Performance Study of Congestion Price Based Adaptive Service

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Outline

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

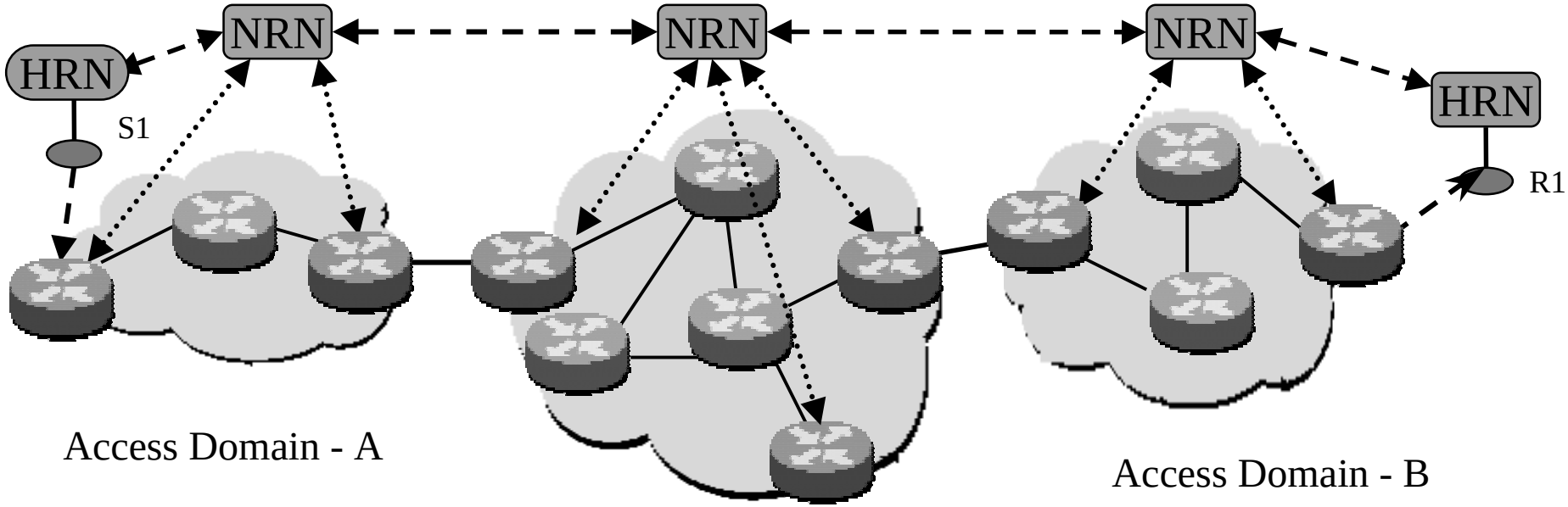
Resource Negotiation & RNAP

- 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.)

- 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

NRN Network Resource Negotiator

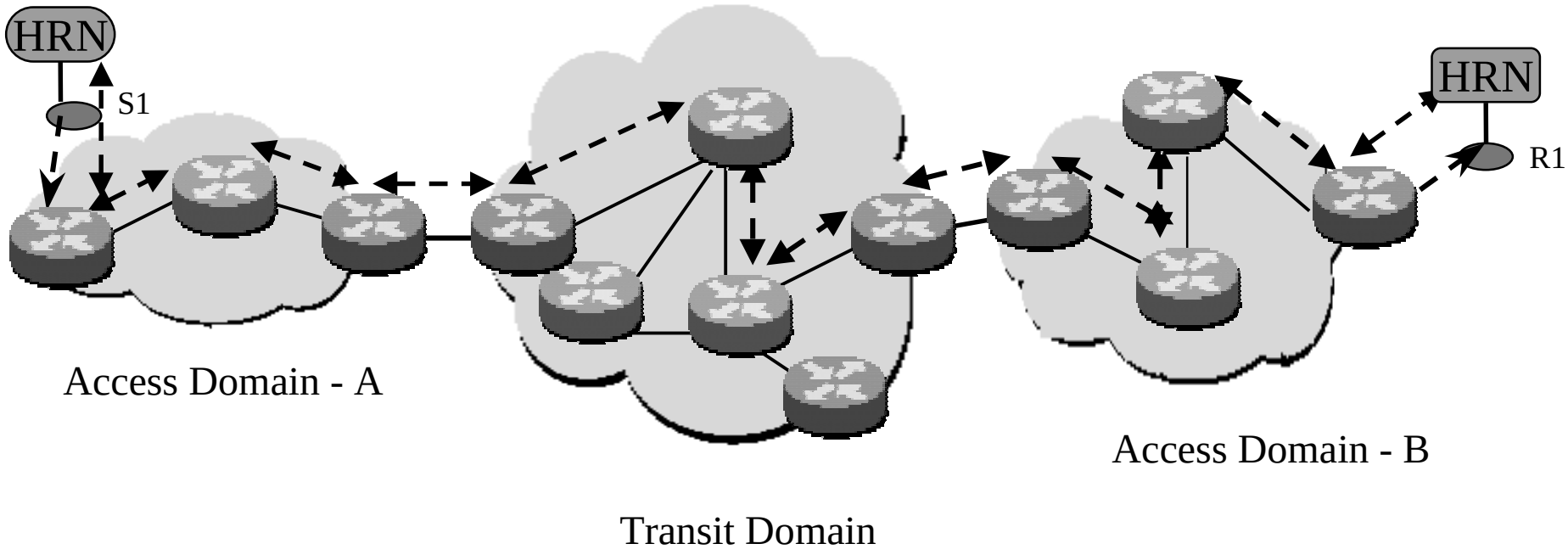
HRN Host Resource Negotiator

Data

RNAP Messages

Intra domain messages

Distributed Architecture (RNAP-D)




Internal Router


Edge Router

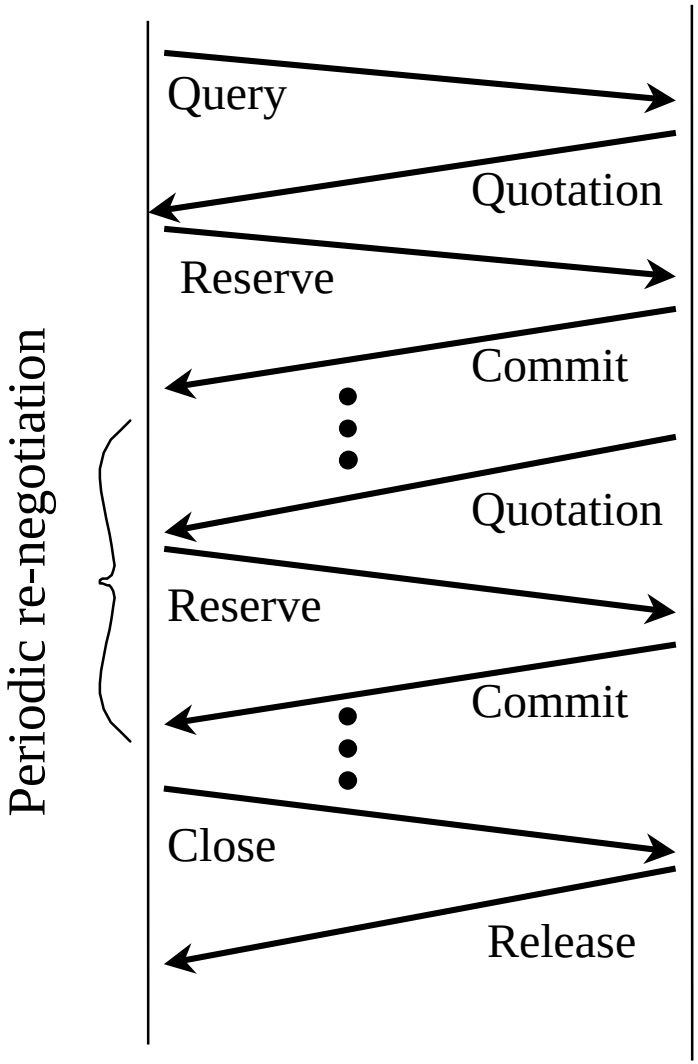

Host

HRN Host Resource Negotiator

RNAP Messages

Data

Resource Negotiation & RNAP (cont'd.)



Query: User enquires about available services, prices

Quotation: Network specifies services supported, prices

Reserve: User requests service(s) for flow(s) (Flow Id-Service-Price triplets)

Commit: Network admits the service request at a specific price or denies it (Flow Id-Service-Status-Price)

Close: tears down negotiation session

Release: release the resources

Pricing Strategy

- Current Internet:
  - Access rate dependent charge (AC)
  - Volume dependent charge (V)
  - AC + V ⟶ 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

- Congestion-based Pricing
  - Usage charge:
    $p_u = f$ (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.)

- A generic pricing structure
  - $Cost = c_{ac}(r_{ac}) + p(r_{ac}) \times (t-t_m)^+ + \Sigma_i\Sigma_n [p_h^i(n) \; x \; r^i(n) \; x\tau + (p_u^i(n) + p_c^i(n)) \times v^i(n)] (v^i-v_m^i)^+$
    - **c_{ac}:** access charge; **r_{ac}** : *access rate*
    - p (r_{ac}): unit time price
    - i: class i; n: nth negotiation interval;
    - *τ: negotiation period*
    - t_m: the minimum time without charge
    - v_m: the volume transferred free of charge

User Adaptation

- Based on perceived value
- Application adaptation
  - Maximize total utility over the total cost
  - Constraint:

