Performance Analysis of Multiclass FIFO: 
Motivation, Difficulty and a Network Calculus Approach

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Outline

• Motivation

• Performance Analysis of Multi-Class FIFO: Difficulty with the Classic Queueing Theory

• Direct Analysis using Network Calculus

• A New Idea for Analysis using Network Calculus

• Concluding Remarks
Motivating Scenarios

- Internet packet size distribution
  - 40 (60%)
  - 1300-1500 (40%)

- Flows with different packet sizes sharing the same output link
Motivating Scenarios (cont’)

• Downlink sharing in wireless networks (e.g. DSCH – downlink shared channel)

Figure from “WCDMA for UMTS”, edited by Harri Holma and Antti Toskala, 2002
Motivating Scenarios (cont’)

• Input queueing in switches / routers
Performance Analysis of Multi-Class FIFO: System Model

- A packet-switched network node serves packets in FIFO manner.

- There are $N$ traffic classes.

- The service rate of each class is constant $C_n$ in bps.
Analysis using Queueing Theory: Difficulty

- How to define system states? Is (# of each class packet in queue) sufficient? If not, what else?

- Assume Poisson arrival process and exponentially distributed packet lengths of each class. What is the state transition diagram? Or, *is it possible to get one?*

- If interarrival times are not exponentially distributed, or packet times are not exponentially distributed, how to do the analysis?
Analysis using Network Calculus

- Assumption: The traffic flow of each class is \((\sigma, \rho)\)-constrained:

\[ A_n(s, t) \leq \sigma_n + r_n(t - s) \]
Direct Results from Network Calculus

- If the service rates to all classes are the same $C$, the system becomes the normal single-class FIFO;

- The total input $A(t)$ is constrained by:

$$A(s, t) \leq \sum_n \sigma_n + \sum_n r_n (t - s)$$
Direct Delay Bound from Network Calculus
(with ignoring the “last” packetizer effect)

\[ \beta(t) = Ct \]
\[ \alpha(t) = rt + \sigma \]

- If the total arrival rate is smaller than \( C \), the delay of any packet is bounded by:

\[ D \leq \frac{\sum_{n=1}^{n} \sigma_n}{C} \]
Analysis of Multiclass FIFO: Network Calculus Approach

- Easy 😊
- But, wait: What if the service rate (in bps) for each class is different?

\[ A(t) \xrightarrow{C} A^*(t) \]
Direct Delay Bound from Network Calculus

- For multiclass FIFO, the minimum service rate to any class is \( \min_n C_n \).
- If the total arrival rate is smaller than \( \min_n C_n \), the delay is bounded:

\[
D \leq \frac{\sum_{n} \sigma_n}{\min_n C_n}
\]
Analysis of Multi-Class FIFO: A new idea for the network calculus approach

- Inequality: For any packet arriving at $t$, its delay is bounded by:

$$D \leq \sum_n \sup_{s \leq t} \left[ A_n(s, t) - r_n(t - s) \right] \frac{C_n}{C_n}$$
Improved Delay Bound

• Suppose the following condition holds

\[ \sum_n \frac{r_n}{C_n} < 1 \]

• The delay of any packet is bounded by:

\[ D \leq \sum_n \frac{\sigma_n}{C_n} \]

• The bound is tight!
Comparison of Delay Bounds

- Condition:

\[
\sum_n \frac{r_n}{\min_n C_n} < 1
\]

- Direct bounded:

\[
D \leq \sum_n \frac{\sigma_n}{\min_n C_n}
\]

- Condition:

\[
\sum_n \frac{r_n}{C_n} < 1
\]

- Improved Bound:

\[
D \leq \sum_n \frac{\sigma_n}{C_n}
\]
Comparison of Delay Bounds

- Two classes
- $C_1 = 10$ Mbps
- $C_2 = 100$ Mbps

- Each class has one flow.
- Each flow is $(\sigma, \rho)$-constrained with burstiness parameter 1KB and rate parameter 100 Kbps.

$A_i(s, t) \leq 8Kb + 100Kbps \times (t - s)$

- Condition:

$$\sum_2 \frac{100Kbps}{10Mbps} < 1$$

- Direct bounded:

$$D \leq \sum_2 \frac{8Kb}{10Mbps} = 1.6ms$$

- Condition:

$$\frac{100Kbps}{10Mbps} + \frac{100Kbps}{100Mbps} < 1$$

- Improved Bound:

$$D \leq \frac{8Kb}{10Mbps} + \frac{8Kb}{100Mbps} = 0.88ms$$
Implication of the Delay Bound Difference

- Suppose the same 2-class FIFO system.
- Question: How many Class 1 & Class 2 flows, \((M_1, M_2)\), may be admitted if a delay bound of 8ms needs to be guaranteed?

Must consider both the condition and the corresponding delay bound in finding the region for \((M_1, M_2)\).
Concluding Remarks

• **Surprisingly difficult to analyze multi-class FIFO using Queueing Theory.**

• Network calculus approach may be used directly, but with limited application scenarios and/or loose bounds.

• A new idea for the network calculus approach can improve the bounds.

• The analysis has been extended to stochastic and network cases.

• The analysis has been extended for other performance metrics e.g. backlog and leftover service, but more difficult and has room to improve.

• *Part of the results were presented at 2nd European Teletraffic Seminar (ETS), Sept 2013, and included in arXiv (http://arxiv.org/abs/1306.4773).*