# Scheduling Strategies Support for Multiple VPNs over Broadband PLC Access Networks

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**Workshop ITG 5.2.1: Network Resource Allocation**

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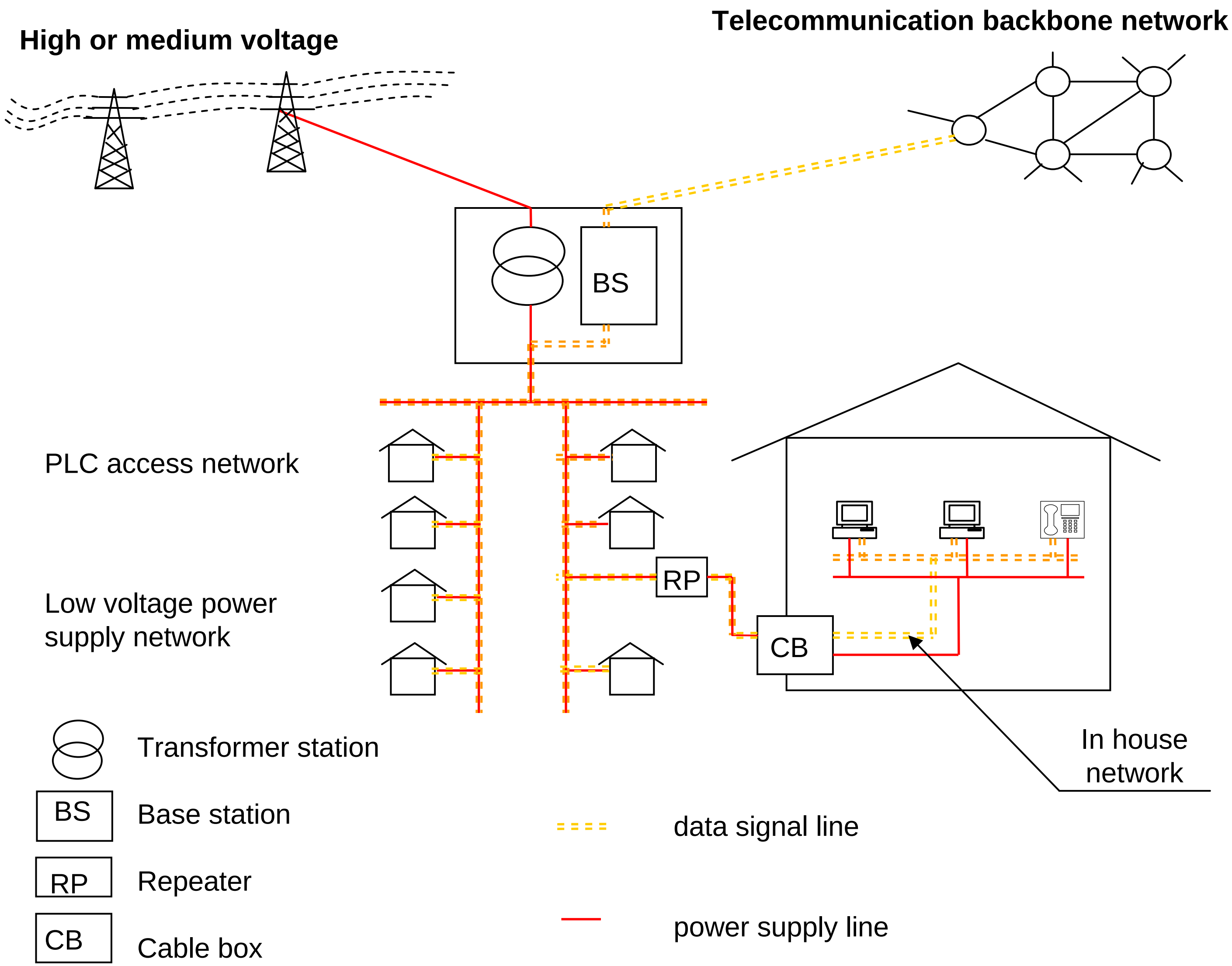
**(to be presented in ITCSS20)**

# Contents

# PLC Network



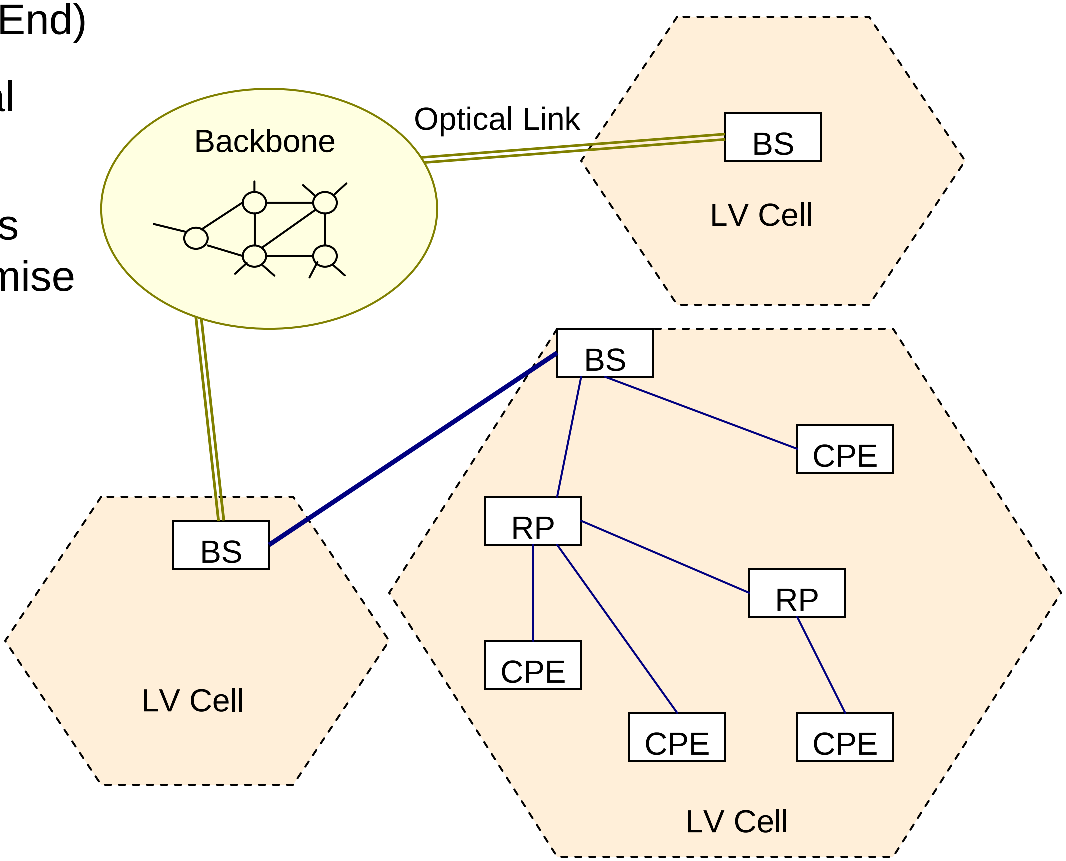

High or medium voltage
Telecommunication backbone network
BS
PLC access network
RP
CB
Low voltage power
supply network
In house
network
Transformer station
BS
Base station
RP
Repeater
CB
Cable box
data signal line
power supply line