    budget, min QoS & max QoS

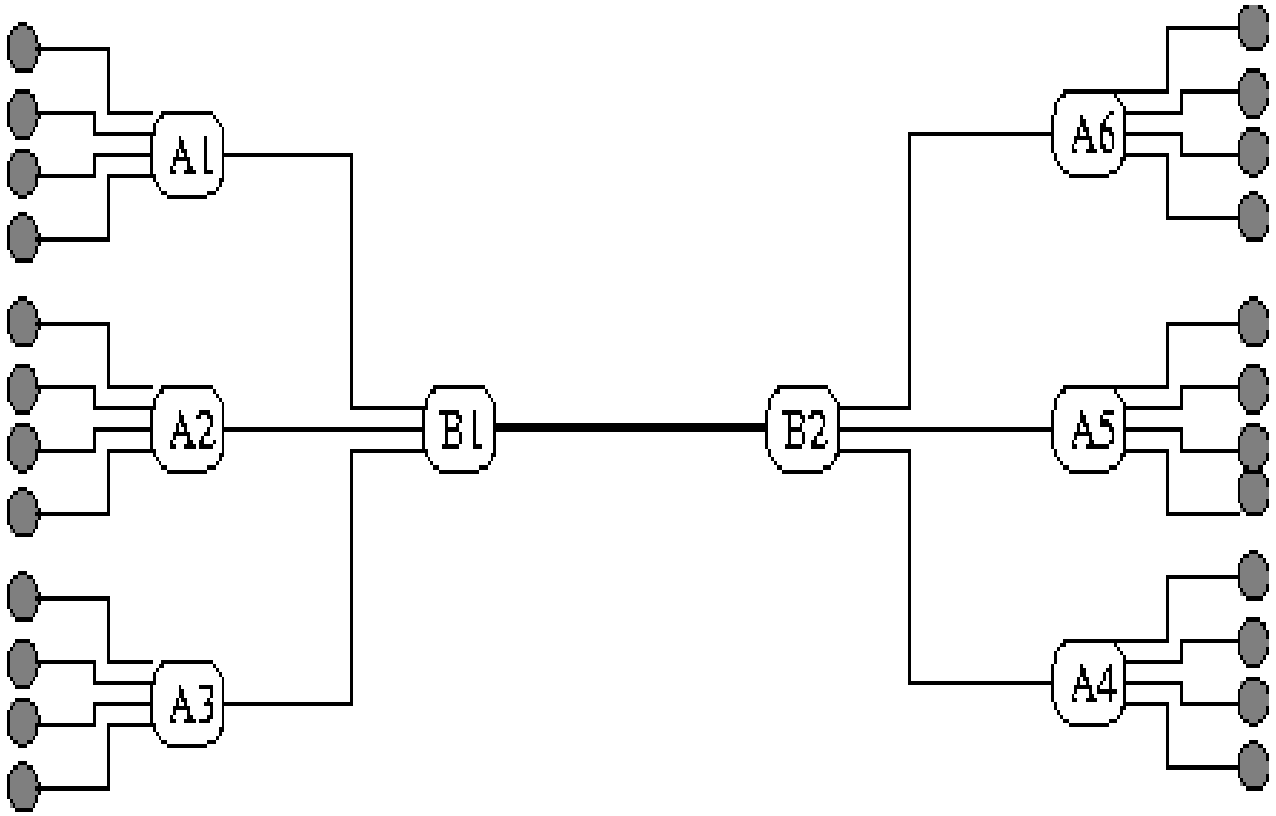
CPA & FP

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

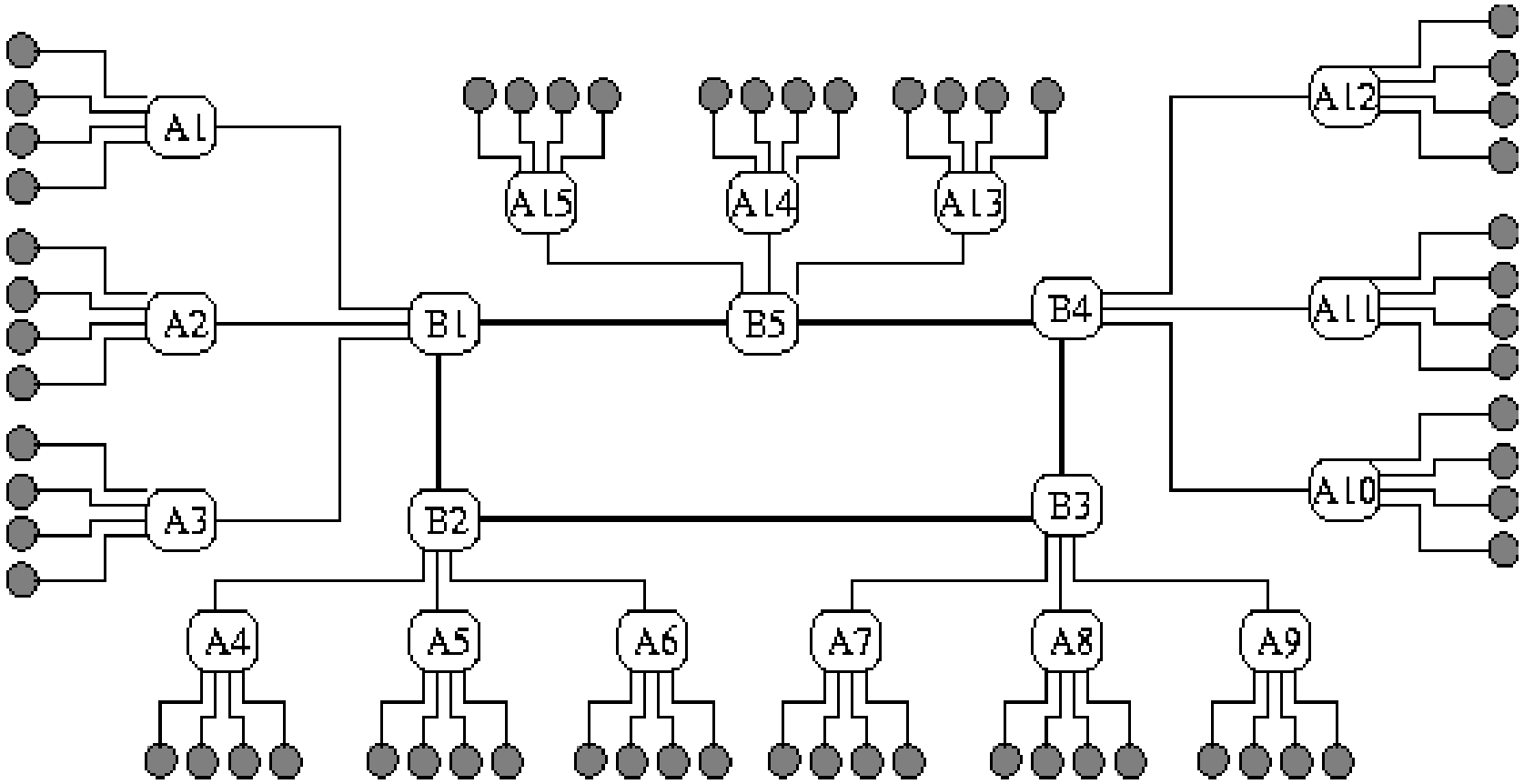
User Adaptation (cont'd.)

- 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: $x^j = (b \times \omega^j / \Sigma_l \omega^l) / p^j$
    - Affordable resource is distributed proportionally among applications of the system, based on the user's preference and budget for each application.

Simulation Model



Simulation Model



Simulation Model (cont'd.)

- 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.)

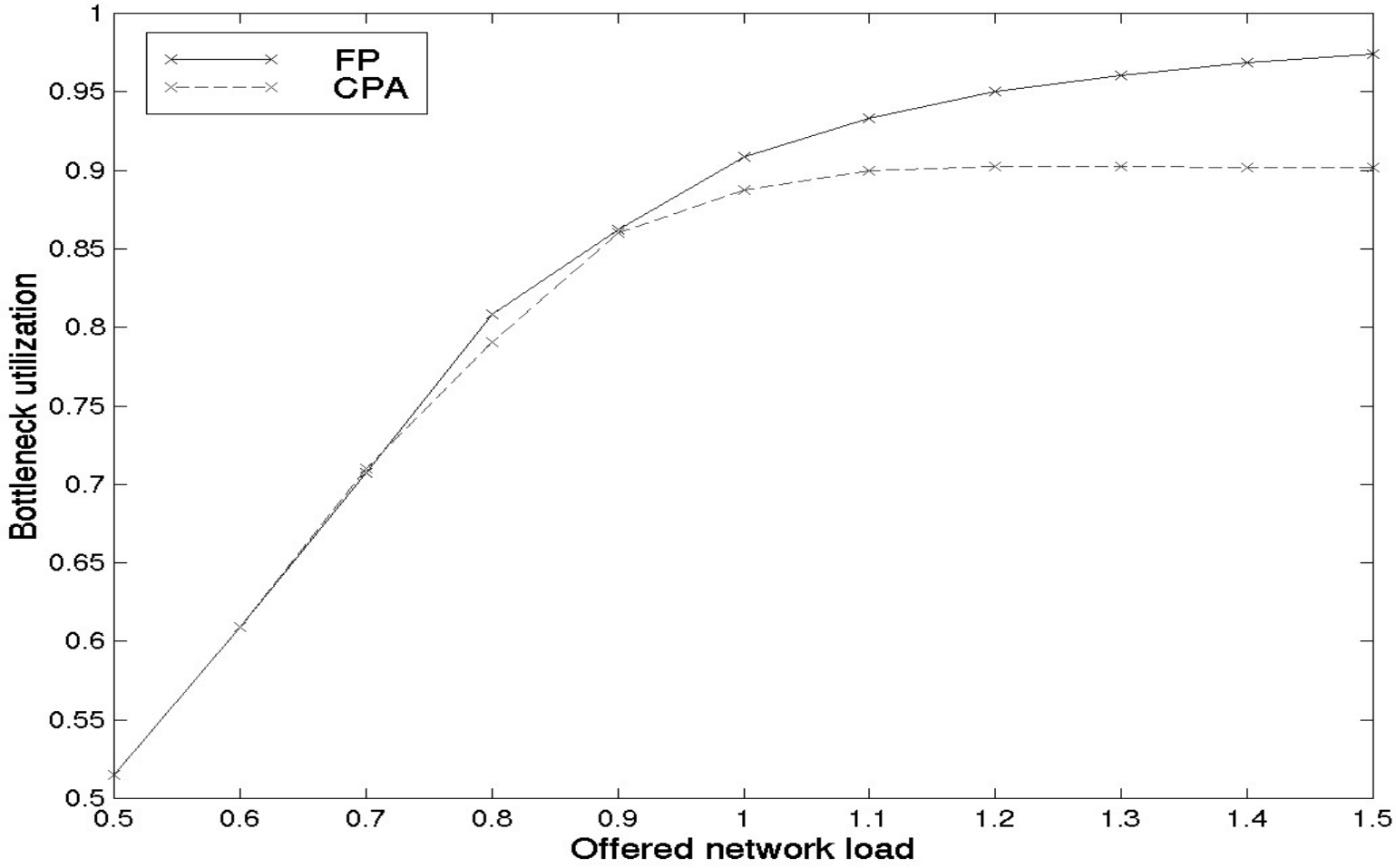
- Performance measures
  - Bottleneck bandwidth utilization
  - User request blocking probability
  - Average and total user benefit
  - Network revenue
  - System price
  - User charge

Design of the Experiments

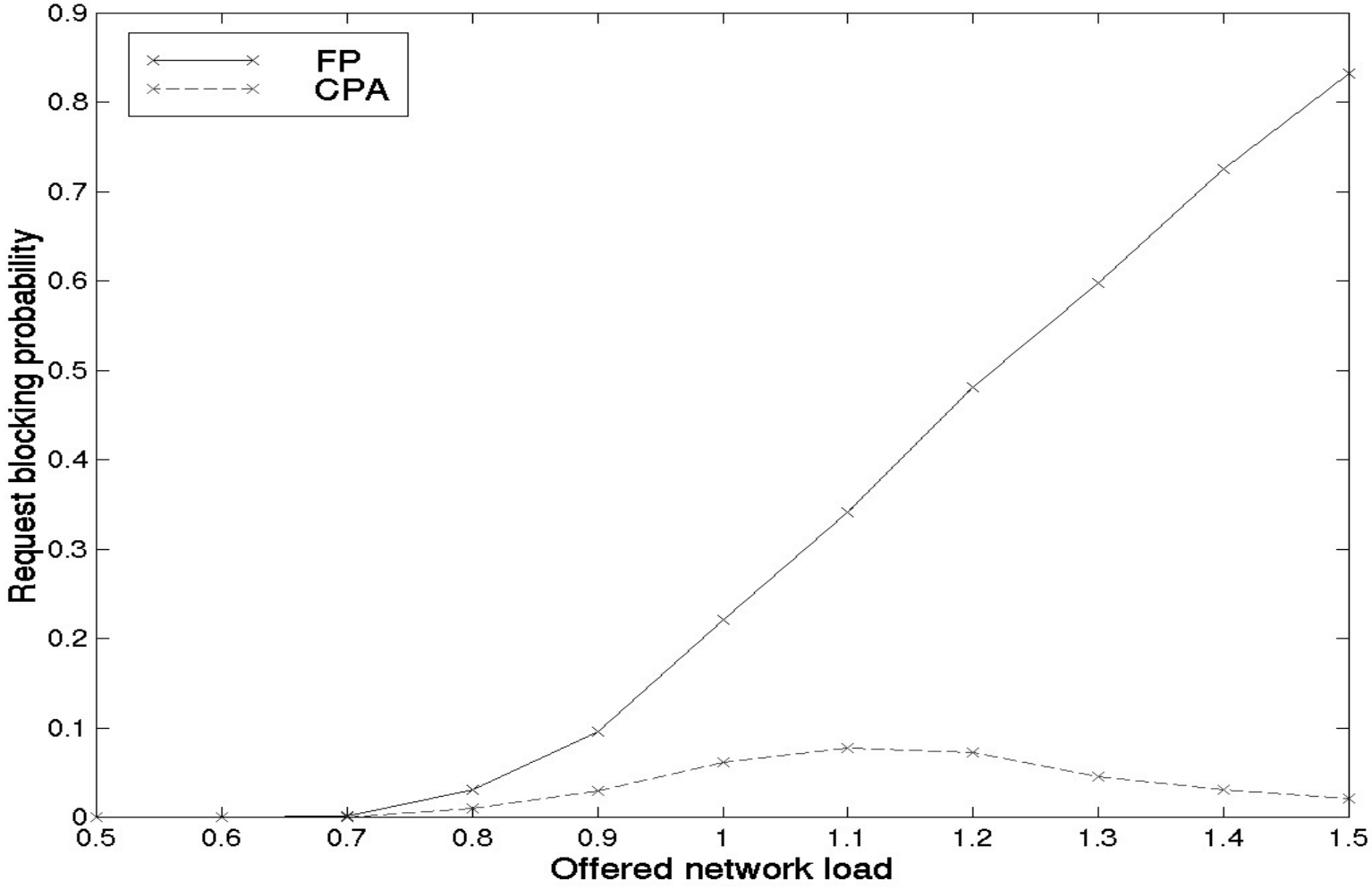
- Performance comparison of CPA & FP
- Effect of system control parameters:
  - target reservation rate
  - price adjustment step
  - price adjustment threshold
- Effect of user demand elasticity
- Effect of session multiplexing
- Effect when part of users adapt
- Session adaptation and adaptive reservation

