Resource Allocation in Multi-terminal Wireless Communication Systems

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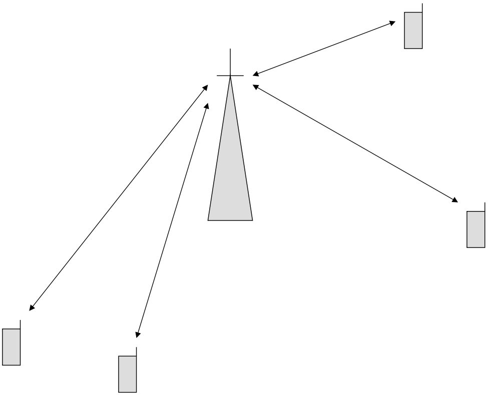
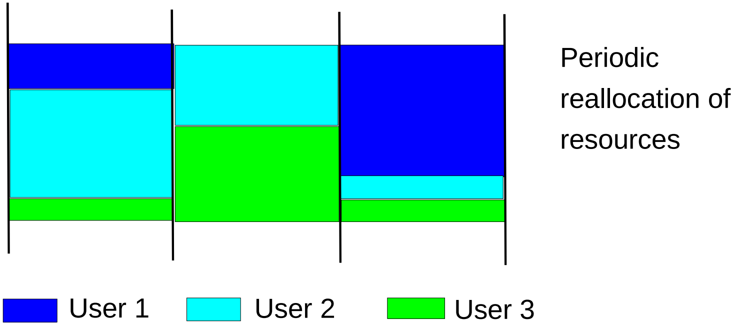
Cellular Systems



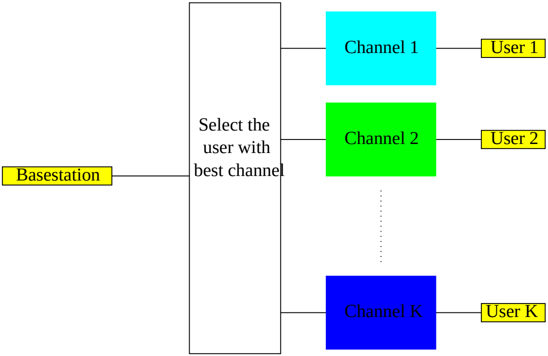
- Time-varying channel
- Resource sharing – Interference constraints

Dynamic Resource Allocation



- Resources: Time, Bandwidth, Power
- Adaptation to channel and traffic conditions
- Dynamic resource allocation
  - Reallocation period of the order of a few milliseconds

Adapting to the Channel: Maximizing Capacity

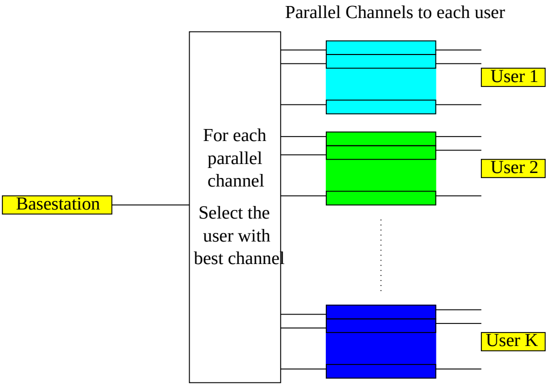


- Infinite backlog assumption
- All power and bandwidth resources to one user
- User with best achievable rate chosen:

$$i = \arg\max_k R_k,$$

where R_k is the rate that can be supported by user k.