# PLC Cells for Access Network



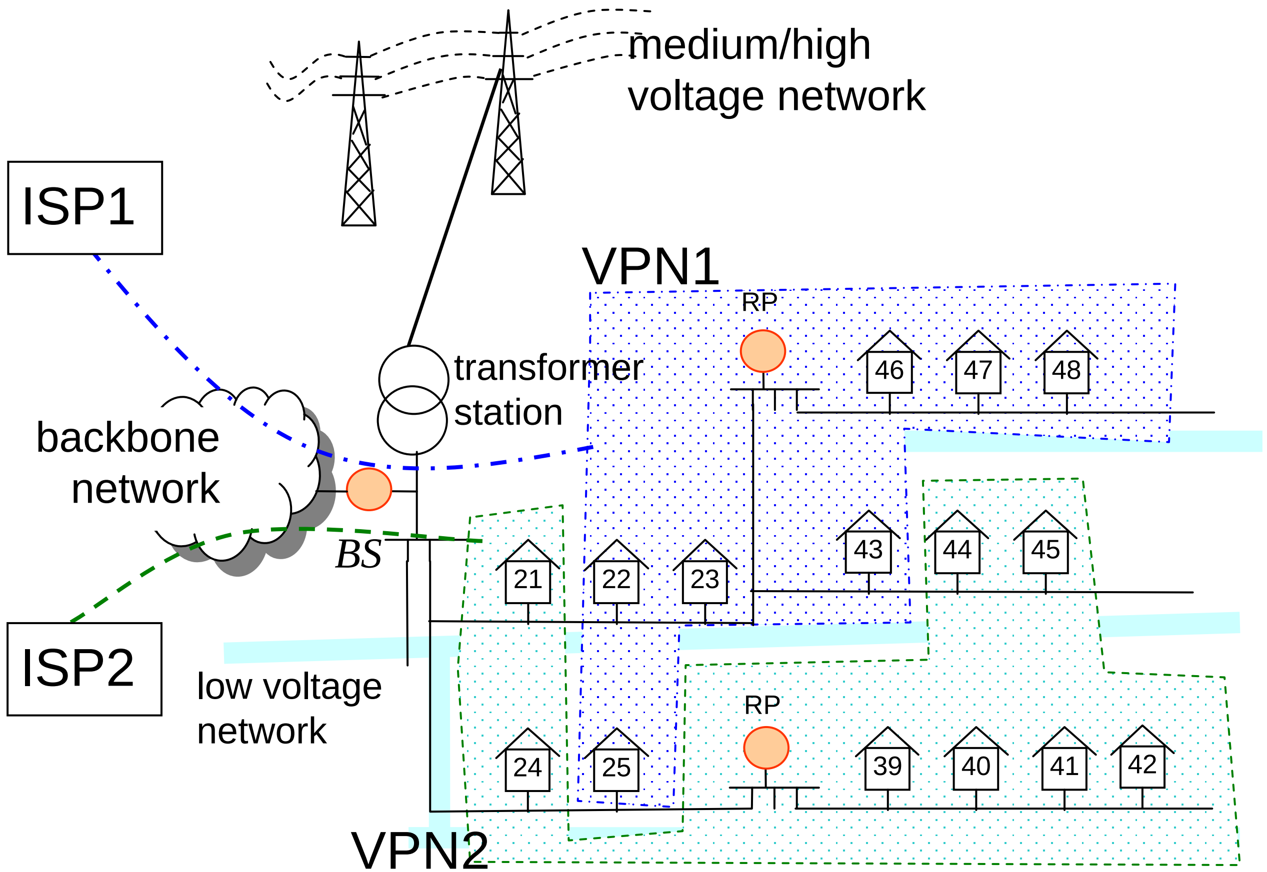
- PLC Cell:

  1. One BS (HE: Head-End)
  2. From zero to several RPs (Repeater)
  3. One or several users (CPEs: Customer Premise Equipment )