Performance Comparison of CPA and FP

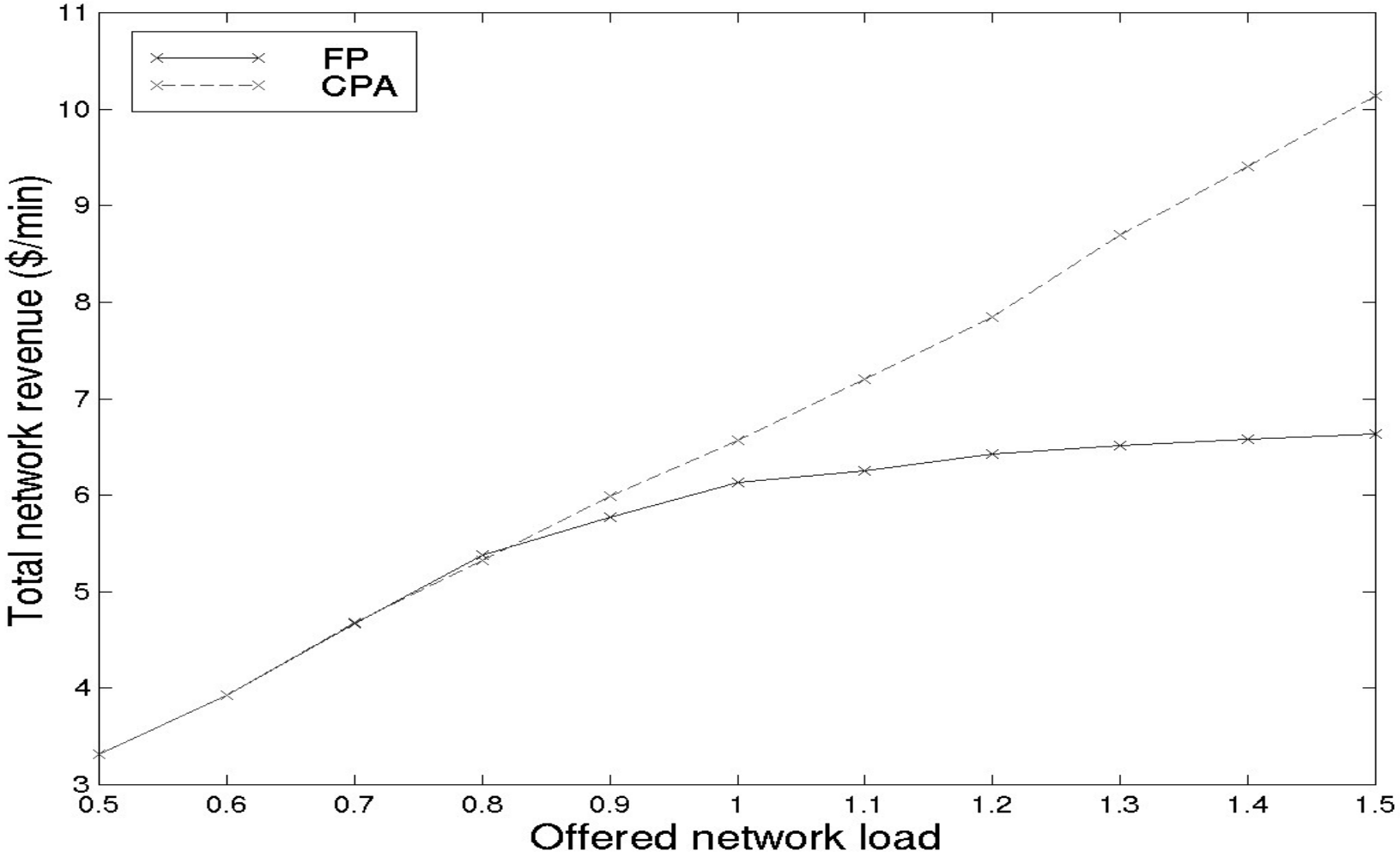
Bottleneck Utilization



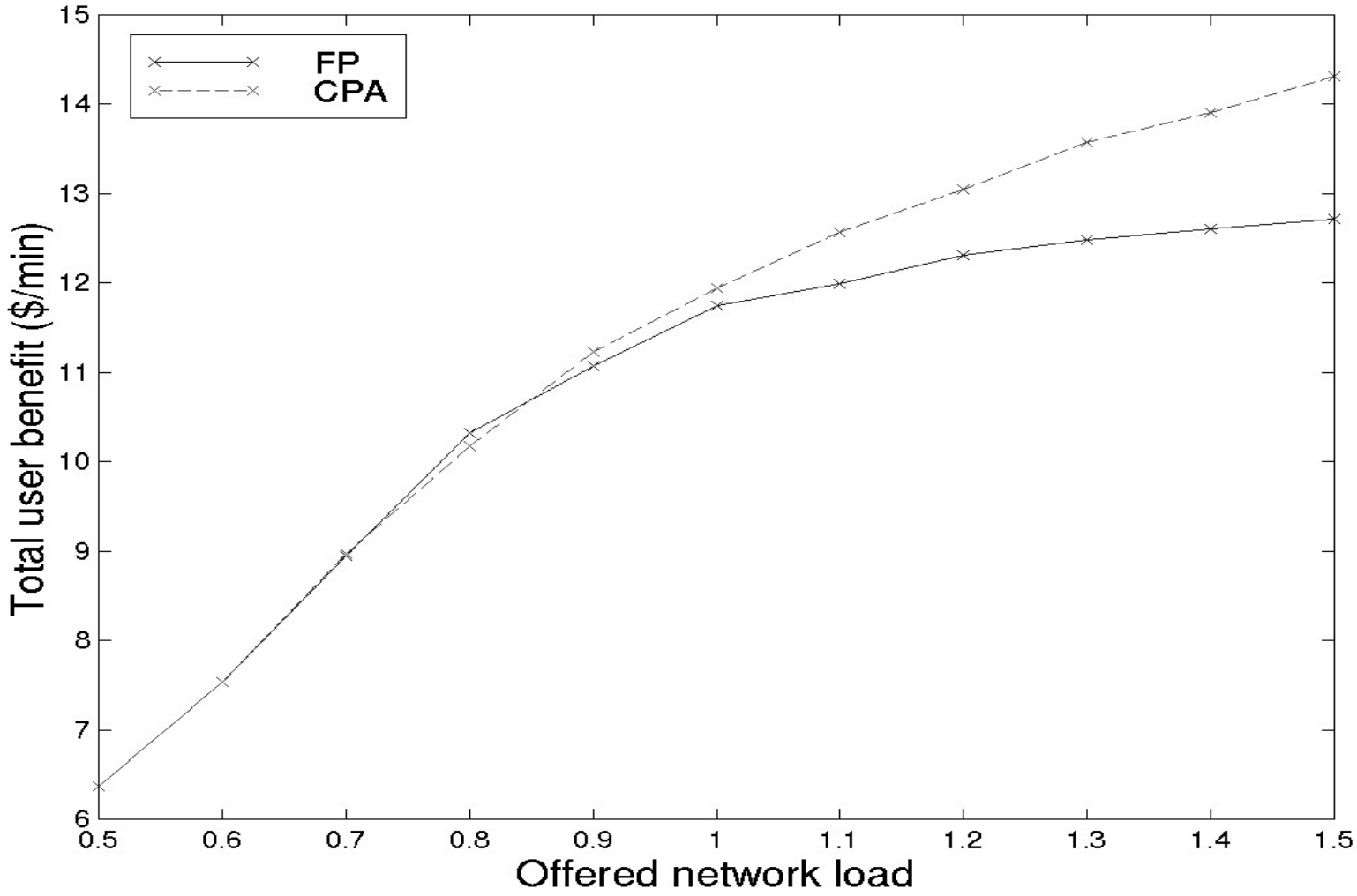
Request blocking probability



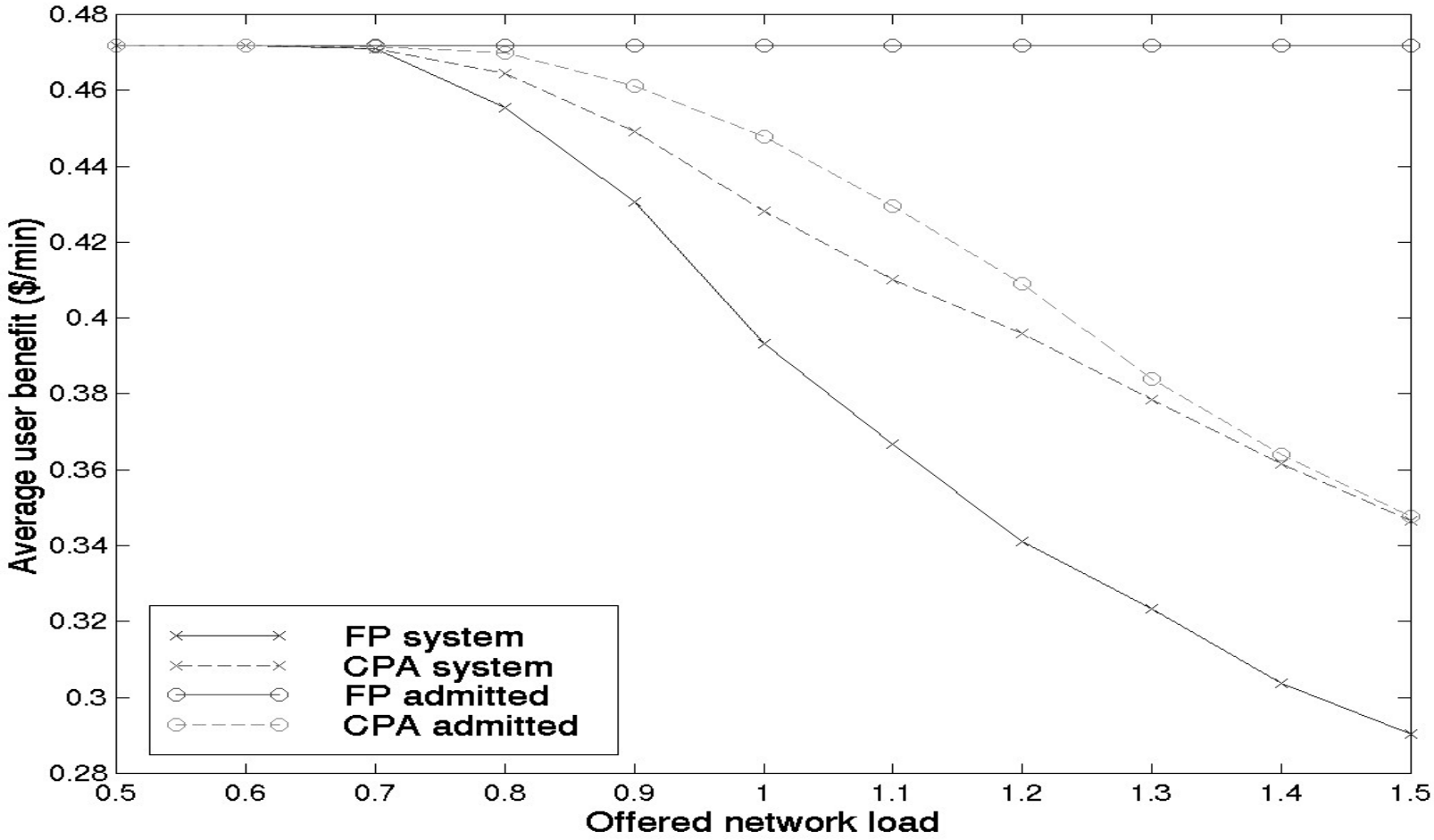
Total network revenue ($/min)



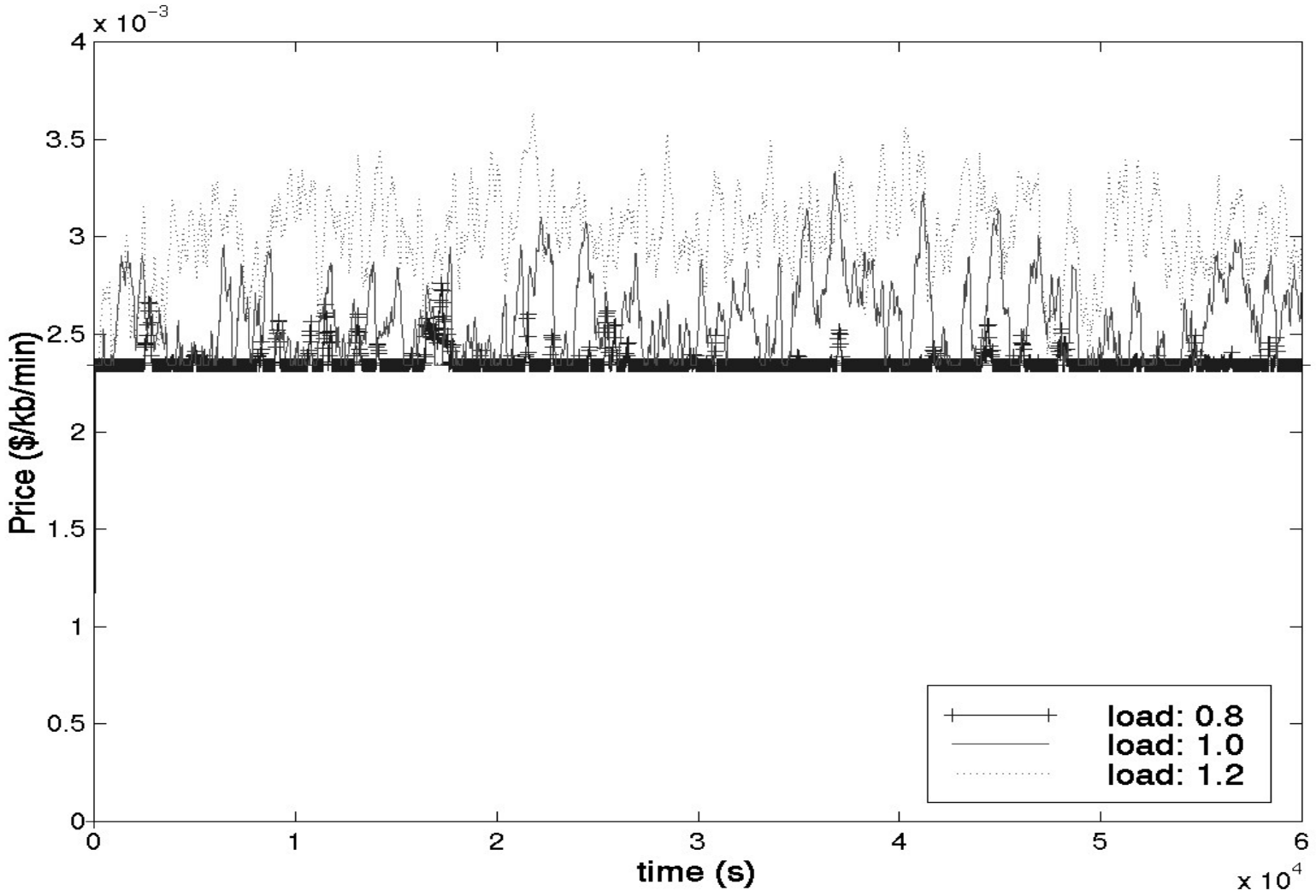
Total user benefit ($/min)