Maximizing Capacity: Parallel Channels

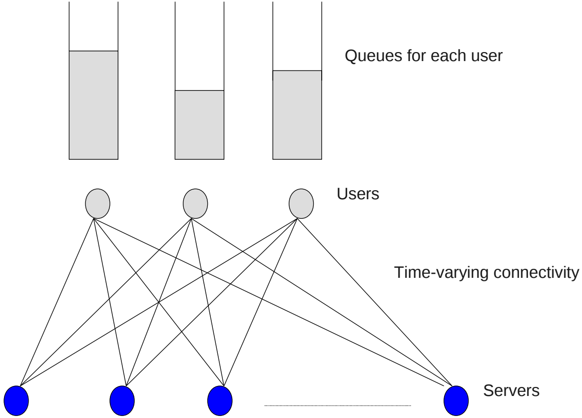


- Bandwidth resources split to achieve parallel channels
- For each channel n, user with best channel conditions chosen:

$$i_n = \arg\max_k R_{k,n}.$$

- Water-filling power allocation

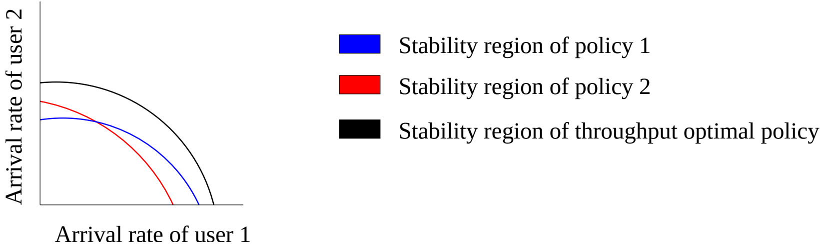
Adapting to the Channel and Traffic



- Multi-Queue Multi-Server Model for each time slot
- Server: Subcarrier/Group of subcarriers/Spreading code

Resource Allocation/Cross-layer Scheduling Goals

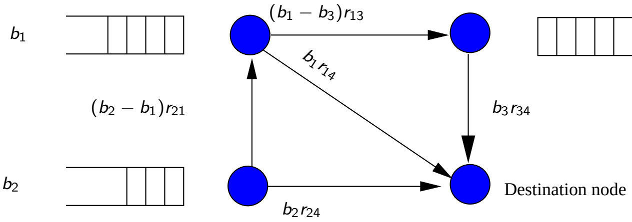
- Scheduling Goals
  - Stability and throughput optimality
    - ★ Stability: Average queue length finite



  - Packet delay constraints
  - Fairness

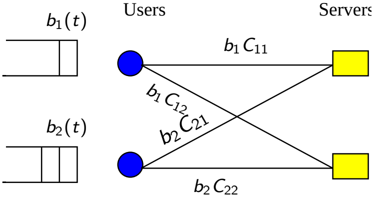
Stability in a general wireless network

- [Tassiulas et al 1992, Georgiadis et al 2006]
  - Dynamic backpressure policy



- Interference model: Only certain links can be activated simultaneously
- Scheduling problem: Which links will you activate?
- Solution: Activate those links such that the sum of their weights is maximum.

Dynamic back-pressure policy for our setting

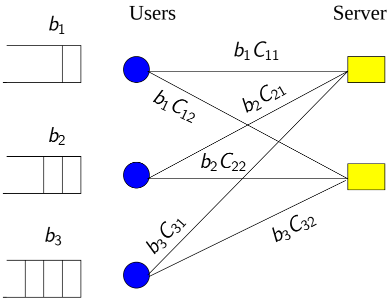


- Only one link per server to be activated. Which links to activate?
- *Solution*:
  - Make the servers as destination nodes.
  - Assign the weights for each link as in back-pressure policy.
  - Activate those links such that the sum of their weights is maximum.

$$\max \sum_k b_n C_{nk}$$

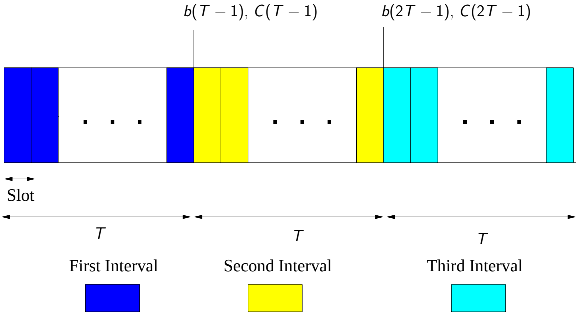
b_n: Backlog of user n, C_{nk}: Capacity of user n on server k