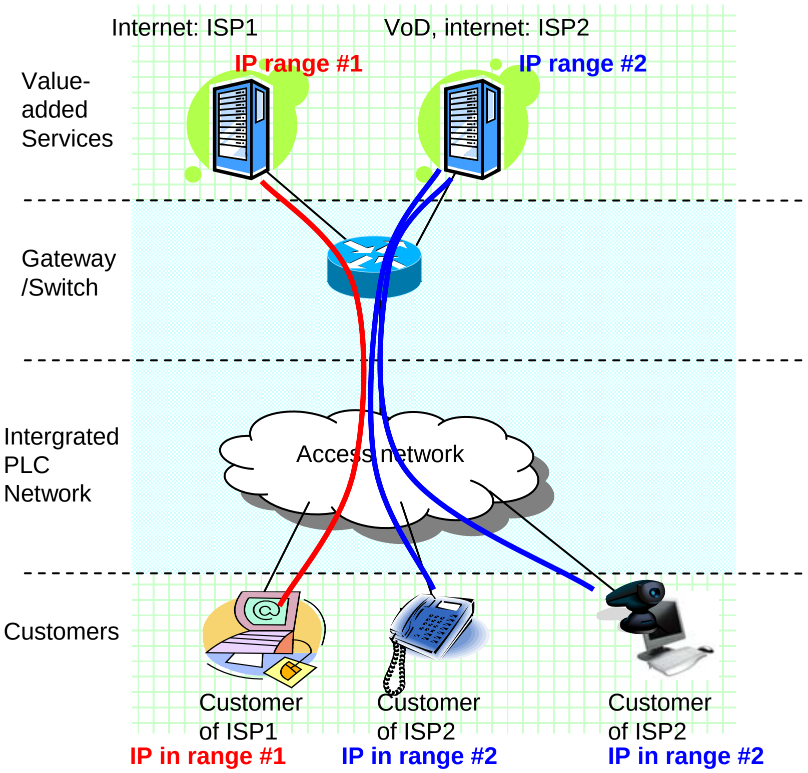

- LV: Low Voltage

# Mulitple VPNs Inside a PLC Cell

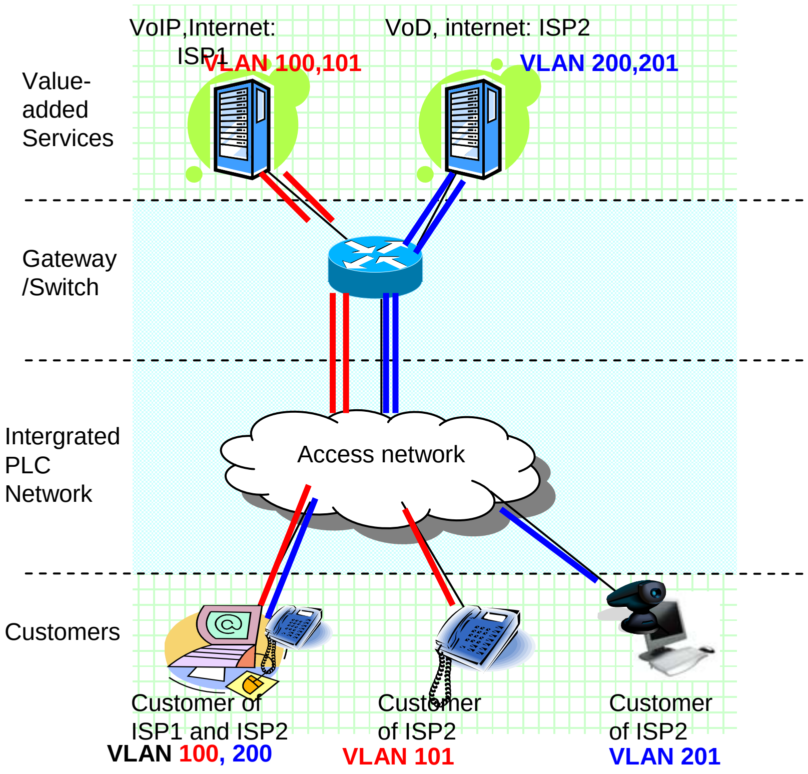



→**carriers' carrier model**

# Multiple VPN-Traffic Flows

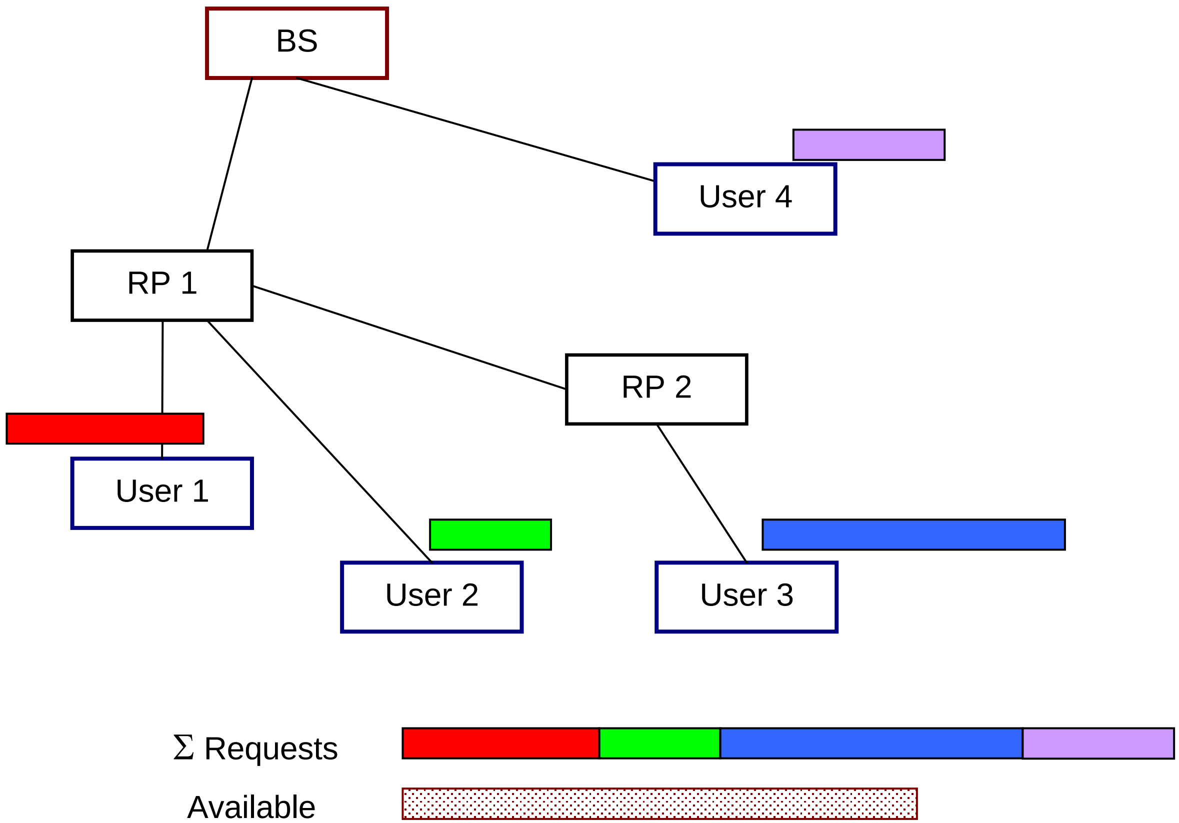



IP-range selection solution




VLAN selection solution

# Limited Transmission Capacity

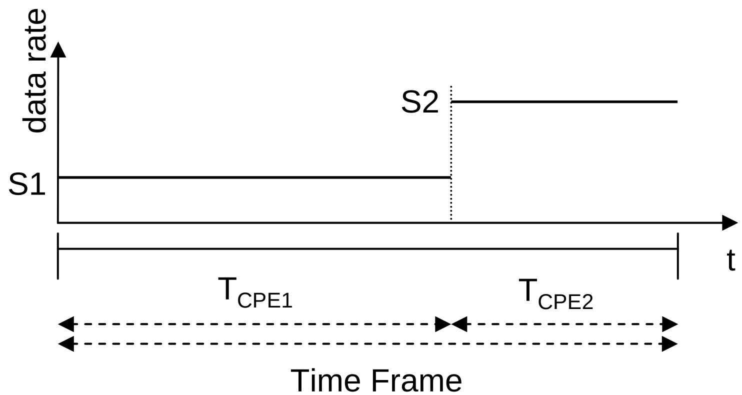



➡ **Devide the available transmission capacity to the users in accordance with their services and QoS requirements**

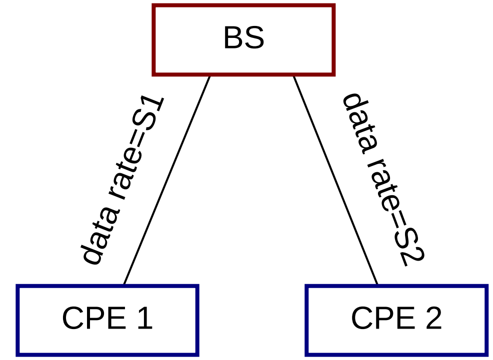
# Effective Data Rate Calculation



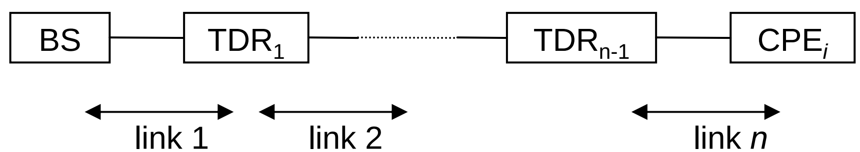
- TDMA: Granted duration of transmission based on transmission data rate of connections. E.g. fair trans for both users