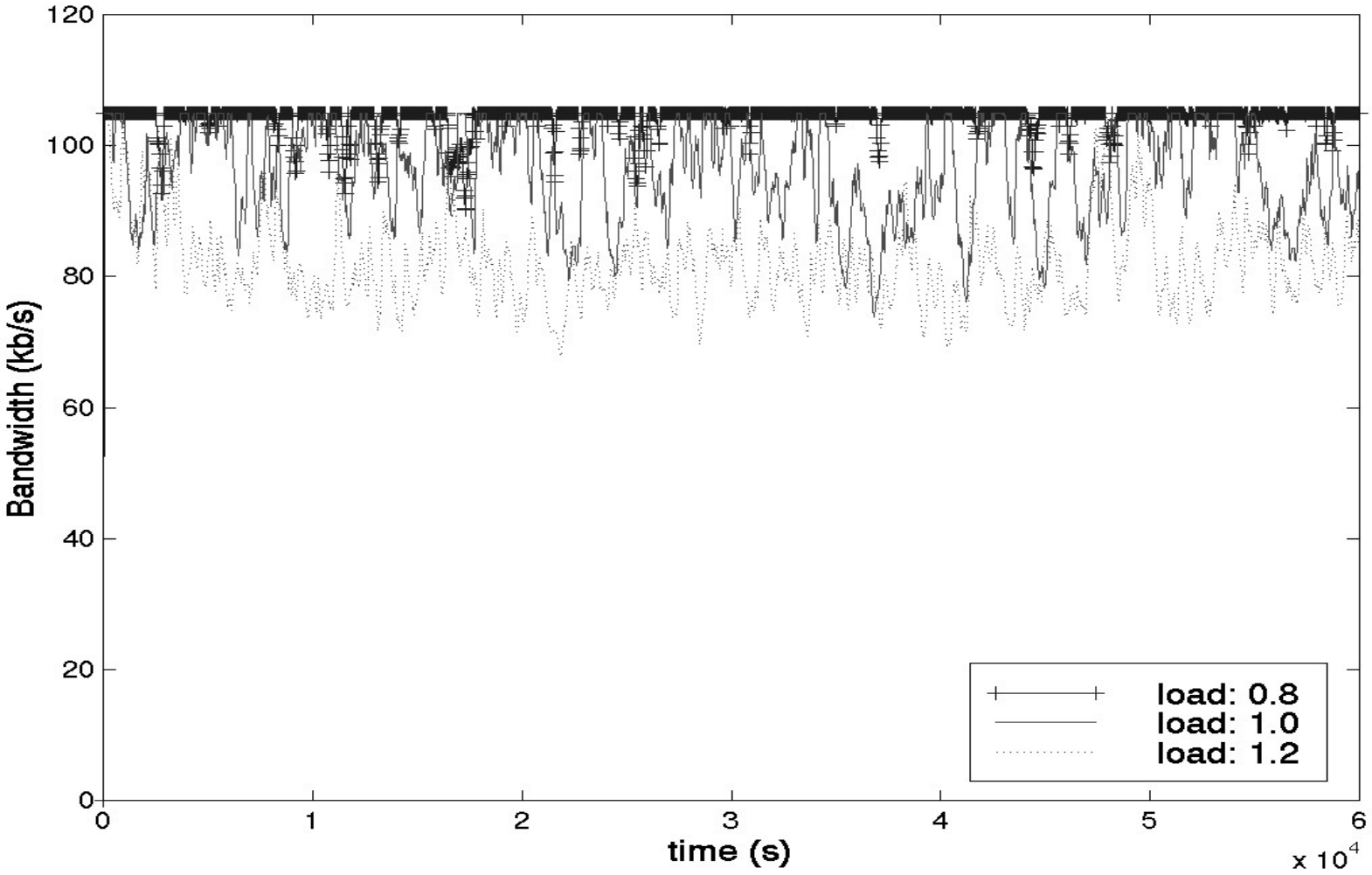
Average user benefit ($/min)



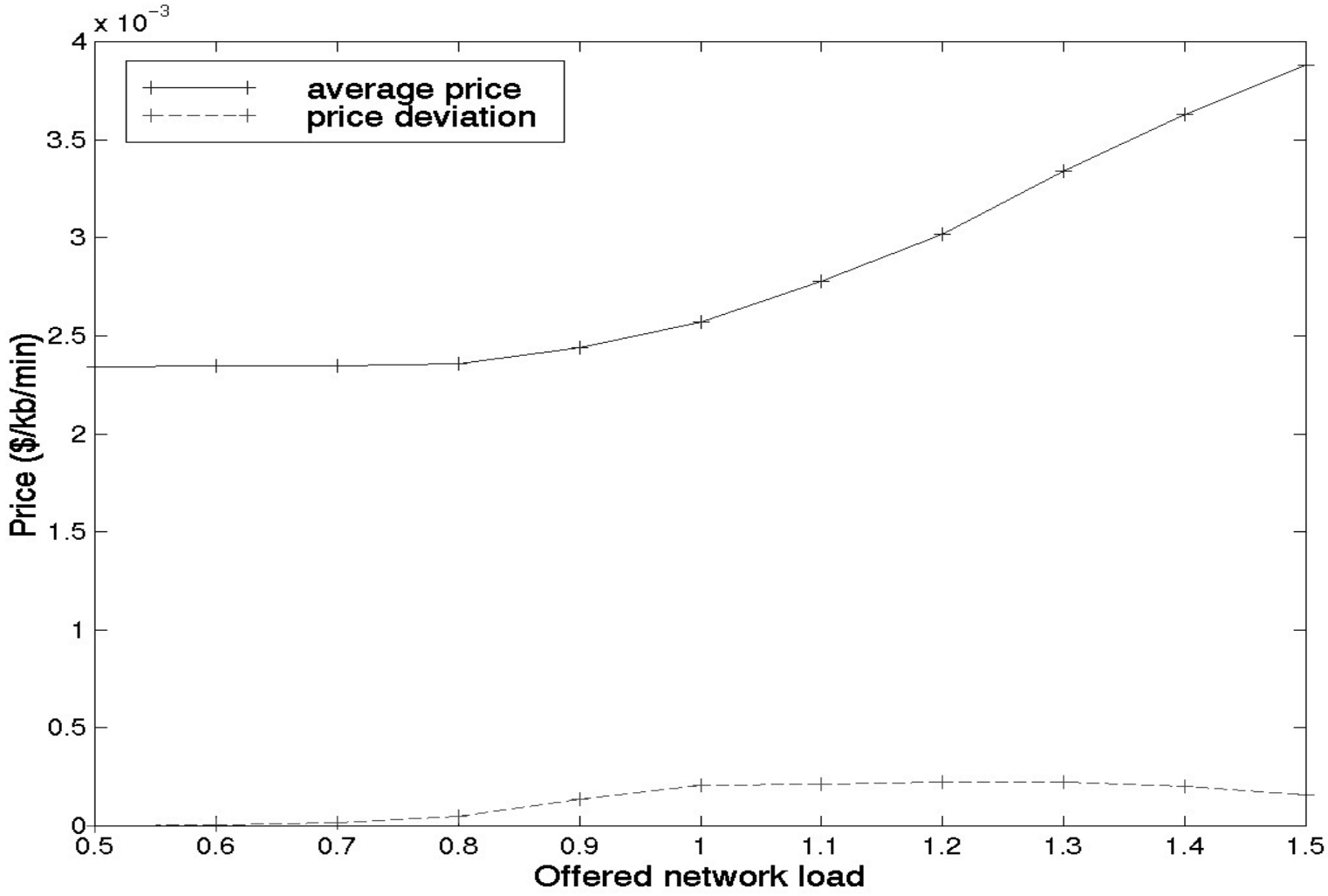
Price ($/kb/min)


x 10^-3
4
3.5
3
2.5
2
1.5
1
0.5
0
Price ($/kb/min)
0
1
2
3
4
5
6
time (s)
x 10^4
load: 0.8
load: 1.0
load: 1.2

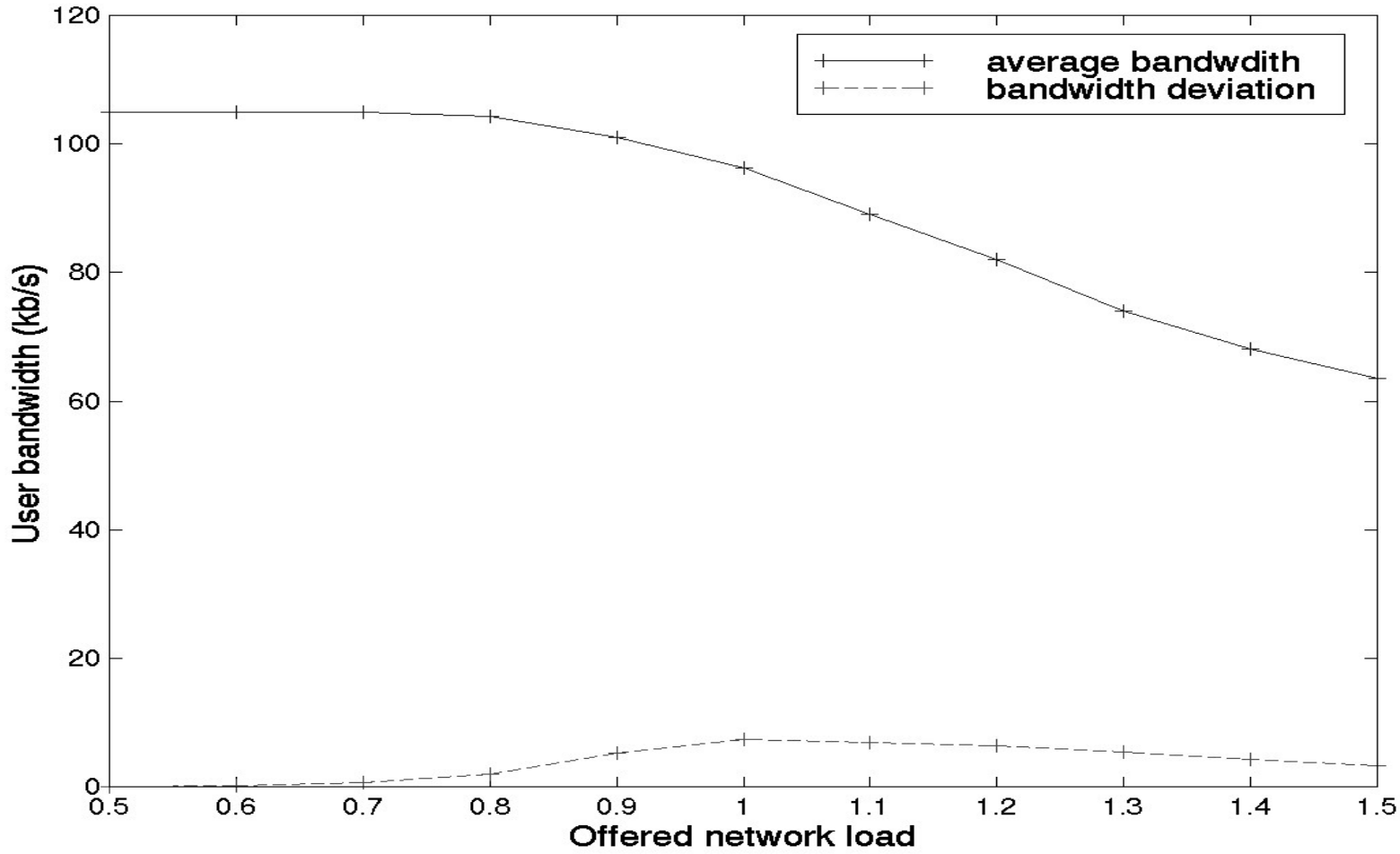
User bandwidth (kb/s)



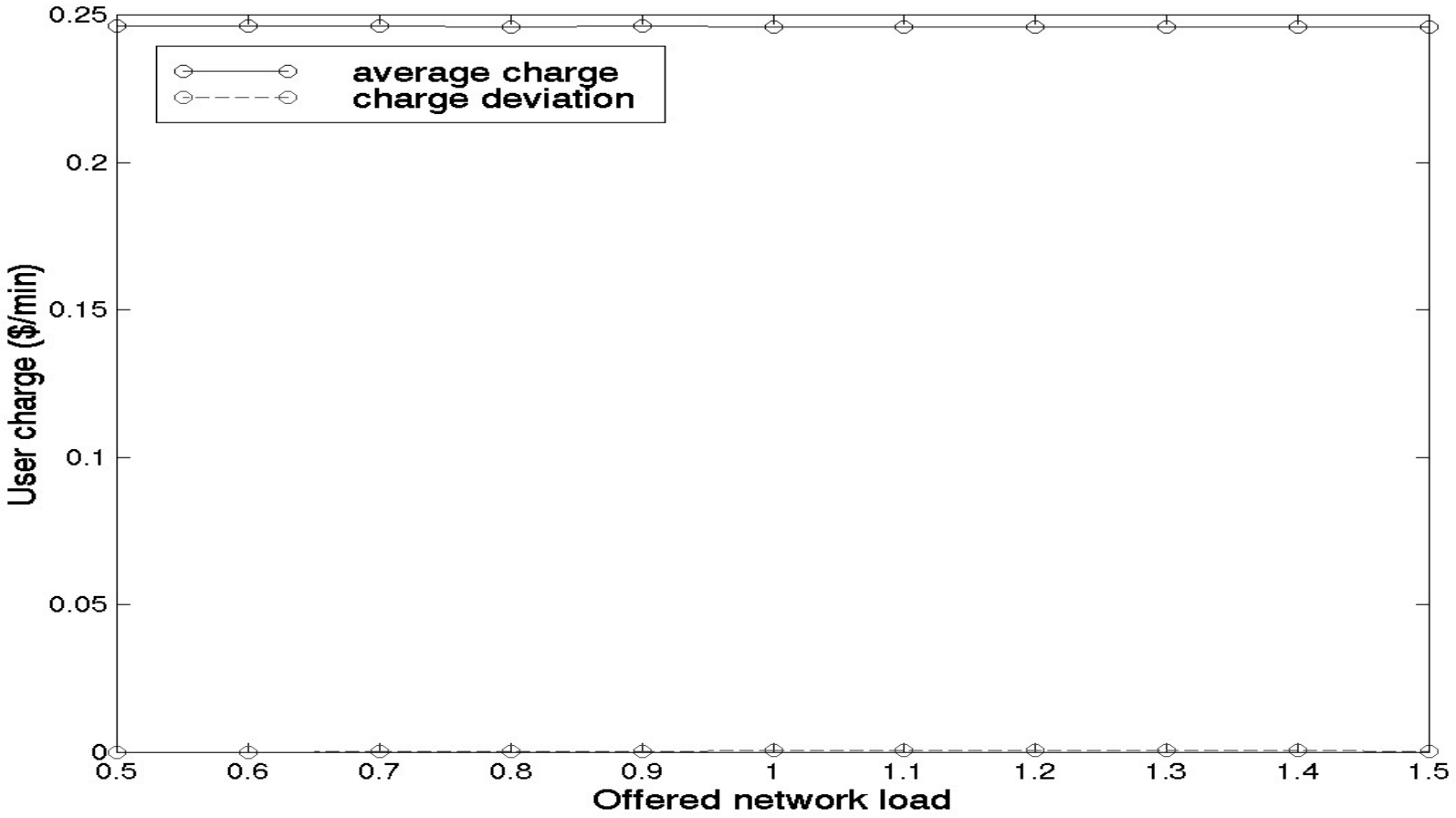
Average price ($/kb/min)



