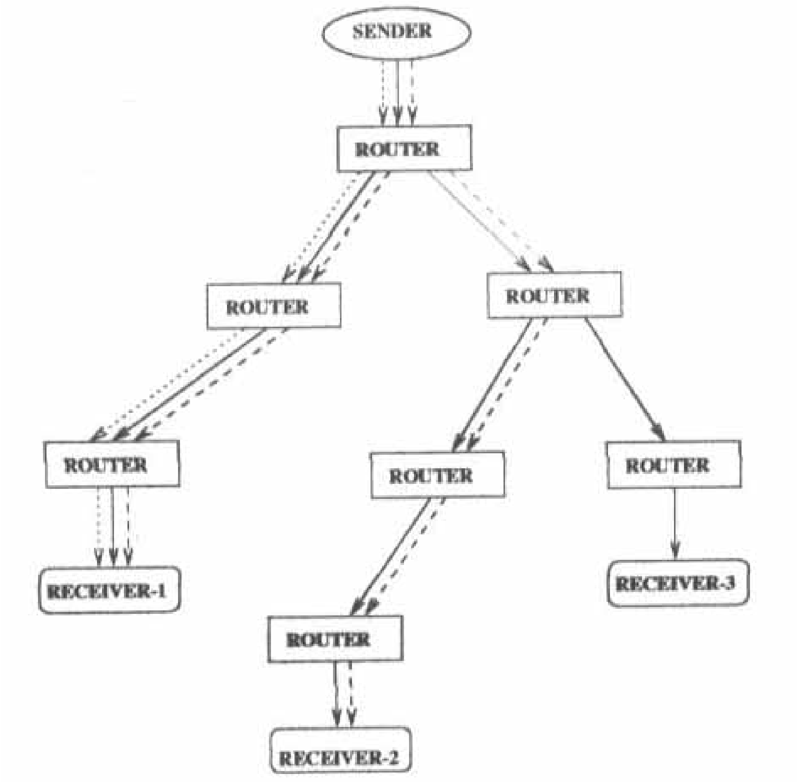
Layered Media Multicast Control (LMMC)

Rate Allocation & Partitioning

http://www.ece.uci.edu/~hyousefi/pub.html

Multimedia Traffic over Mbone



Multimedia Traffic over Mbone

- Replicated Media (RM) Approach
  - Independent Replicated Multicast Groups
  - B/W Overhead
  - Protocol Simplicity

- Layered Media (LM) Approach
  - Successively Refinable Multicast Groups
  - B/W Efficiency
  - Protocol Complexity

Background Work

- Multicasting over Mbone
  - S. Deering, Stanford
- Intra-Session & Inter-Session Fairness
  - M. Ammar, Georgia Tech
- Multicast Layering Fairness
  - D. Rubenstein, Columbia
  - J. Kurose, UMass
- Rate Allocation & Partitioning
  - S. Lam, UT Austin
  - J. Bolot, UCB
- Error Control
  - I. Rhee, NCSU
  - J. Kurose, UMass
- Feedback Implosion
  - D. DeLucia, USC
- Receiver Centric Models
  - S. McCanne, UCB
  - M. Ammar, Georgia Tech
- Congestion Control
  - S. Floyd, UCB
  - L. Vicisano, UC London

LMMC Scope

- Replicated & Layered Media
- Intra-Session (Receiver) Fairness
- Intersession (Flow) Fairness
- Rate Allocation & Partitioning (RAP)
- Error Control

Rate Allocation & Partitioning

- Problem Definition:

  Delivering Multimedia Traffic from One Source to N Receivers with K Bandwidth Groups Considering Intra-Session (Receiver) and Inter-Session (Flow) Fairness.

- Approach:

  Deliver Multimedia Traffic over Mbone.