$$\frac{S1}{S2} = \frac{T_{CPE2}}{T_{CPE1}}$$




- Typical transmission path: one equipment transmits at a point of time

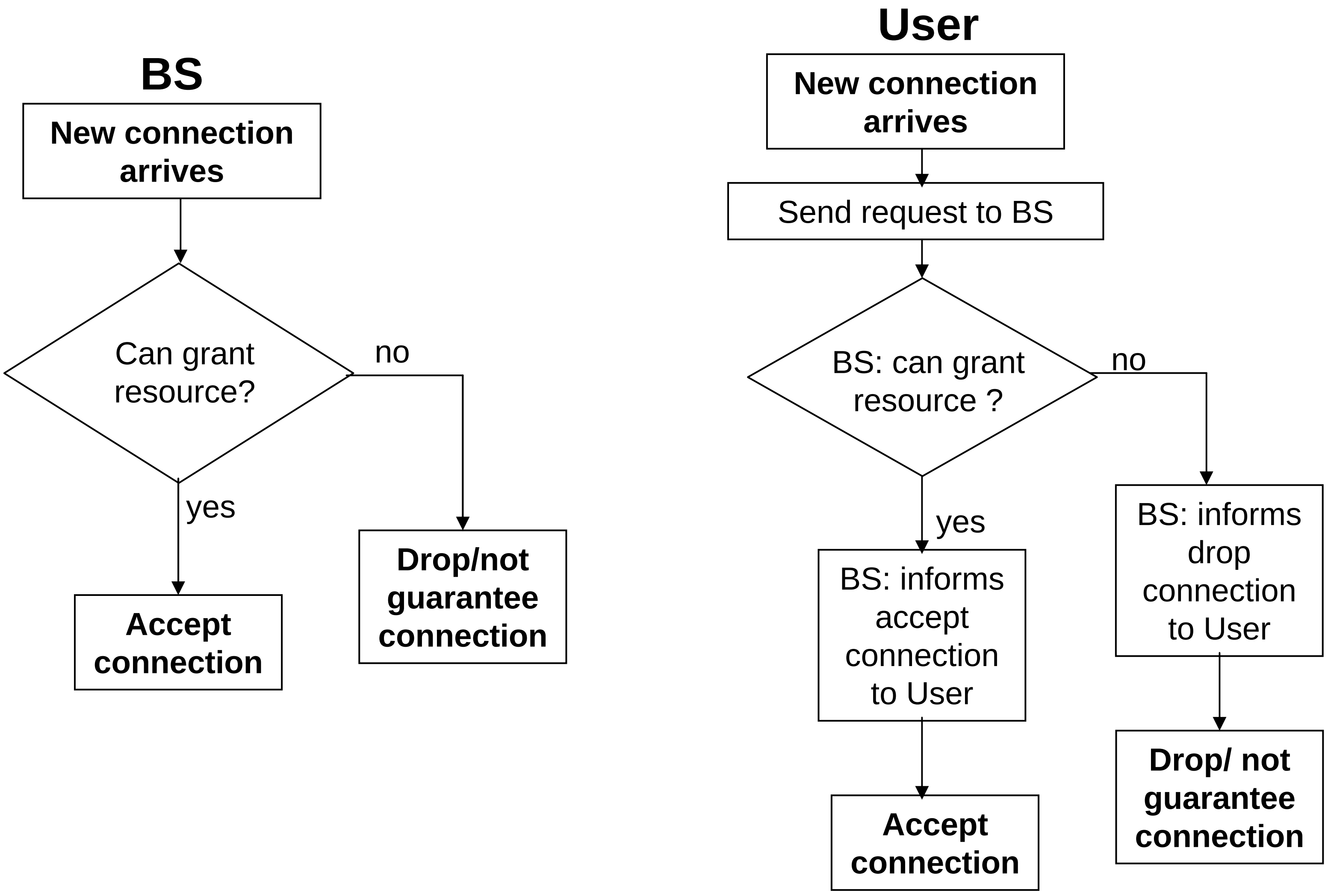



- Transmission duration of a data (L) over the path $T = \sum_{i=1}^{n} T_{li} = \sum_{i=1}^{n} \frac{L}{S_{li}}$

- "Effective" data rate of the path

$$ES_{Ui} = \frac{L}{T} = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_{li}}}$$