Two Throughput Optimal Policies



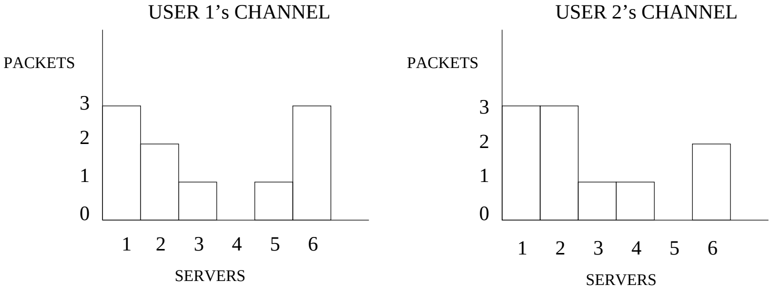
- Policy 1: Dynamic backpressure policy
- Policy 2: Improving delay performance
  - Update queue information after each server is scheduled

Using Delayed Information



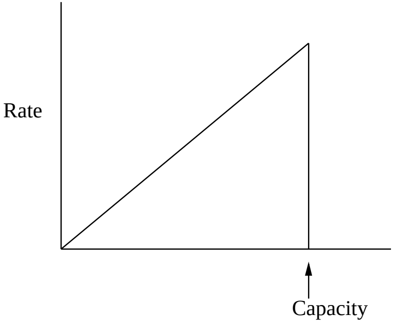
- Time-slots are grouped into intervals
- Channel and queue information available only once in T slots

Channel model



- C_{nk}: channel capacity of user n on server k.
- $C_{nk} \in \{0, 1, 2, 3\}$.

Loss model



Packets sent

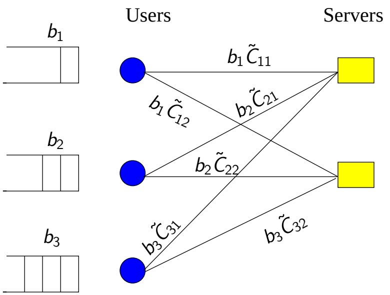
R_{nk}	0
$R_{nk} <= C_{nk}$	$R_{nk} > C_{nk}$

- R_{nk}: number of packets user n transmits on server k.
- $C_{nk}(lT-1)$: channel information available at the start of l^{th} interval.

Results

- Retain throughput optimality of dynamic backpressure policy
- Two policies: Policy 1 and Policy 2
- Comparison with KLS policy [Kar et al 2007]

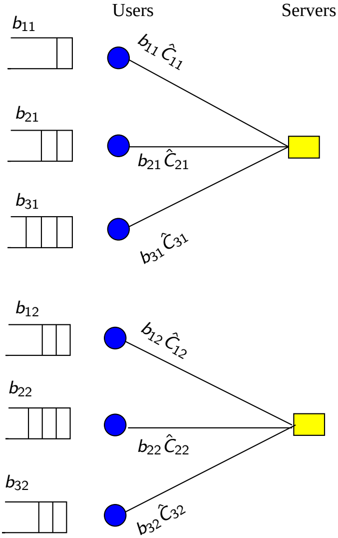
Policy 1 & Policy 2



$$\text{Define} \quad \tilde{C}_{nk} = \max E\left[T_{nk}(t) | C_{nk}(lT-1)\right]$$
$$= \max_r r \Pr\{r \leq C_{nk} \mid C_{nk}(lT-1)\}$$

- Policy 1 is the dynamic back pressure policy for our setting
- Assignment changes every slot
- Policy 2: Update queue information after each server is scheduled

KLS Policy



- Virtual queue for each user-server pair
- Define $\hat{C}_{nk}(lT)$ as

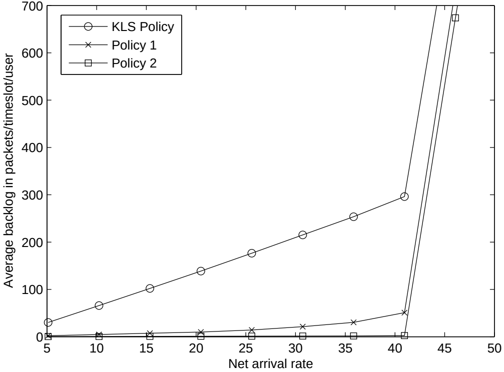
$$\frac{1}{T}\mathbb{E}\left[\sum_{t=lT}^{(l+1)T-1} C_{nk}(t) \,\middle|\, C_{nk}(lT-1)\right]$$