Average user bandwidth (kb/s)

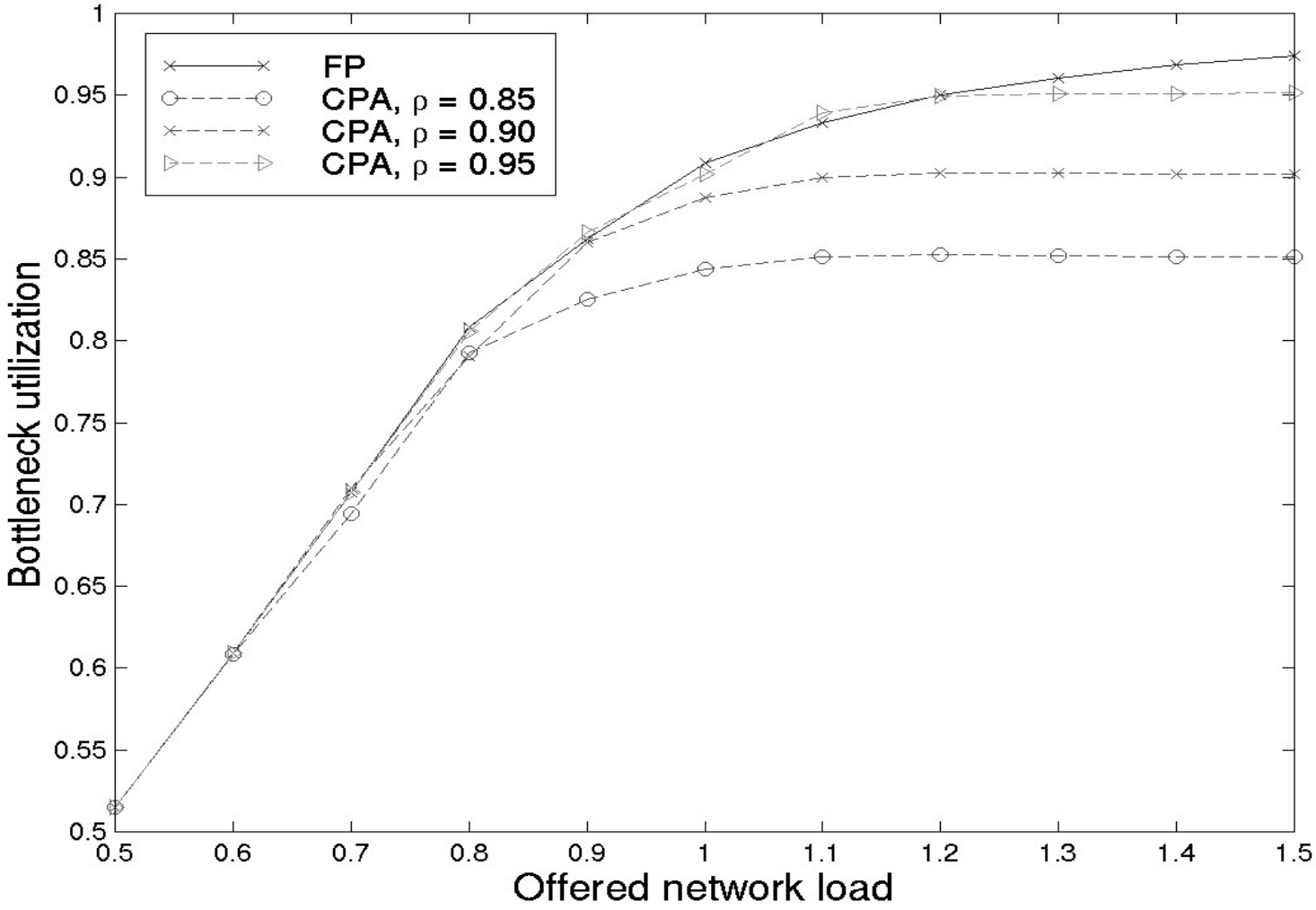


Average user charge ($/min)