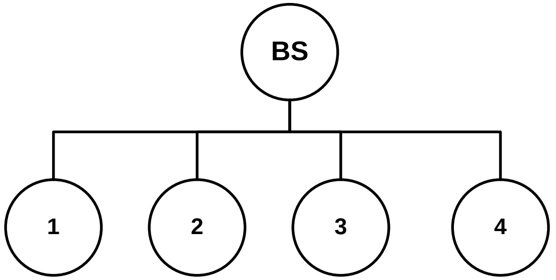
# Connection Control by Head-End

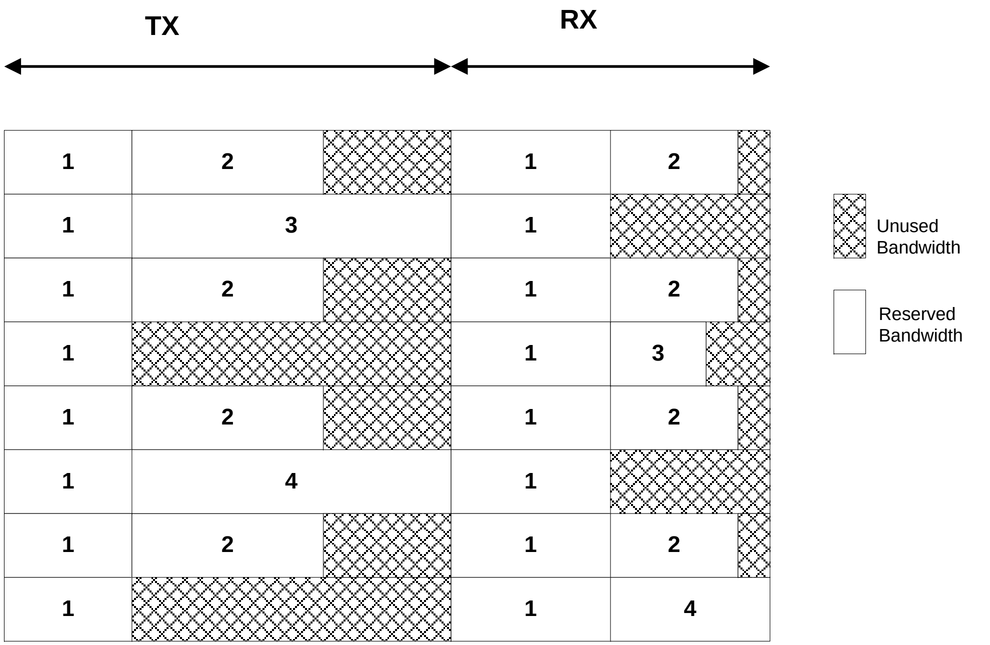


# Scheduling with Bandwidth Assignment



- Bandwidth allocation based on class of service agreements

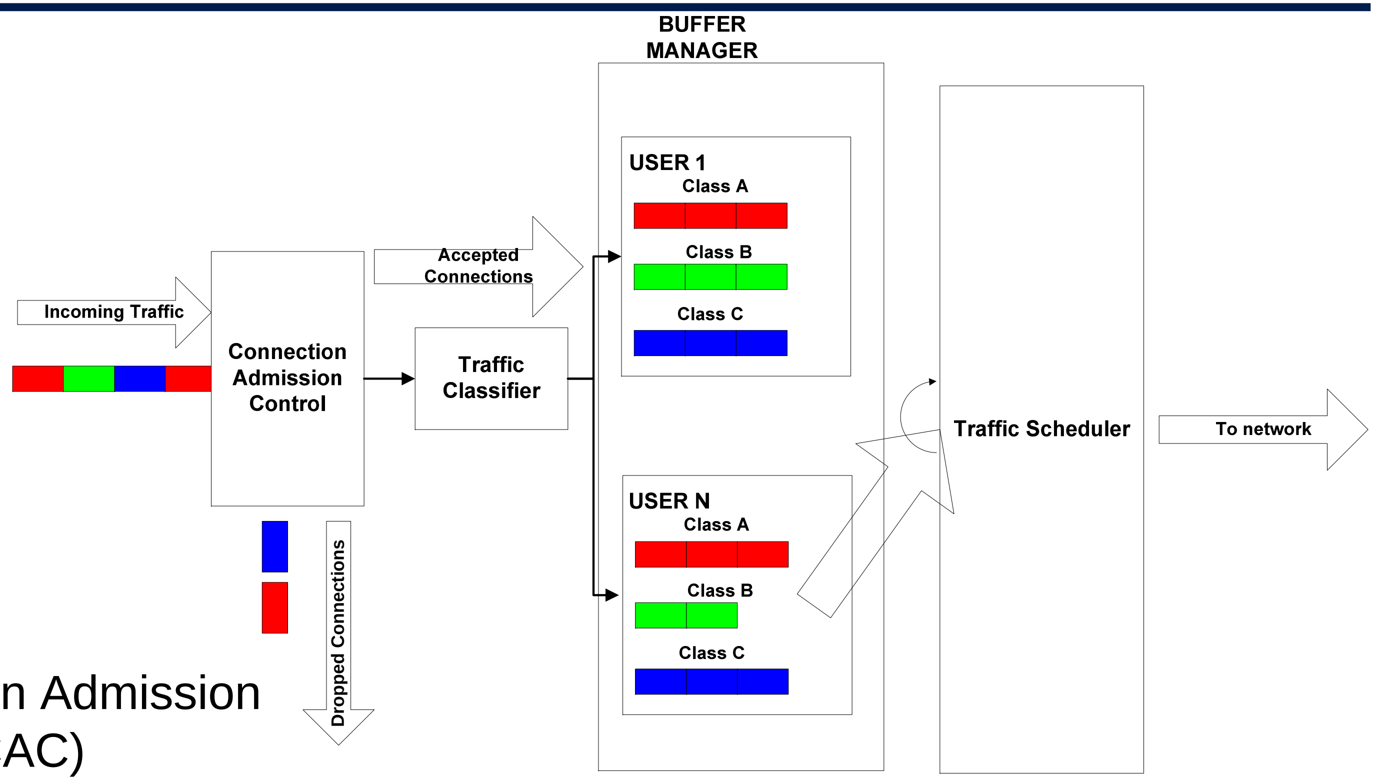



TX+RX=STEP_LATENCY (30ms)

# Traffic Control in BS (Downlink)



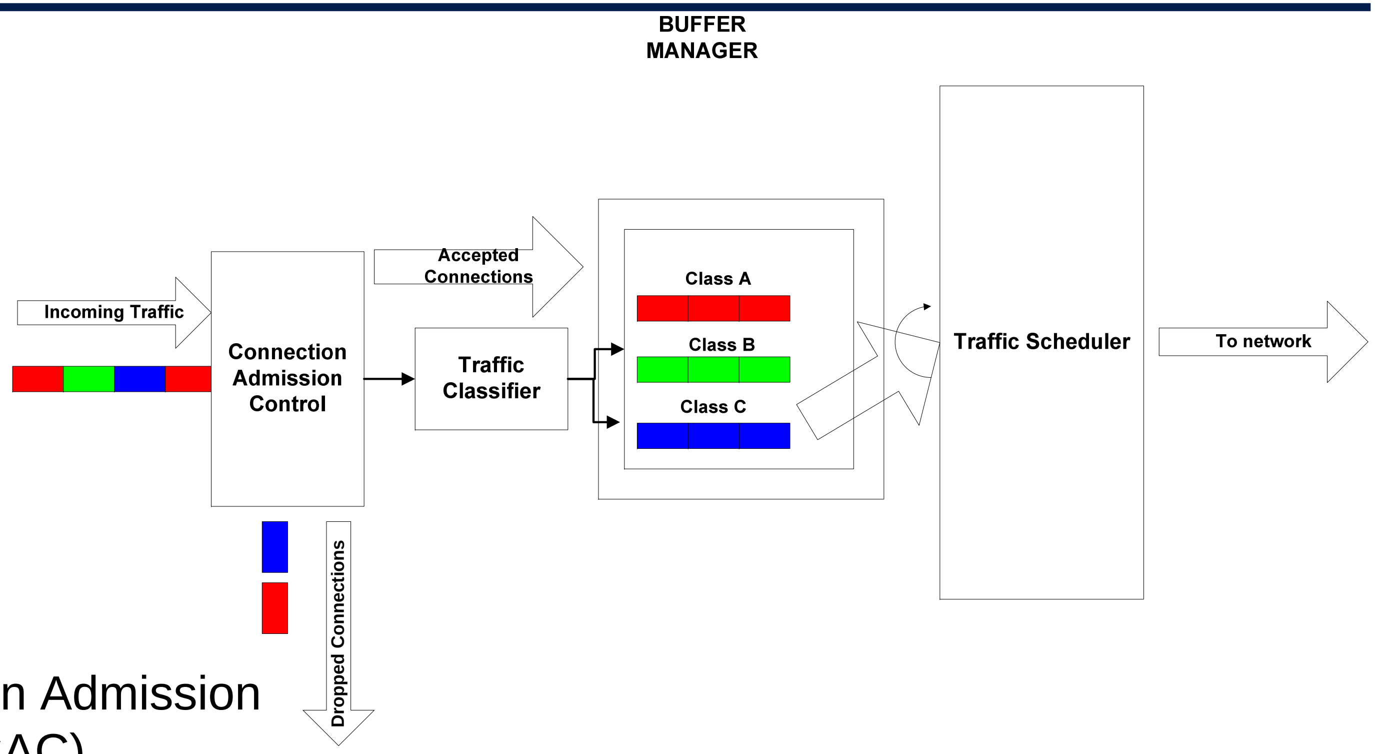



4 Blocks:

- Connection Admission Control (CAC)
- Traffic Classifier
- Buffer Manager
- Scheduler

# Traffic Control in User-CPE (Uplink)






4 Blocks:

- Connection Admission Control (CAC)
- Traffic Classifier
- Buffer Manager
- Scheduler

# Sharing Transmission Capacity Inside a Cell



- Problems:
  - Multiple connection requests from/to each User
  - Multiple service classes
  - Different between users in different VPNs
  - Not enough capacity for all requests
- Solutions:
  - Round robin (e.g. weighted round robin)
    - Serving duration based on the priorities of queues
    - New connection is accepted if resource is available. If not:
      - Reduce allocated capacity of all flows
      - Drop low priority flows
  - Evaluate a solution by its benefit and fairness indexes
    - Evaluate a schedule by a “benefit function” and fairness indexes
    - Formulate as an optimization problem: maximizing the benefit and fairness indexes

