1. Internet Pricing
   • Pricing for best effort service
     Pricing with QoS guarantees
   • Single class pricing
     Priority pricing
   • Uniform pricing
     Differentiated pricing
   • Noncooperative game
     Cooperative game

2. General Network
   Problem Formulation
   1. The network (ISP) and the users play a noncooperative game.
   2. The users play an n-player noncooperative game.

Results
   • Positive solution (admission) condition:
     \[
     \frac{2w_i}{w_{av}} > 1, \quad i = 1, 2, \ldots, n, \quad (1)
     \]
     where \( w_{av} = \frac{1}{n} \sum_{j=1}^{n} w_j \)
   • If the above condition is not satisfied for all the users, then order the users according to their utility weight parameters from the largest to the smallest and the first \( n \) users are admitted where \( n \) is the largest possible integer such that the admission condition is satisfied

3a. Uniform Price (UniPri) [1]
   Problem Formulation
   • The network charges a uniform price \( p_1 = p_2 = \cdots = p_n = p \) for all the users
   • User \( i \) determines \( x_i \) to maximize his utility \( F_i = w_i \log(1 + x_i) - \frac{1}{n} \sum_{j=1}^{n} x_j - px_i \)
   • The network must choose \( p \) to maximize revenue \( R = p \sum_{j=1}^{n} x_j \)

Results
   • Positive solution (admission) condition:
     \[
     \left( \frac{2w_i}{w_{av}} - 1 \right) \left( \frac{n^2 w_{av}}{c_i^2} \right)^{1/2} > 1, \quad i = 1, 2, \ldots, n, \quad (2)
     \]
     where \( \frac{1}{w_{av}} = \frac{1}{n} \sum_{j=1}^{n} \sqrt{w_j} \)
   • If the above condition is not satisfied for all the users, then the solution can be obtained similarly as in UniPri

3b. Differentiated Prices (DiffPri)
   Problem Formulation
   • The network can charge different prices for different users
   • User \( i \) determines \( x_i \) to maximize his utility \( F_i = w_i \log(1 + x_i) - \frac{1}{n} \sum_{j=1}^{n} x_j - p_i x_i \)
   • The network must choose \( p_i \)'s to maximize revenue \( R = \sum_{j=1}^{n} p_i x_j \)

Results
   • Positive solution (admission) condition:
     \[
     \left( \frac{2w_i}{w_{av}} - 1 \right) \left( \frac{n^2 w_{av}}{c_i^2} \right)^{1/2} > 1, \quad i = 1, 2, \ldots, n, \quad (2)
     \]
     where \( \frac{1}{w_{av}} = \frac{1}{n} \sum_{j=1}^{n} \sqrt{w_j} \)
   • If the above condition is not satisfied for all the users, then the solution can be obtained similarly as in UniPri

4. Admission Condition Comparison
   \( (1) \Rightarrow (2) \)
   Hence:
   1. If the users are admitted in UniPri, they must be admitted in DiffPri.
   2. More users can be admitted in DiffPri than in UniPri.

4a. Same Users Admitted
   Results
   By price differentiation:
   • Congestion decreases
   • Revenue increases for the network
   • Users with smaller \( w_i \)'s are better off but not the others (see example)

Example
   \( n = 50 \) with users' utility weight parameters evenly distributed around \( w_{av} = 0.001 \).
   • Individual flows:

4b. More Users Admitted in DiffPri
   Asymptotic Analysis Results
   1. By price differentiation, congestion decreases, the network is better off with revenue and those users with smaller \( w_i \)'s are better off but not the others.
   2. Both for UniPri and DiffPri, as the number of admitted users increases, all parties are better off in terms of the throughput, flows, congestion, prices, utilities and revenue. Therefore, the network intends to increase the capacity to accommodate more users as possible, which benefits the users in return.

5. Linear Network
   Result
   • Asymptotic analysis shows that the revenue increases as the number of users increases. Thus, the network has an incentive to increase link capacities, which also reduces the congestion cost.

6. Extensions
   • Stochastically distributed users
   • Multiple service providers

Reference