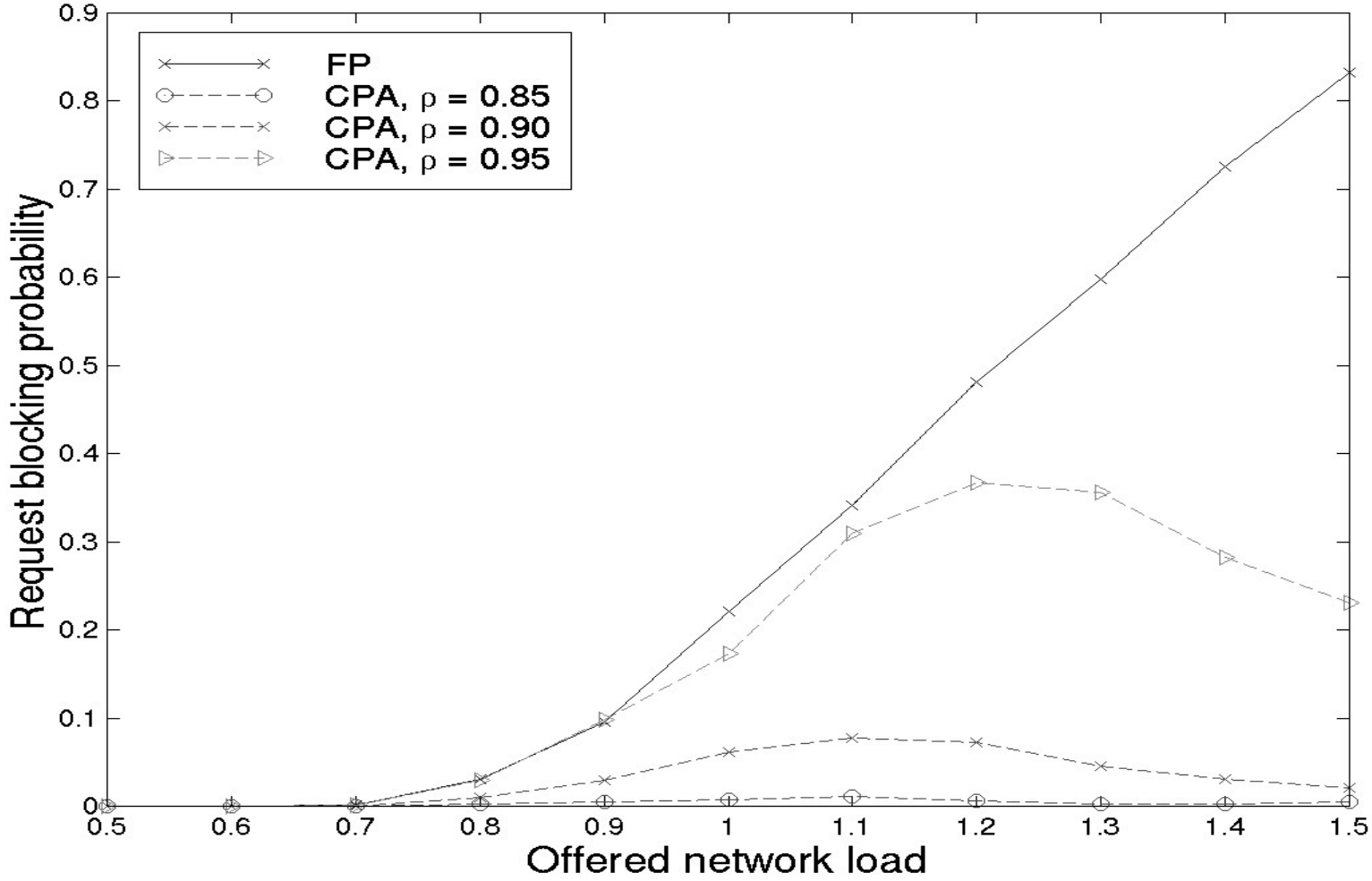


Effect of target reservation rate

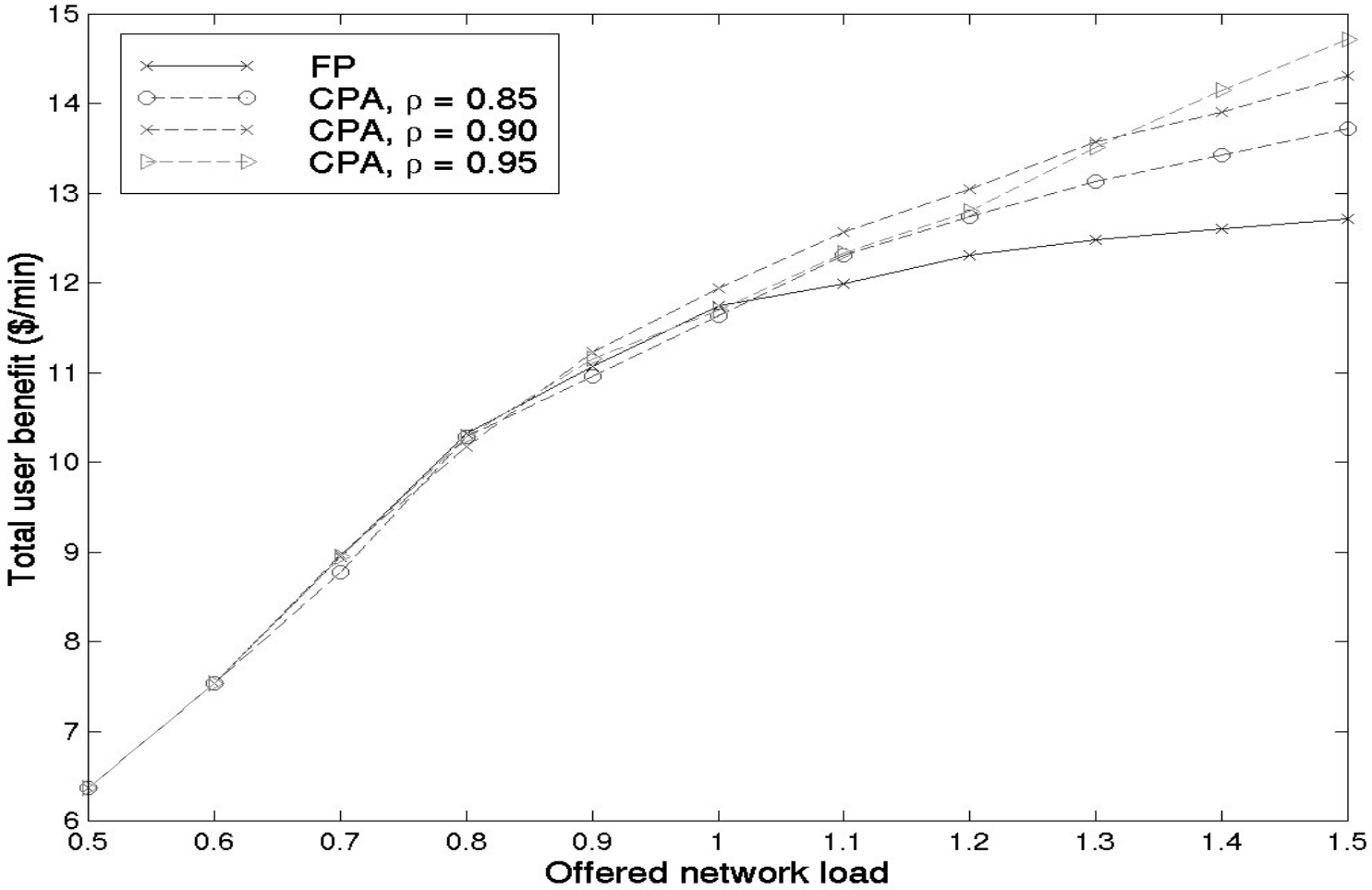
Bottleneck utilization



Request blocking probability

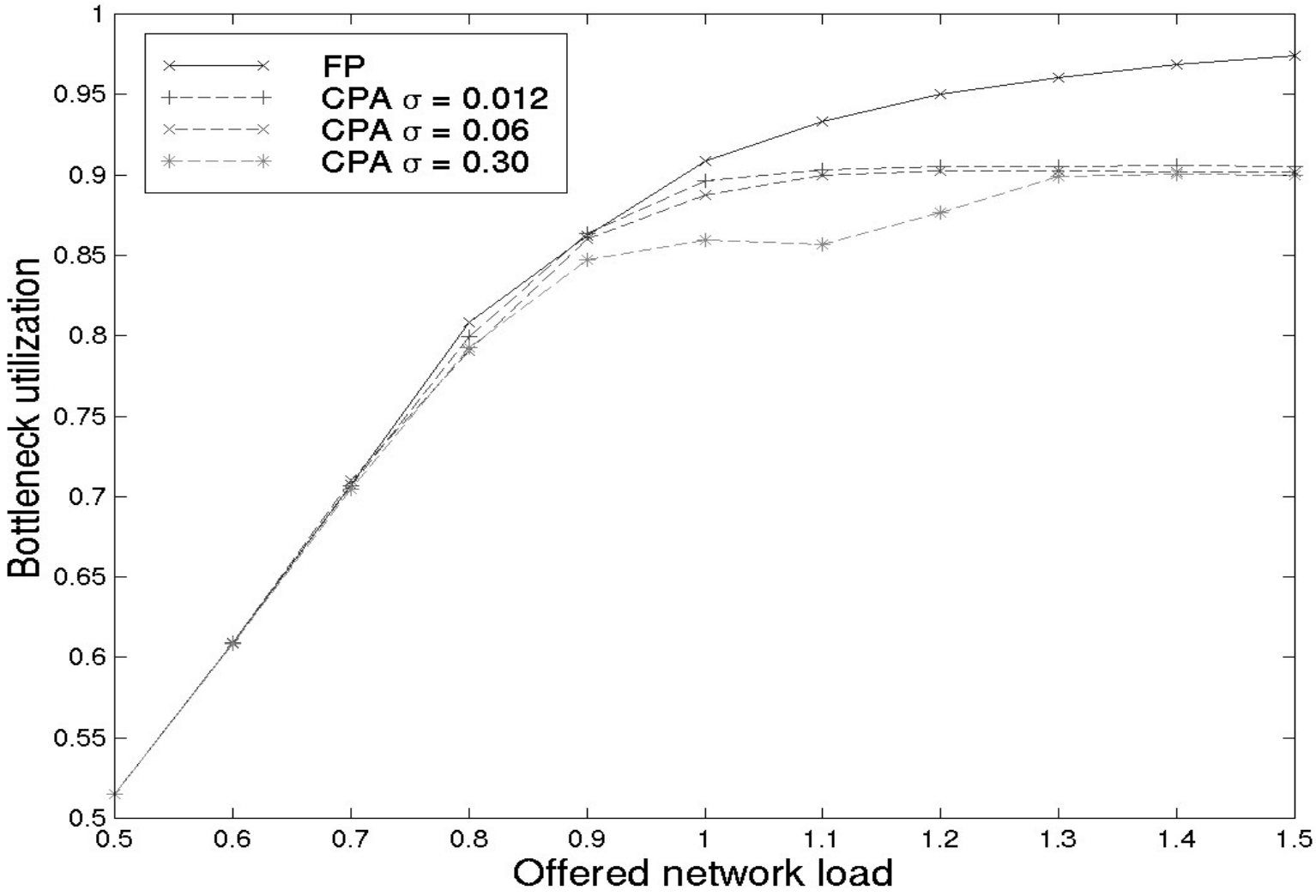


Total user benefit

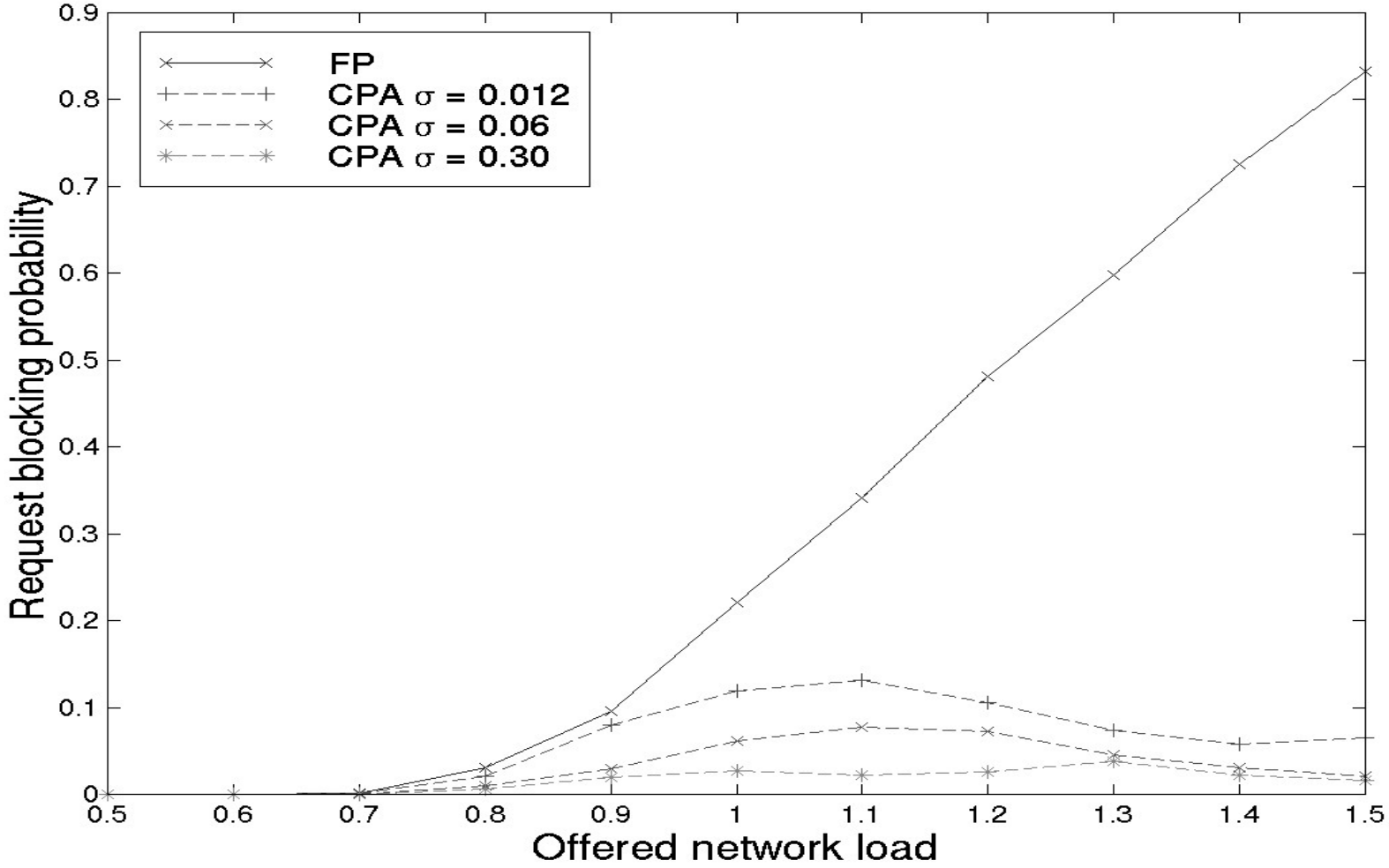


Effect of Price Adjustment Step

Bottleneck utilization

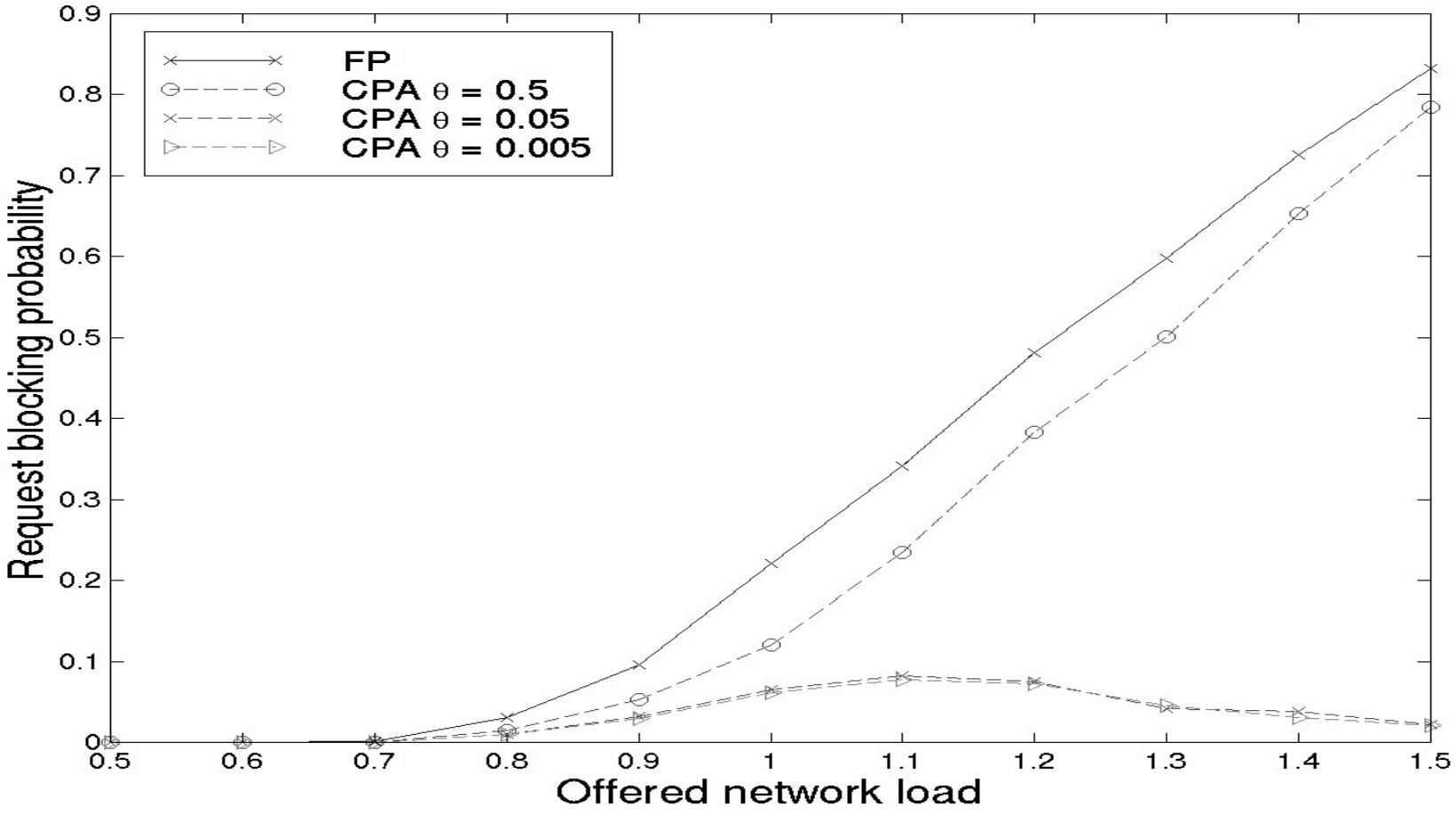


Request blocking probability



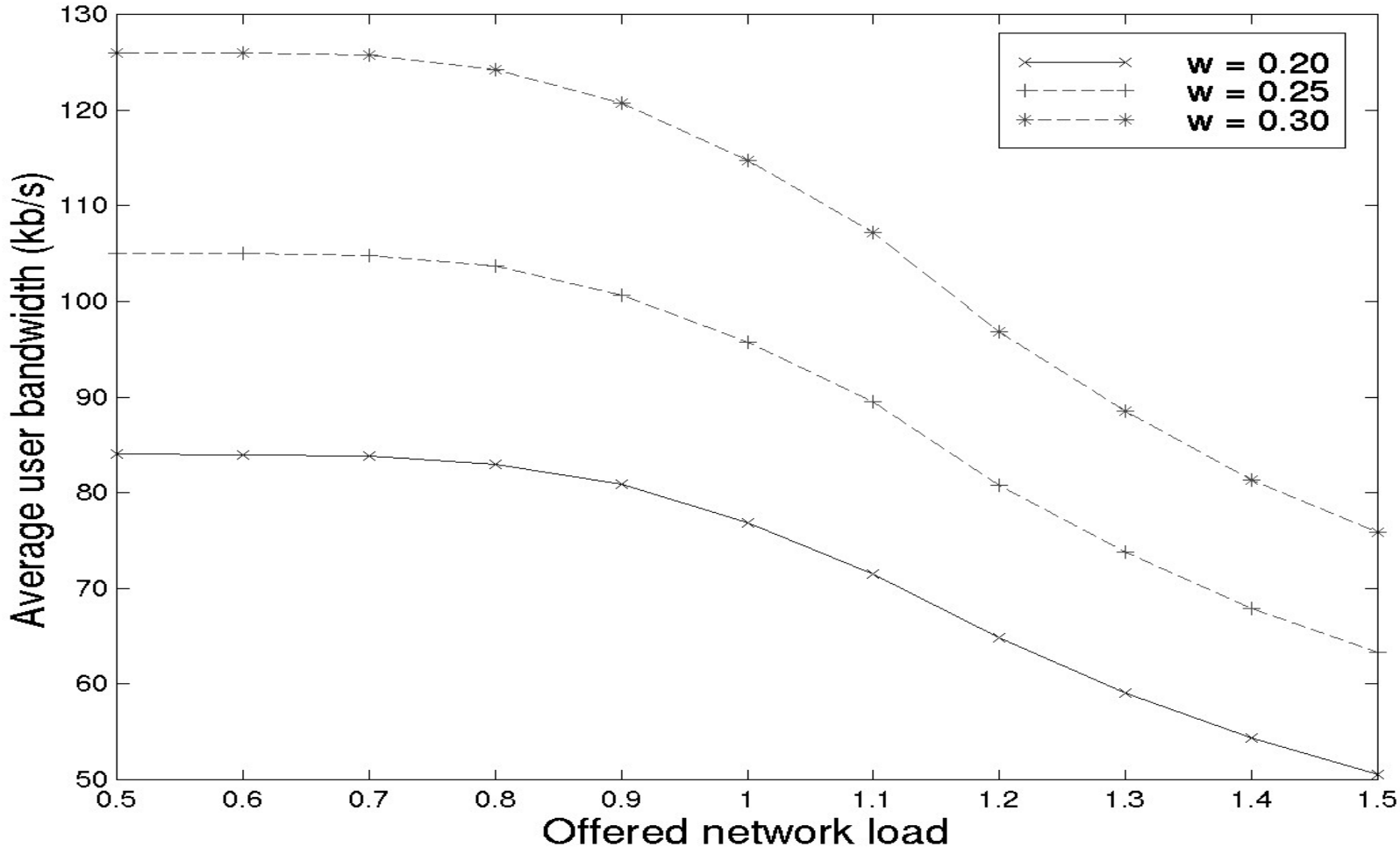