# Problem Formulation: Definitions



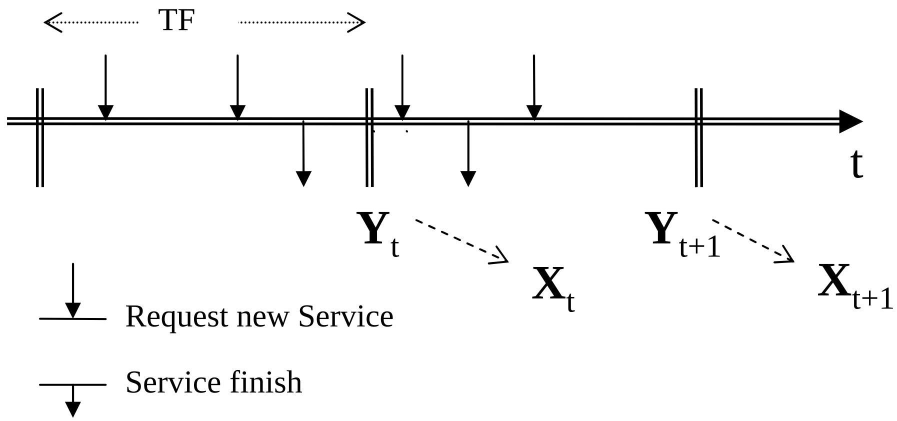
- Users: $U_1 .. U_N$
- Services: $S_1 .. S_S$
- Request Matrix $\mathbf{Y}=\{y_{ij}\}$, $y_{ij}$=Number of request units for service $j$ from user $i$
- Granted Matrix $\mathbf{X}=\{x_{ij}\}$, $x_{ij}$=Number of granted request units of service $j$ to user $i$
- $b_j$: Benefit of a service $j$
- $R_{ij}$: Resource needed for service $j$ to user $i$
- $w_i$: "Weight" of the user $i$

| Service Class | Throughput requirement ($R_{ij}$) | Benefit ($b_j$) | Example |
|---|---|---|---|
| S1 | 64kbps | 8 | VoIP |
| S2 | 128kbps | 4 | Video, Game |
| S3 | 32kbps | 2 | HTTP |
| S4 | 1kbps | 1 | Email, data low priority |

- $K$ VPNs
- VPN table: $V=\{v_{ik}\}$,
- $r_k$: "Weight" of the VPN $k$

# Collection of Connection Requests






Y=

| | S1 (voip) | S2 (video, data hi prio) | $S_S$ (data low prio) |
|---|---|---|---|
| U1 | 1 | 0 | 1 |
| U2 | 0 | 2 | 0 |
| $U_N$ | 0 | 1 | 3 |

X=

| | S1 | S2 | $S_S$ |
|---|---|---|---|
| U1 | 1 | 0 | 1 |
| U2 | 0 | 1 | 0 |
| $U_N$ | 0 | 1 | 2 |

# Problem Formulation: Benefit and Limited Resource

- Benefit function with simple model:

$$B = \sum_{i=1}^{N} B_{Ui} = \sum_{i=1}^{N} \left[ w_i \sum_{j=1}^{S} \left( x_{i,j} \cdot b_j \right) \right]$$

- Constraints:
  - Variables: $0 \leq x_{ij} \leq y_{ij}$
  - Limited Capacity (Resource) $R = \sum_{i=1}^{N} R_{Ui} = \sum_{i=1}^{N} \sum_{j=1}^{S} \left( R_{ij} \cdot x_{i,j} \right) \leq R_{Max}$

- Example showing disadvantage:
  - 2 Users:
    U1 requests for 2 VoIP,
    U2 requests for 1 VoIP
  - 2 solutions with the same benefit

Y=

| | VoIP |
|---|---|
| U1 | 2 |
| U2 | 1 |

$R_{Max}$=2 (VoIP units)

$X_1$=

| | VoIP |
|---|---|
| U1 | 2 |
| U2 | 0 |

$B_{U1}$ = 1+1 = 2
$B_{U2}$=0
$B(X_1)=B_{U1}+B_{U2}=2$

$X_2$=

| | VoIP |
|---|---|
| U1 | 1 |
| U2 | 1 |

$B_{U1}$= 1
$B_{U2}$=1
$B(X_2)=B_{U1}+B_{U2}=2$

# Problem Formulation: Fairness Indexes

- Intra-VPN Fairness:

$$FI = \frac{1}{K}\sum_{k=1}^{K} FI_k = \frac{1}{K}\sum_{k=1}^{K}\frac{\left(\sum_{i=1}^{N} B_{Ui}\cdot v_{ik}\right)^2}{N_k\cdot\sum_{i=1}^{N}\left(B_{Ui}\cdot v_{ik}\right)^2}$$

- Inter-VPN Fairness

$$FV = \frac{\left(\sum_{k=1}^{K}\frac{B_{Vk}}{r_k}\right)^2}{K\cdot\sum_{k=1}^{K}\left(\frac{B_{Vk}}{r_k}\right)^2}$$

$$B_{Vk} = \sum_{i=1}^{N}(B_{Ui}\cdot v_{ik}) = \sum_{i=1}^{N}\sum_{j=1}^{S}(b_j\cdot x_{ij}\cdot v_{ik})$$

$$B_{Ui} = \sum_{j=1}^{S}(b_j\cdot x_{ij})$$

# Problem Formulation as An Optimization Problem

- Benefit and finesses for a solution

Find **X** to maximize: $BFF = B \cdot FV \cdot FI$

The overall benefit $B$,

The inter-VPN fairness $FV$

The intra-VPN fairness $FI$

- Constraints
  - Variables:
  - Limited Capacity (Resource):

Subject to: $0 \le x_{ij} \le y_{ij}$

$$R = \sum_{i=1}^{N} R_{Ui} = \sum_{i=1}^{N} \sum_{j=1}^{S} \left( R_{ij} \cdot x_{i,j} \right) \le R_{Max}$$

# Methods to Solve the Optimization Problem

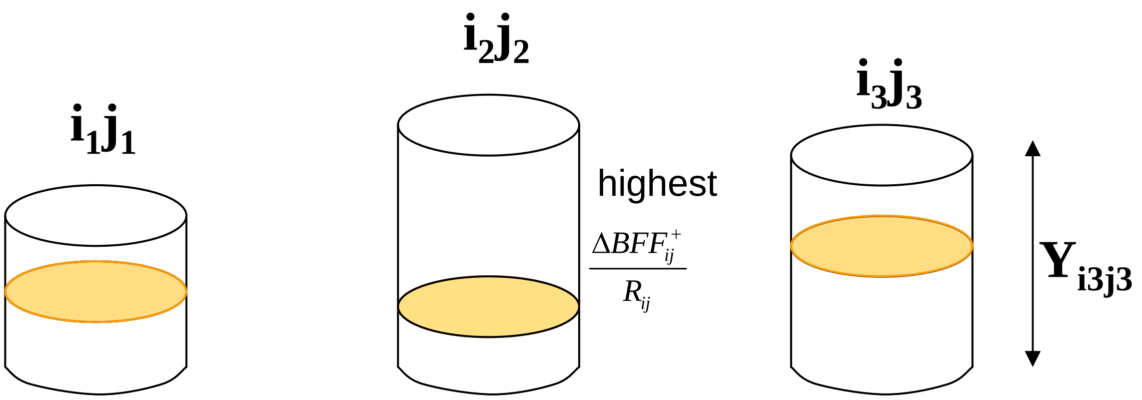
- **Round Robin Scheduler (RRS)**: resource is reserved based on the weight of user's VPN and equally for all users in the same VPN:

$$R_{Ui} = \frac{R_{Max} \cdot r_{v_{Ui}}}{\sum_{k=1}^{K} \left( r_k \cdot N_k \right)}$$