- Problem Formulation:

  Find a partitioning of N receivers into K groups

  $$P = \{G_1 | \ldots | G_K\}$$

  optimizing max-min fairness utility function

$$IRF_{Total} = \sum_{k=1}^{K} IRF_k = \sum_{k=1}^{K} \sum_{i \in G_k} F(r_i, g_k)$$

$$= \sum_{k=1}^{K} \sum_{i \in G_k} \frac{\min(r_i, g_k)}{\max(r_i, g_k)}$$

$$\text{Subject To:} \quad g_k \le \frac{r_i}{1-L_i} \quad k = 1, \ldots, K$$

Max-Min Fairness: LMMC Approximation

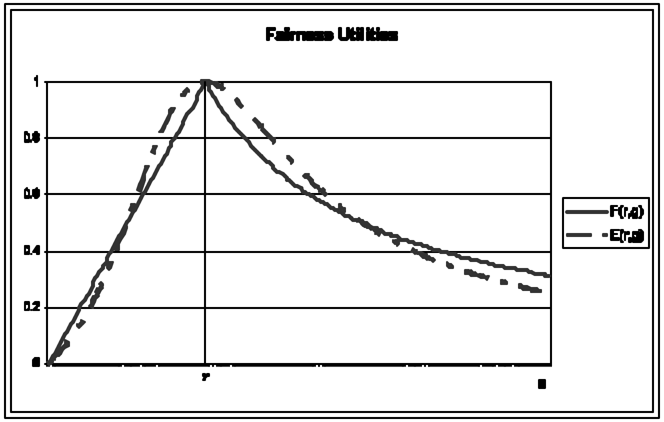
- Approximate Max-Min Fairness

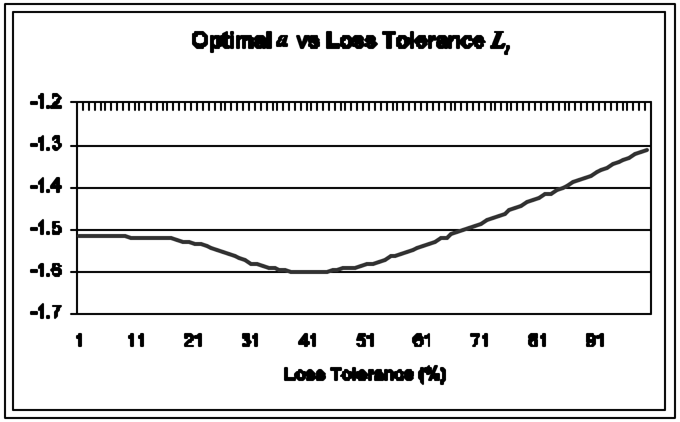
$$F(r_i, g_k) = \frac{\min(r_i, g_k)}{\max(r_i, g_k)} = \begin{cases} \frac{g_k}{r_i}, & g_k \le r_i \\ \frac{r_i}{g_k}, & g_k \ge r_i \end{cases}$$

with the Continuously Differentiable Function

$$E(r_i, g_k) = \frac{(2+a) r_i g_k}{g_k^2 + a r_i g_k + r_i^2}$$

Using MLS Technique.





LMMC Formulation

- Optimization Problem

$$\max_{g_1,,g_K} \sum_{k=1}^{K} IRFA_k = \max_{g_1,,g_K} \sum_{k=1}^{K} \sum_{i \in G_k} \frac{(2+a) r_i g_k}{g_k^2 + a r_i g_k + r_i^2}$$

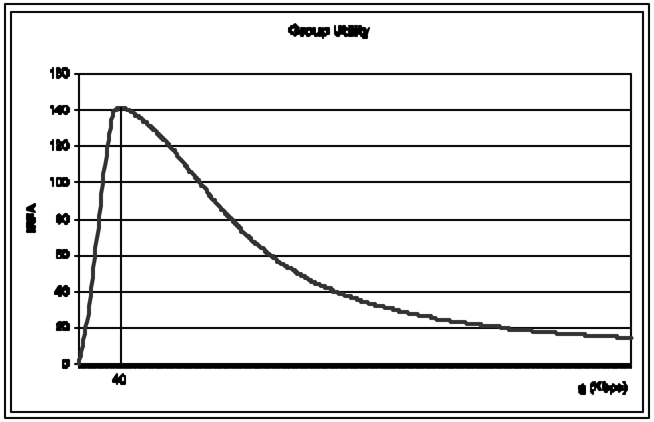
$$\text{Subject To:} \quad g_k \le \mathrm{BWA}_k \quad k = 1, \ldots, K$$

