Embedded Systems

4a. Example Network Processor

Lothar Thiele
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Software and Programming
Processing and Communication
Hardware
How to Schedule the CPU cycles meaningfully?

- Differentiating the level of service given to different flows
- Each flow being processed by a different processing function
Our Model – Simple NP

- Real-Time Flows (RT)
- Best Effort Flows (BE)

![Diagram showing packet processor and streams from RT and BE flows]

- Real-time flows have deadlines which must be met
- Best effort flows may have several QoS classes and should be served to achieve maximum throughput
Task Model

- Packet processing functions may be represented by directed acyclic graphs
- End-to-end deadlines for RT packets
Architecture

Input ports

Classifier

F1

F2

F3

Fn

Real-time Flows

Packet Processing functions

Output ports

CPU Scheduler

Best effort flows

Real-time Flows

Packet Scheduler

Best effort flows
CPU Scheduling

- First Schedule RT, then BE (background scheduling)
  - Overly pessimistic

- Use **EDF Total Bandwidth Server**
  - EDF for Real-Time tasks
  - Use the remaining bandwidth to serve Best Effort Traffic
  - WFQ (weighted fair queuing) to determine which best effort flow to serve; not discussed here …
CPU Scheduling

Real-time Flows

Packet Processing functions

Has Deadlines

Use EDF

Assign Deadline using remaining CPU bandwidth

One Packet out

Classifier

F_1

F_2

F_3

... 

F_n

WFQ

Best effort flows
CPU Scheduling

As discussed, the **basis is the TBS**:

\[ d_k = \max\{r_k, d_{k-1}\} + \frac{c_k}{U_s} \]

- computation demand of best effort packet
- deadline of best effort packet
- arrival of best effort packet
- utilization by real-time flows

**But**: utilization depends on time (packet streams)!

- Just taking upper bound is too pessimistic
- Solution with time dependent utilization is (much) more complex – BUT IT HELPS …
CPU Scheduling

Before

a) plain best effort + EDF scheme

end-to-end packet delay [sec]

deadline

RT flows
CPU Scheduling

- After

```
c) approximation with two segments

RT video flow

simulation time [sec]
```

deadline RT flows

```
c) approximation with two segments

NRT ftp flow

RT video flow

simulation time [sec]
```