Effect of Price Adjustment Threshold

Request blocking probability

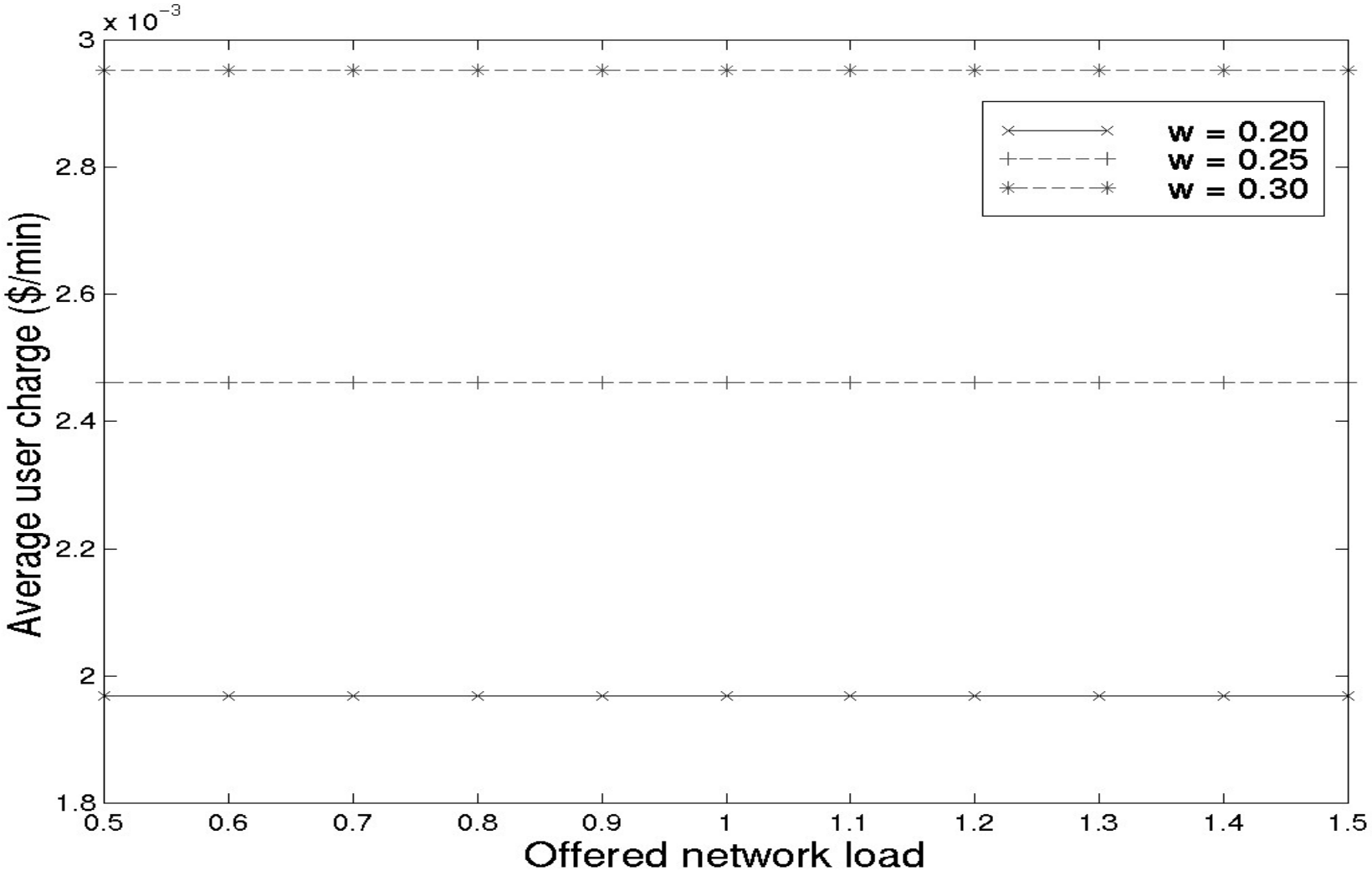


Effect of User Demand Elasticity

Average user bandwidth

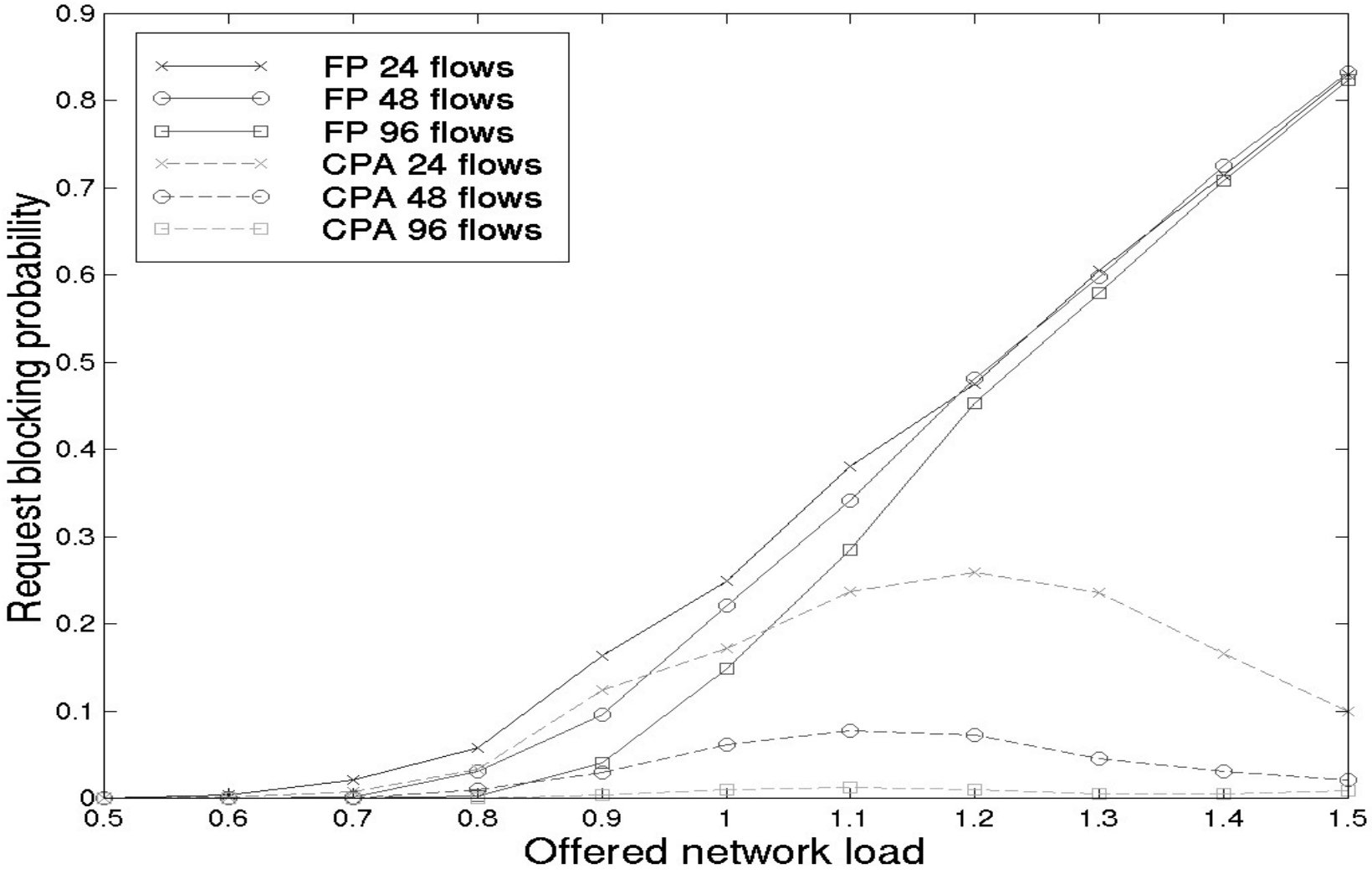


Average user charge

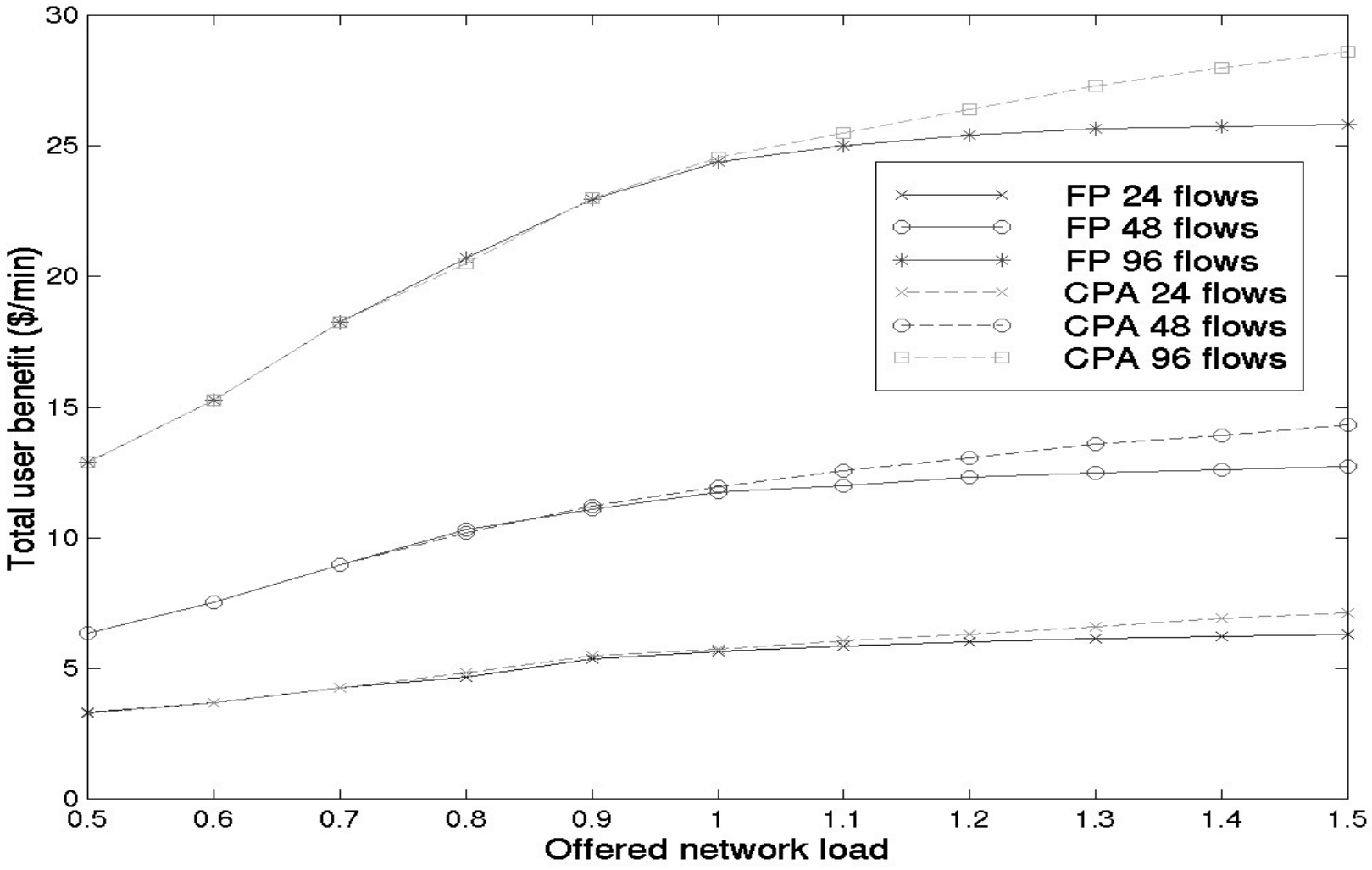


Effect of Session Multiplexing

Request blocking probability

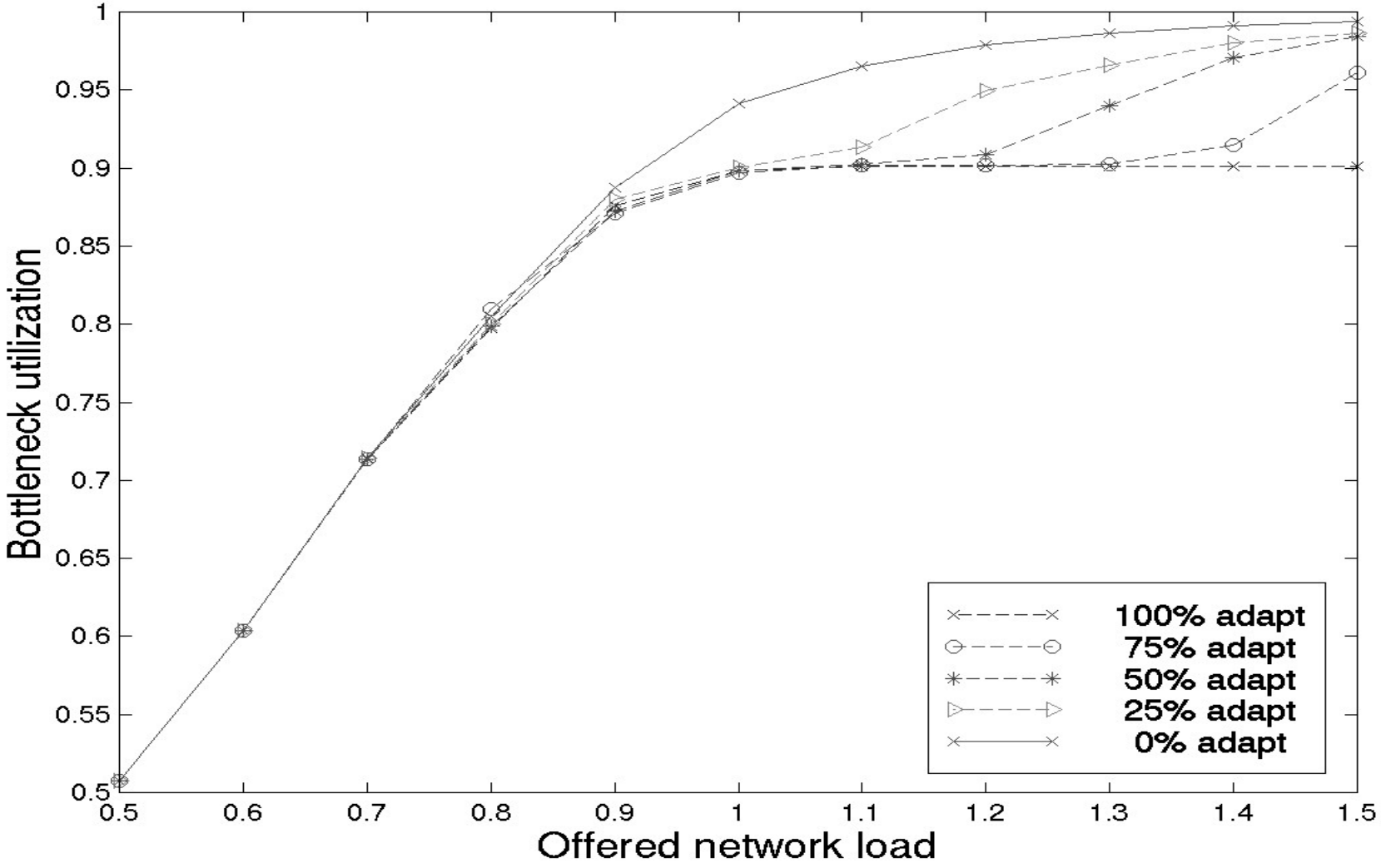


Total user benefit

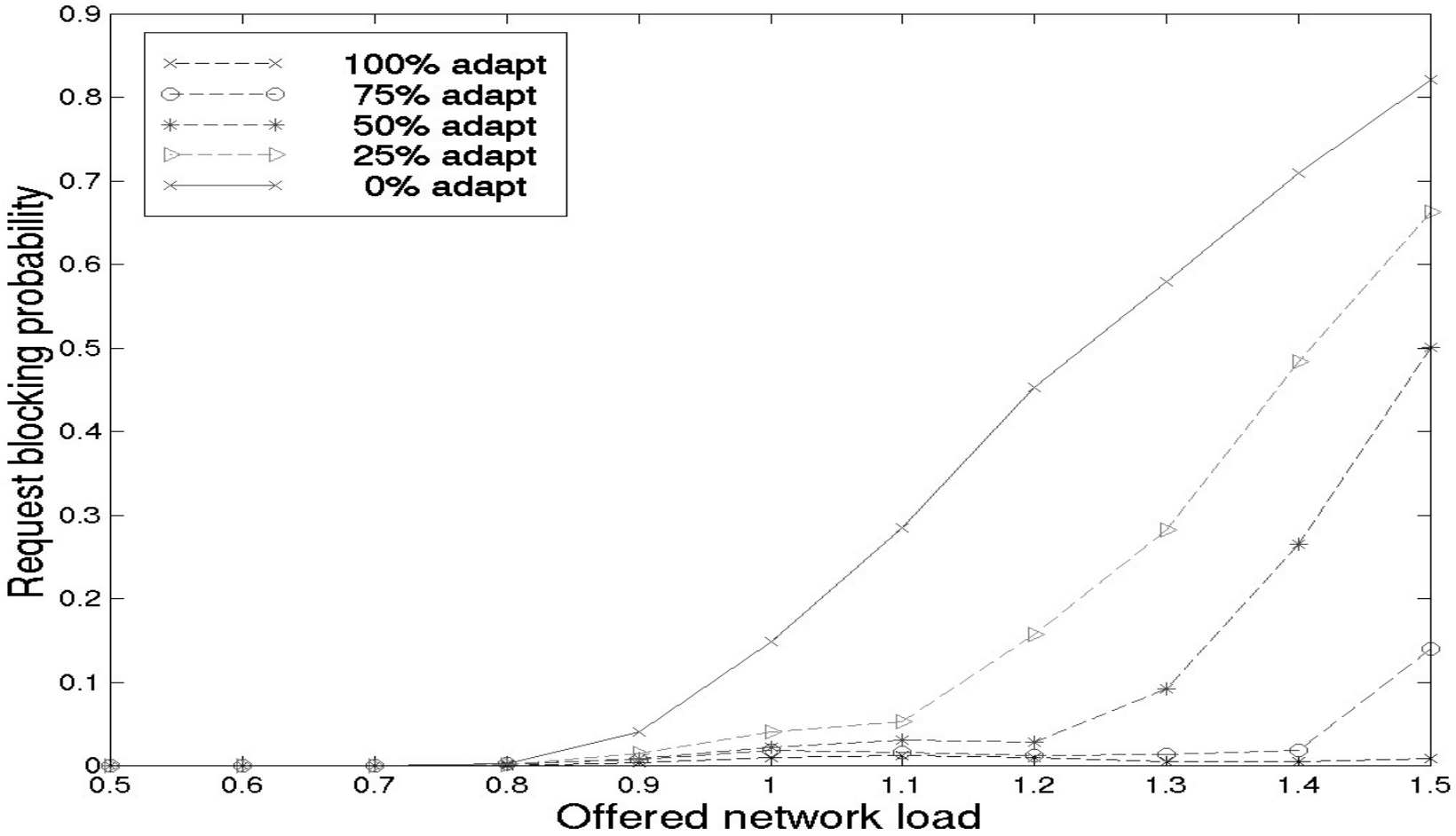