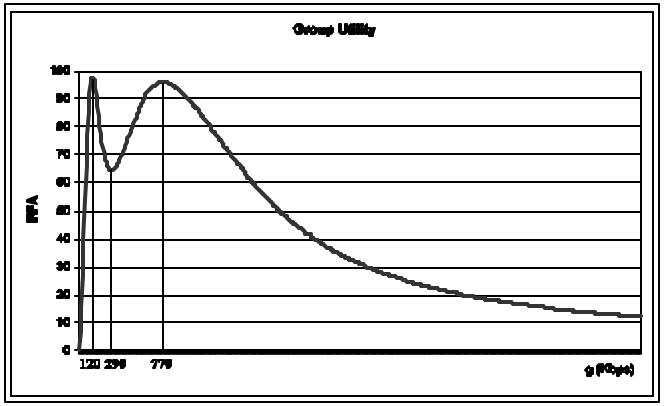
$$BWA_k \equiv \min(\mathrm{BWL}_k, \mathrm{BWF}_k)$$

$$\mathrm{BWL}_k \equiv \min_{i \in G_k} \frac{r_i}{1 - L_i}$$

BWF_k Flow Constraint

$$IRFA_k \equiv \sum_{i \in G_k} E(r_i, g_k) = \sum_{i \in G_k} \frac{(2+a) r_i g_k}{g_k^2 + a r_i g_k + r_i^2}$$





LMMC 2-Phase Solution

- Phase 1:

  For A Fixed Partitioning Obtain the Optimal Solution

  - K Independent Optimal Control Problems

$$\max_{g_k} IRFA_k = \max_{g_k} \sum_{i \in G_k} \frac{(2+a) r_i g_k}{g_k^2 + a r_i g_k + r_i^2}$$

$$\text{SubjectTo:} \quad g_k \leq \mathrm{BWA}_k$$

- Gradient

$$\frac{\partial IRFA_k}{\partial g_k} = \sum_{i \in G_k} \frac{(2+a) r_i (r_i^2 - g_k^2)}{(g_k^2 + a r_i g_k + r_i^2)^2} = 0$$

- Hessian

$$\frac{\partial^2 IRFA_k}{\partial g_k^2} = \sum_{i \in G_k} \frac{2(2+a) r_i (g_k^3 - 3 r_i^2 g_k - a r_i^3)}{(g_k^2 + a r_i g_k + r_i^2)^3} \leq 0$$

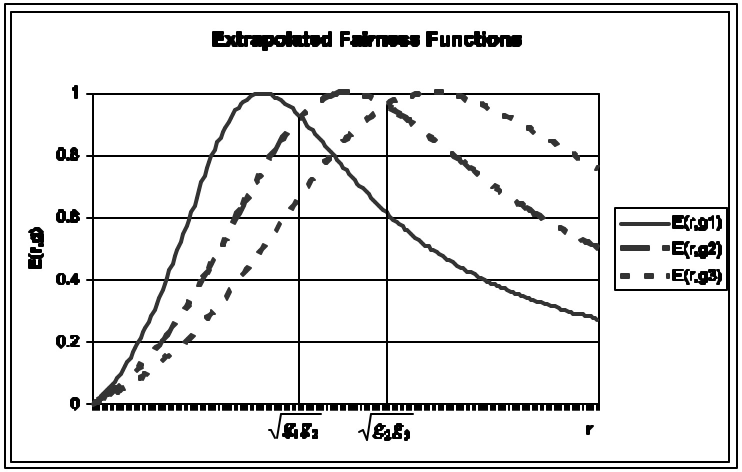
- Numerical Root Range

$$[r_{k_{min}}, BWA_k]$$

LMMC 2-Phase Solution

- Phase 2:

  For A Given Group Rates Obtain the Best Partitioning Strategy



- $for \quad (k=2 \quad to \quad K) \qquad \{$
  - Calculate the partitioning thresholds $\sqrt{g_{k-1}g_k}$.
  - Repartition groups $k-1$ and k. For every receiver belonging to the groups and isolated rate r_i, assign the receiver to group k if $(r_i > \sqrt{g_{k-1}g_k}$) AND (($\frac{r_i}{1-L_i} \geq g_k^*$) OR ($C_2 g_k^* < \frac{r_i}{1-L_i} < g_k^*$)) Otherwise, assign the receiver to group $k-1$.
  - Calculate the new optimal sending rate of group k.

