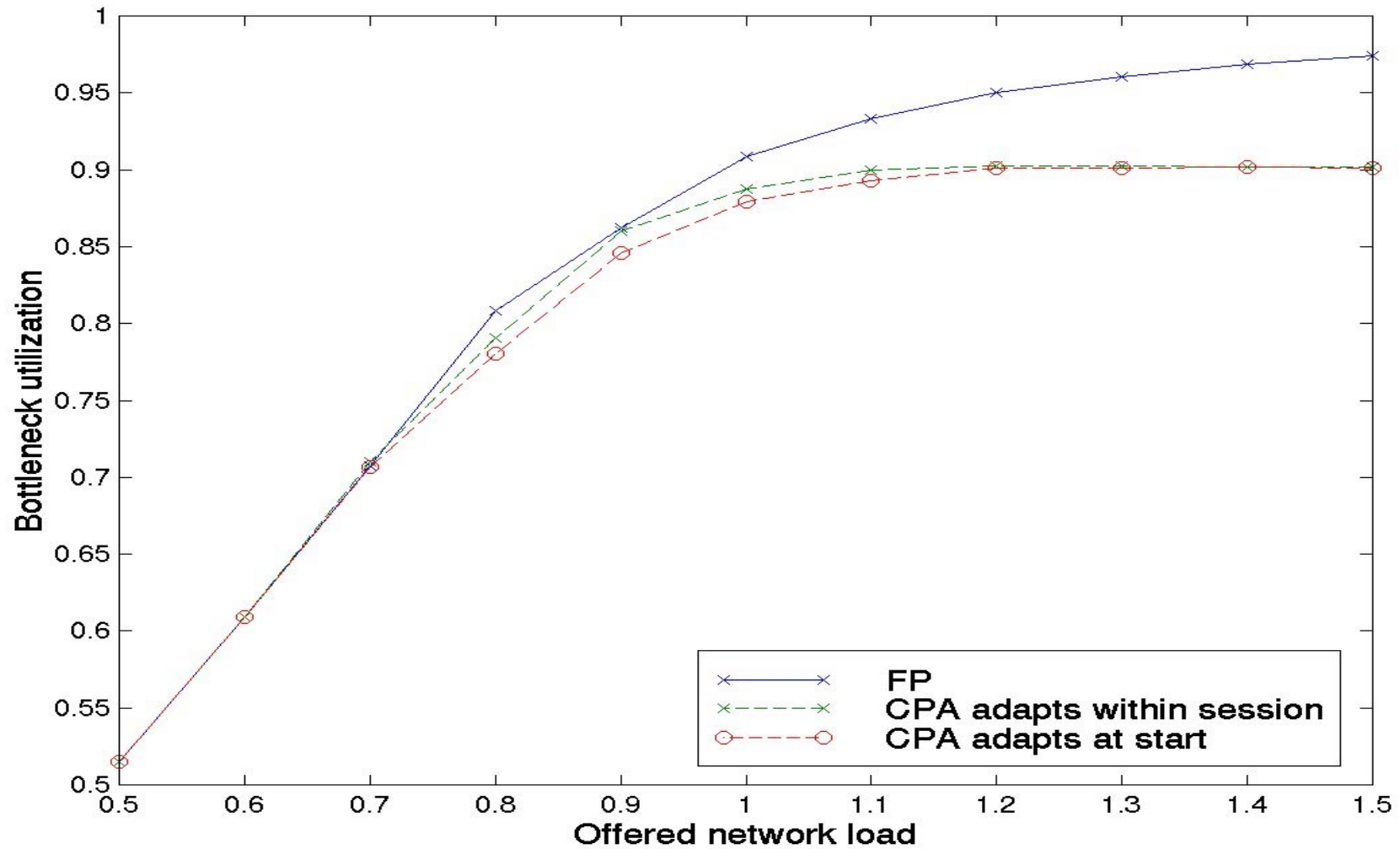


# Session Adaptation & Adaptive Reservation



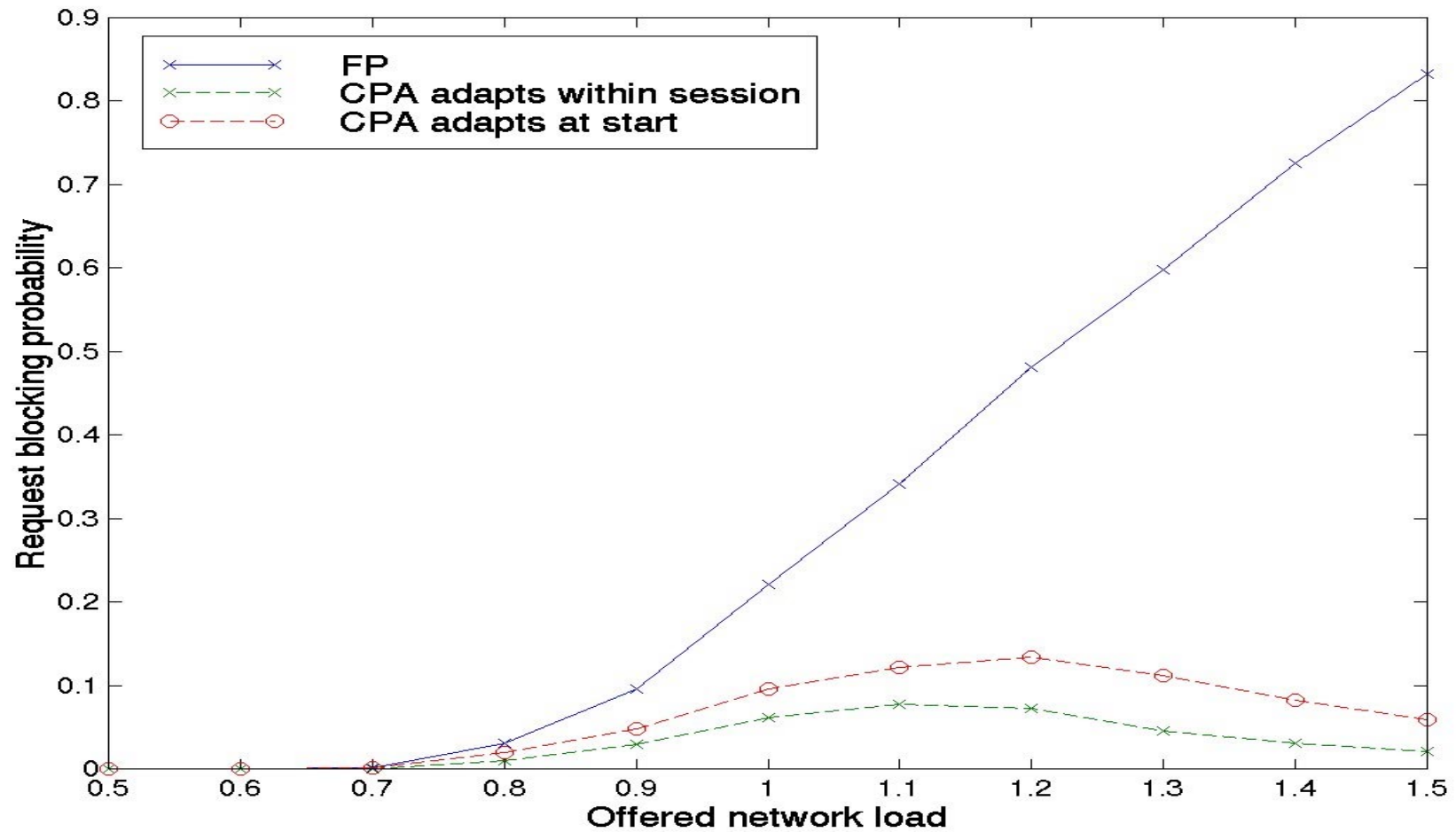
# Bandwidth utilization

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# Blocking probability

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# Conclusions

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- CPA gain over FP
  - Network availability, revenue, perceived benefit
  - Congestion price as control is stable and effective
- Target reservation rate (utilization):
  - User benefit ↓, with too high or too low utilization
  - Too low target rate, demand fluctuation is high
  - Too high target rate, high blocking rate

# Conclusions

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- Effect of price scaling factor  $\sigma$ 
  - $\sigma \uparrow$ , blocking rate  $\downarrow$
  - Too large  $\sigma$ , under-utilization, large dynamics
- Effect of price adjustment threshold  $\theta$ 
  - Too high, no meaningful adaptation
  - Too low, no big advantage

# Conclusions

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- Demand elasticity
  - Bandwidth sharing is proportional to its willingness to pay
- Portion of user adaptation results in overall system performance improvement