Effect When Part of Users Adapt

Bandwidth utilization

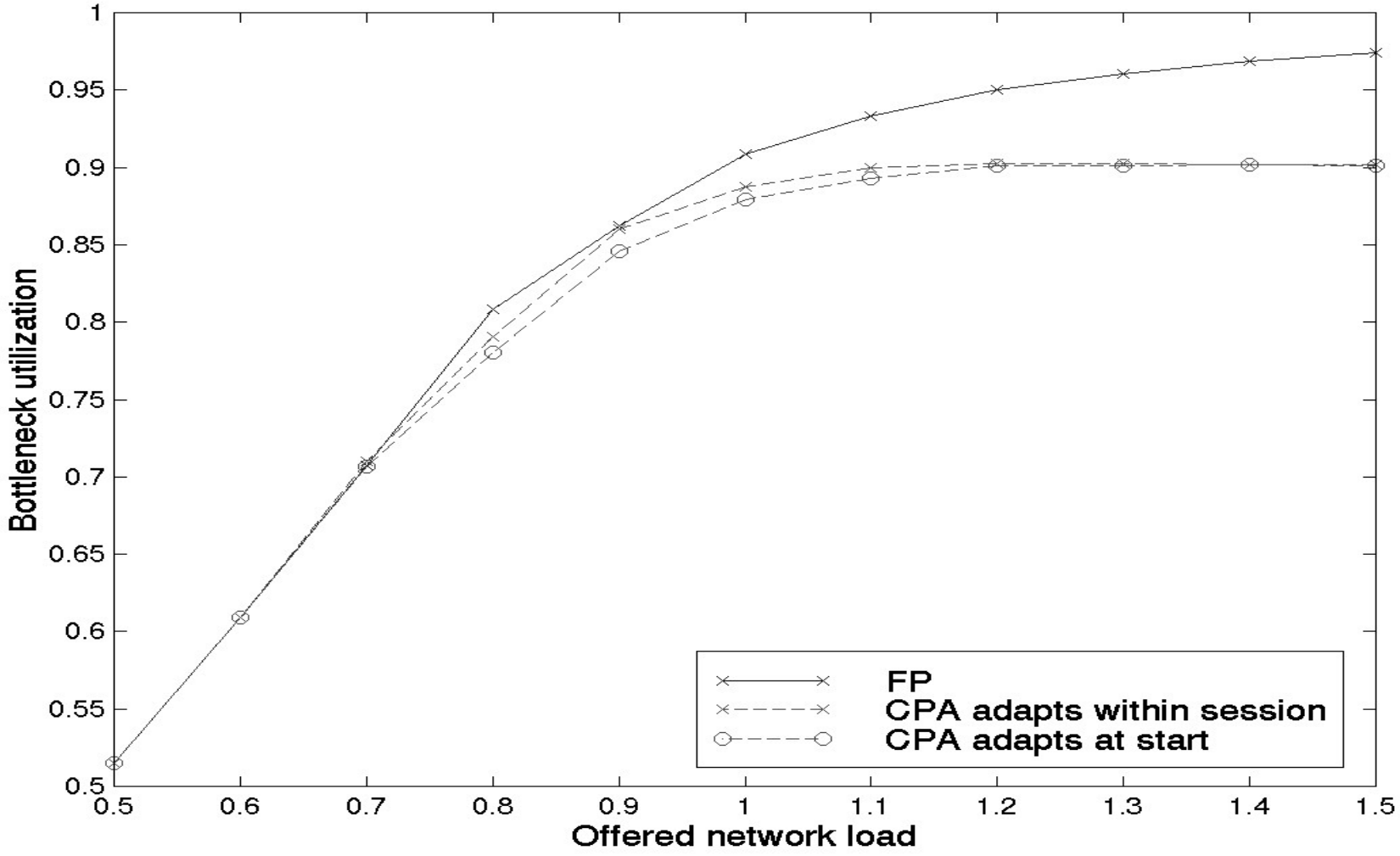


Request blocking probability

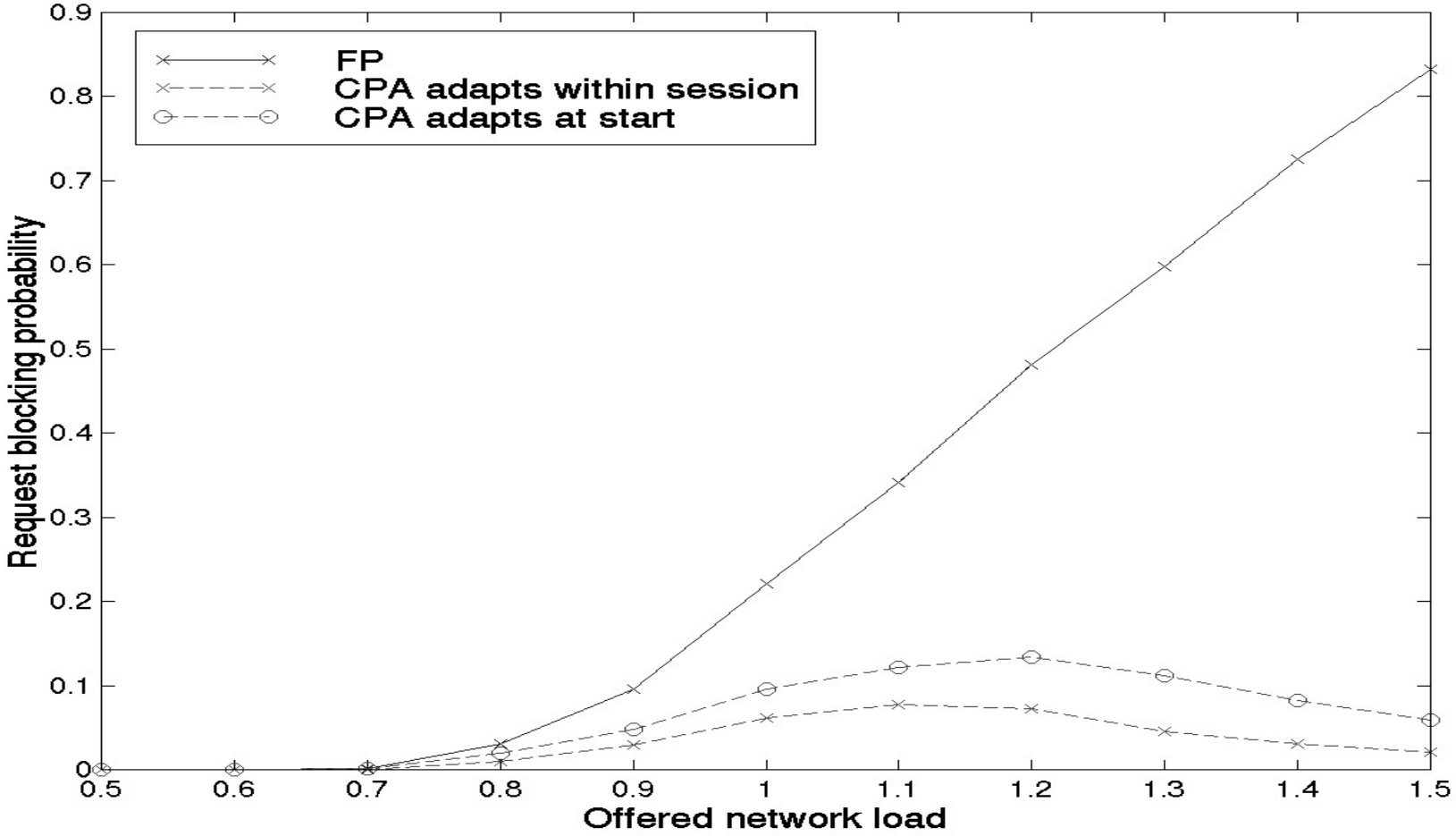


Session Adaptation & Adaptive Reservation

Bandwidth utilization



Blocking probability



Conclusions

- 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

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

Conclusions

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