$\}$

LMMC Iterative Optimal Solution

- Start from an Initial Partition
- Do {
  - Phase I: Obtain Optimal Group Rates for Fixed Partitioning
  - Phase II: Obtain Best Partitioning Strategy for Group Rates of Phase I

} While ($\frac{|SU_1 - SU_2|}{SU_1} < d$)

Alternative Solution

- S. Lam et al. at UT, Austin Solve the Following Iterative Equation

$$IRF_{\{Total\}}^{*}(i,m) = \max_{1 \le j < i} [IRF_{\{Total\}}^{*}(j, m-1) + IRF_{k}^{*}(\{j+1, \ldots, i\})]$$

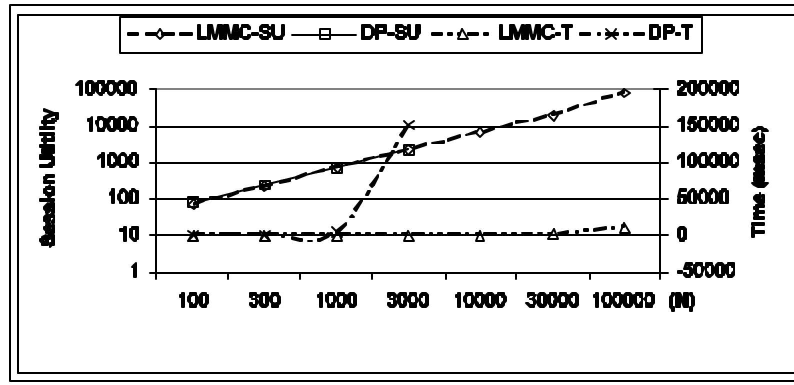
Utilizing Dynamic Programming (DP)

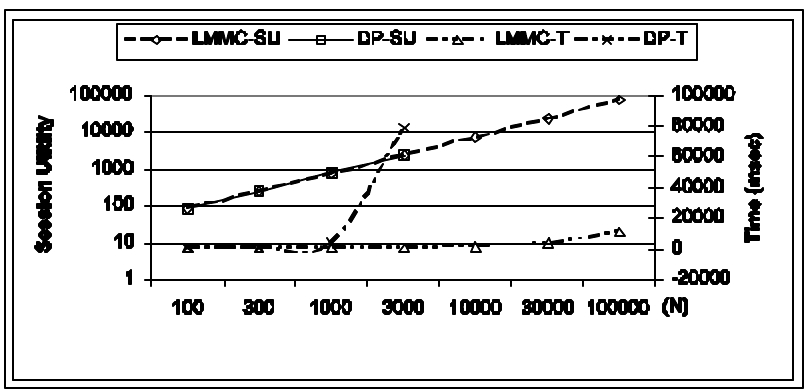
Complexity Analysis

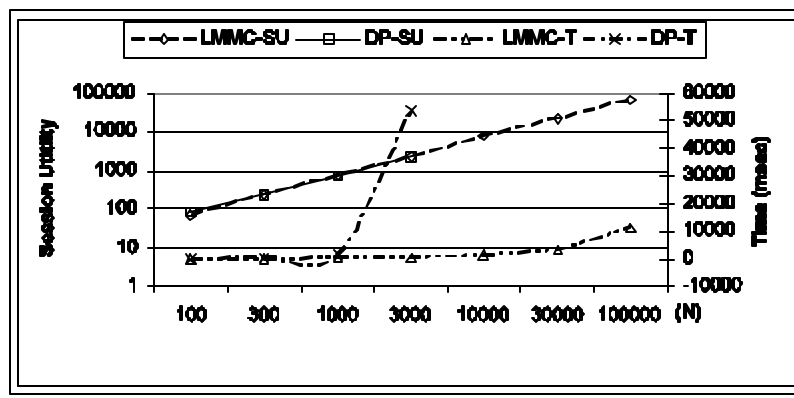
- Time Complexity
  - LMMC: $O(IKN \log N)$
  - DP: $O(N^3)$
- Space Complexity
  - LMMC: $O(N)$
  - DP: $O(N^2)$

Numerical Validation

- Partitioning & Rate Allocation
  - Dynamic Programming: Only Applies to (LM)
  - Layered Media Multicast Control (LMMC): (RM/LM)







Future Work

- LMMC Dynamic Rate Analysis
- LMMC Hybrid Error Control
  - Open-Loop FEC
  - Closed-Loop ARQ

- LMMC for Wireless Networks