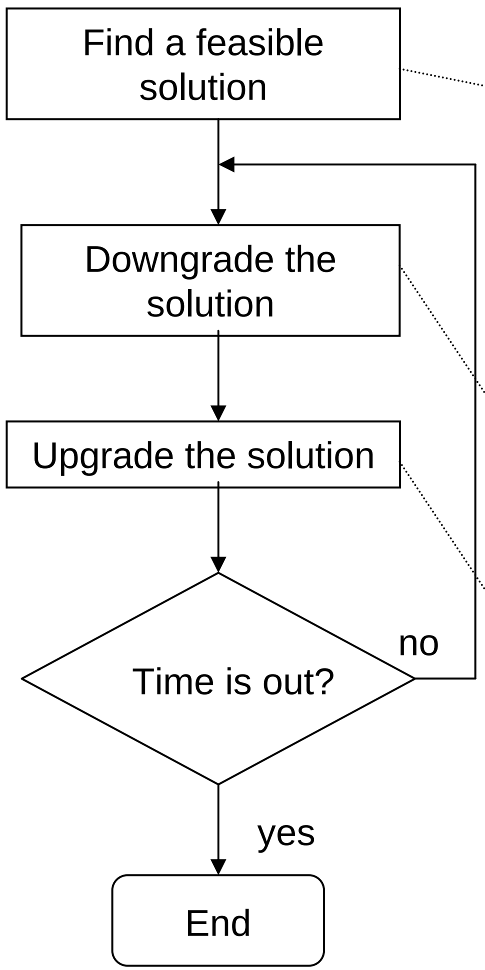
- **Benefit based Selection Algorithm (BSA)**: search and grant resource for the requirement which achieves the highest benefit per granted resource first
- **Heuristic Algorithm (HA)**:
  - Execution time is controllable
  - Solve problem:
    - From beginning
    - Adapt the granted matrix **X** according to the change of the requests

# Benefit based Selection Algorithm

- ***Step 1:***
  - Begin with the current capacity assignment, calculate $\frac{\Delta BFF_{ij}^{+}}{R_{ij}}$ for all possible assignments for all nodes
  - Assign resource for the request with can achieve highest $\frac{\Delta BFF_{ij}^{+}}{R_{ij}}$
- ***Step 2:***
  - Repeat the step 1 until:
    - all requests are fulfilled or
    - out of available resource



# The Heuristic Algorithm




Divide the capacity to node to find a feasible solution (similar to the max-min fairness algorithm)

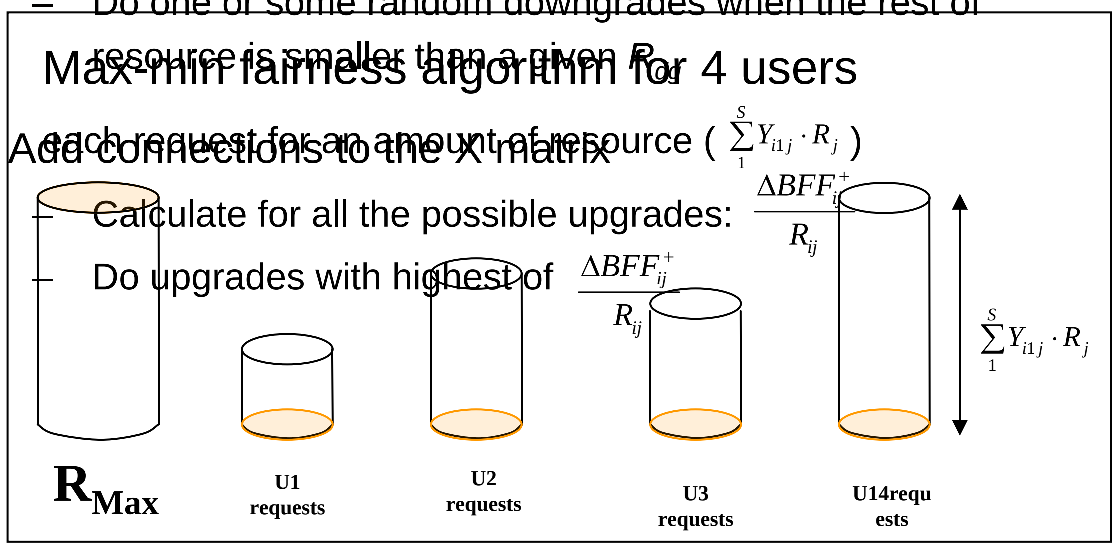
– Grant all nodes to maximum of the minimum resource requests
– Grant the rest of capacity to the next minimum requests, until there is no more request or capacity

Remove connections from the X matrix

– Do one or some random downgrades when the rest of resource is smaller than a given $R_d$

Add connections to the X matrix

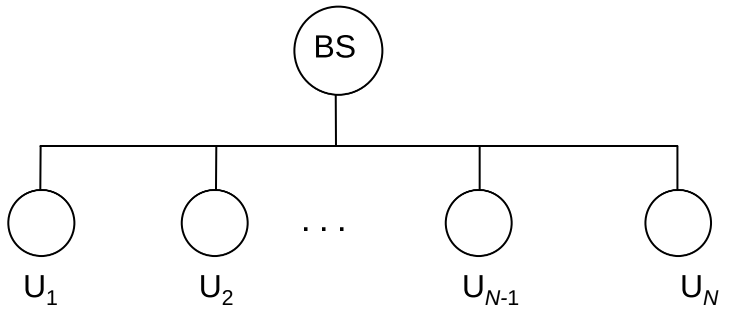
– Calculate for all the possible upgrades: $\frac{\Delta BFF_{ij}^{+}}{R_{ij}}$
– Do upgrades with highest of $\frac{\Delta BFF_{ij}^{+}}{R_{ij}}$




* $\Delta B_{ij}^{+}$:additional benefit achieved by adding a service j to the user i

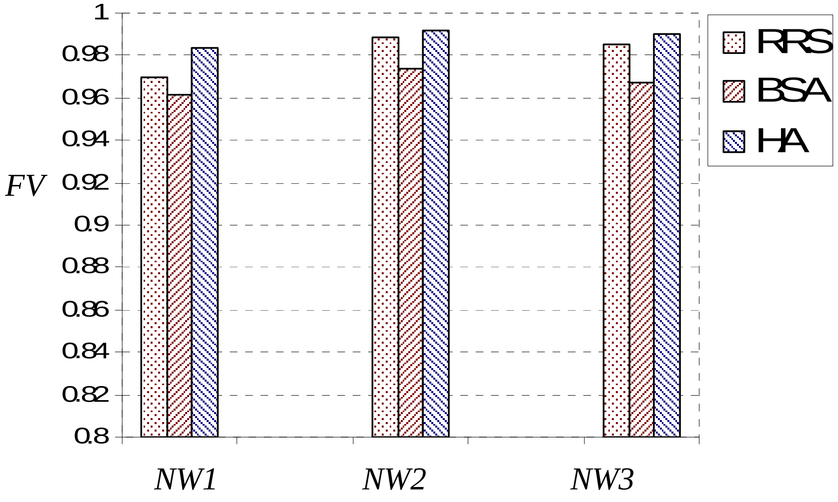
# Sample Networks

- *NW1: 32 users, R=64*
- *NW2: 64 users, R=128*
- *NW3: 128 users, R=256*
- $r_1=1$, $r_2=2$
- $N_1=N_2=N/2$
- *Same PHY speeds between users and BS*
- $y_{ij} \in [0,2]$
- $w_i=1$: all users have the same weight