- Assignment changes once in T slots

Simulation setup

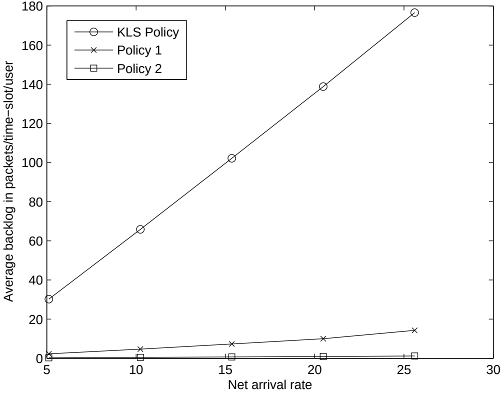
- Truncated Poisson arrivals
- 128 users and 16 servers
- Markov fading channel with probability transition matrix
- Backlog and delay are used as metrics for comparison
- Simulations for both symmetric and asymmetric arrivals
  - Symmetric case shown here

Average backlog comparison: Slow fading, $T = 8$



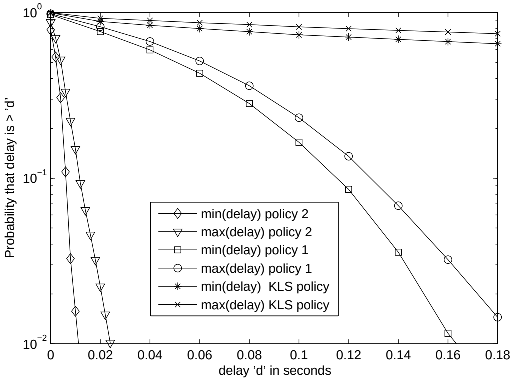
- All the policies have similar stability region.

Average backlog comparison for low traffic



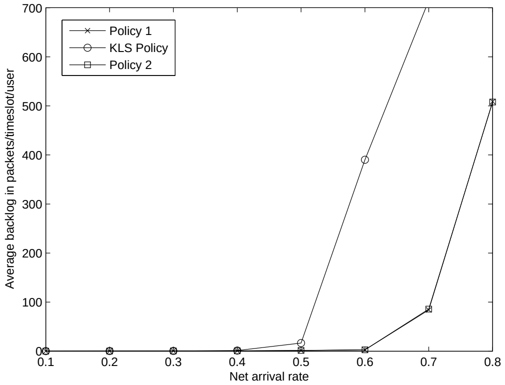
- At low traffic, proposed policies outperform KLS policy.

Delay comparison



- Net arrival rate $= 25.6$, $T = 4$

Comparison of stability regions: Fast fading



- 2 queues, 1 server, $T = 2$, states are $\{0, 1\}$
- Probability transition matrix: $\begin{bmatrix} \delta & 1-\delta \\ 1-\delta & \delta \end{bmatrix}$, $\delta = 0.1$

Fairness and Utility Maximization

- Arrival rate vector outside stability region
  - Support a fraction of the traffic
  - Optimize utility based on long term throughput
  - Flow control to get stabilizable rates + stabilizing policy
  - Fairness based on choice of utility function
    - ★ Proportional fairness

Possible Extensions

- More physical layer options
  - Multiple antennas
  - Power allocation across resources (servers)
  - Interference processing vs. Interference avoidance
  - Multi-cell scenario: Centralized vs. Distributed methods
- Requirements
  - Lower complexity/approximate solutions to optimization problem
  - Appropriate reduction search space of physical layer modes

Summary

- Adapting to the channel
- Adapting to the channel and traffic
  - Dynamic backpressure policy
- Adapting to imperfect information
  - Conditional expected rate in backpressure policy
- Possible extensions
  - Approximate lower complexity solutions
  - Appripriate choice of physical layer modes