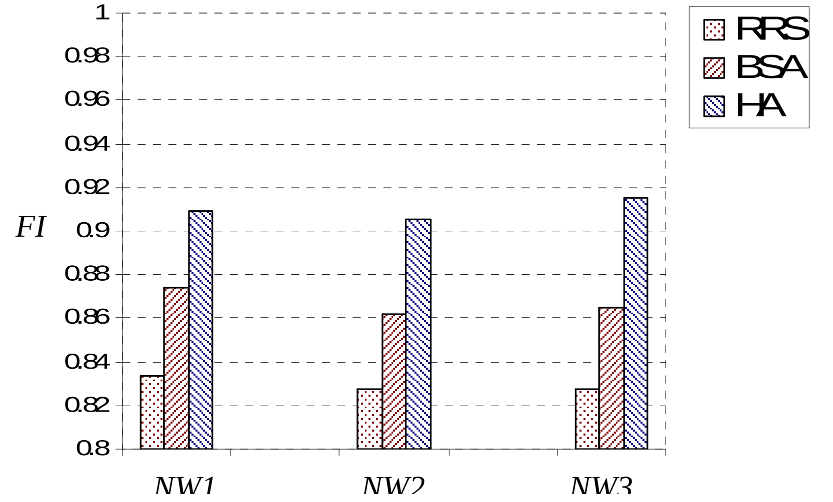


# Result Comparisons (1)

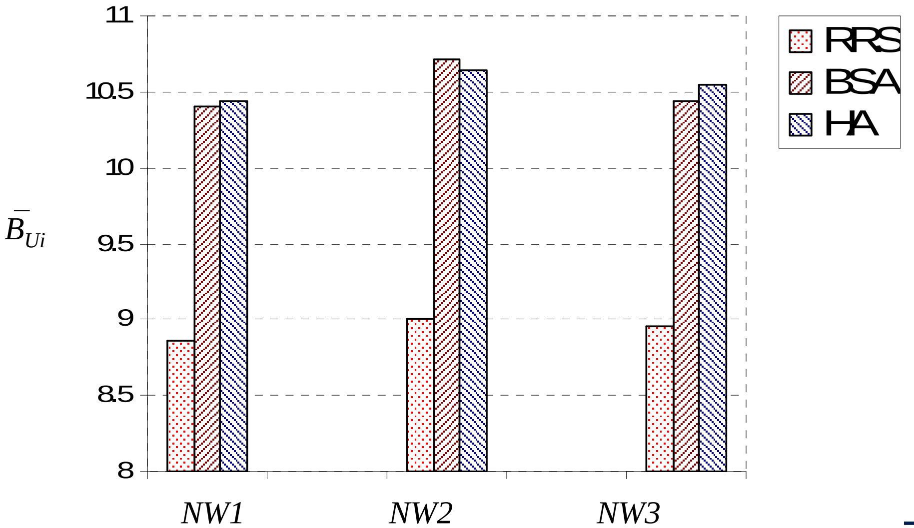





Inter-VPN (*FV*) fairness comparisons



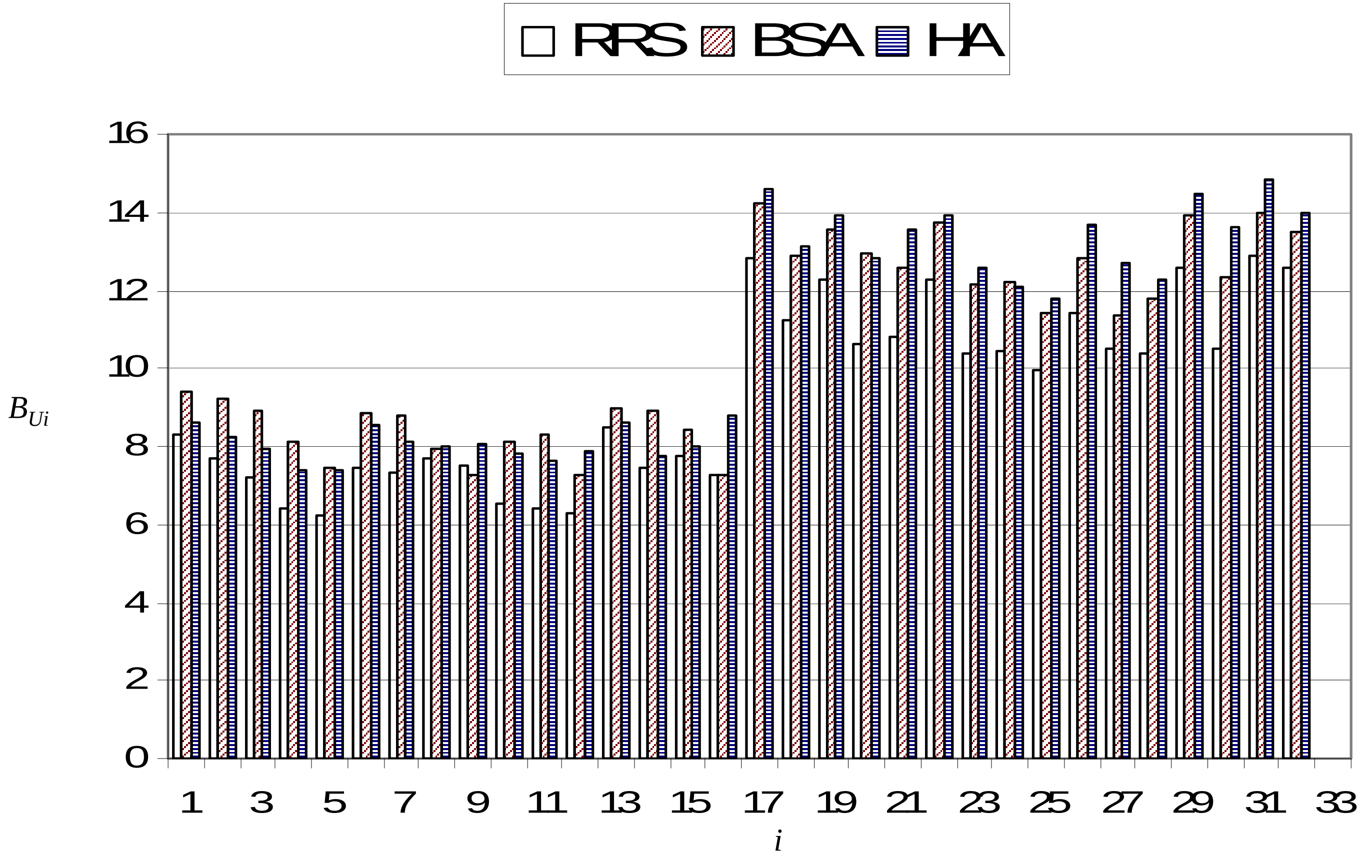

Intra-VPN (*FI*) fairness comparisons




Average benefit comparisons

# Result Comparisons (2)

- *NW1: 32 users, R=64*




Benefit of individual user

# Conclusions



- PLC which supports for multiple VPNs requires an efficient resource sharing method
- By introducing the benefit and fairness indexes of a resource assignment:
  - Formulated as an optimization problem
  - Weight-configurable for VPNs
  - Solved by different methods
- Heuristic algorithm
  - The best to find the solutions in large networks
  - Execution time is controllable
- Further investigations:
  - Differentiate between hard-real-time and elastic traffics for fairness indexes
  - Adapt the granted matrix **X** according to the change of the requests during runtime

Thank You!