A Deficit Round Robin with Fragmentation Scheduler for Mobile WiMAX

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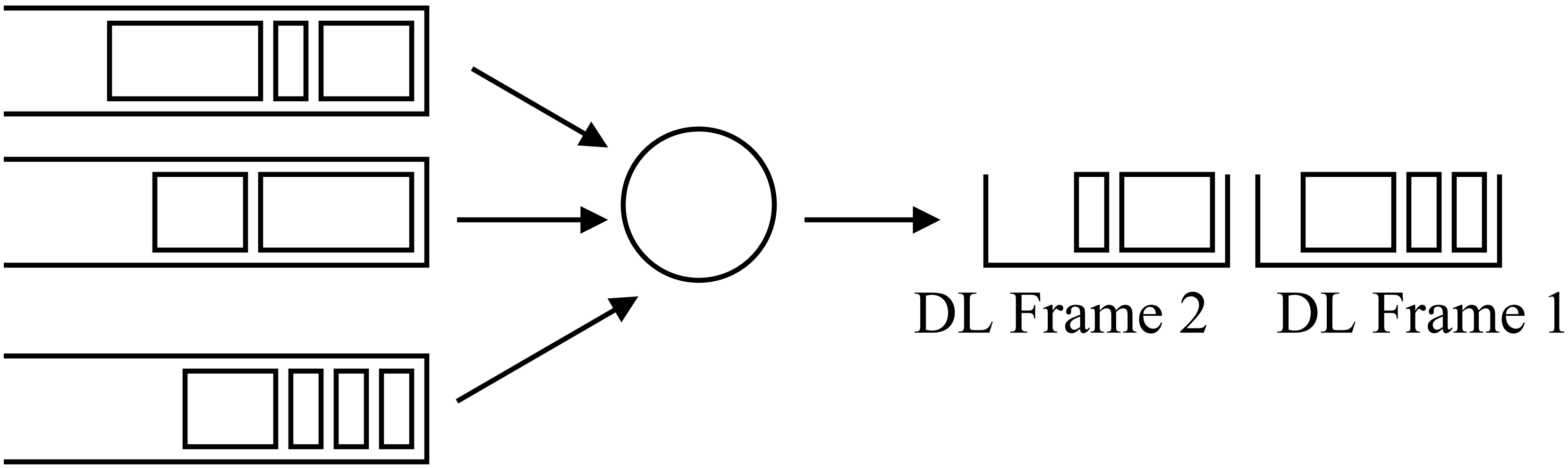
These slides are available at
http://www.cse.wustl.edu/~jain/wimax/drrf.htm

- Fair Scheduling Algorithms
  - General Processor Sharing (GPS)
  - Deficit Round Robin (DRR)
- DRR with Fragmentation Awareness (DRRF)
- Max-Min Fairness
- Minimum Guaranteed Rate Extension
- Performance Evaluation using **WiMAX Forum NS2 model**

Problem Statement



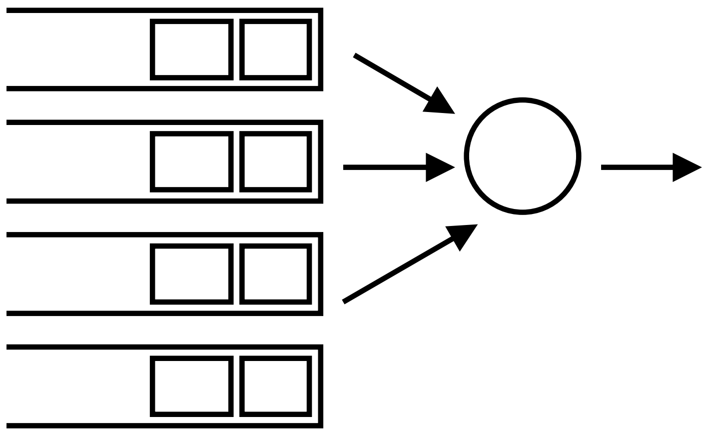
- Which queue(s) to serve in the next PHY DL frame?
- Goals:
  - Maximize throughput (minimize overhead, unused space)
  - Fair allocation

Common Scheduling Algorithms

- General Processor Sharing (GPS) [4]
  - Allocate the fair share to each MS regardless of packet size
    E.g., WiMAX frame capacity = 300B,
    4 MSs with 125B packet size
    → 300/4 = 75B fragmented packet is transmitted.
- Deficit Round Robin (DRR) [5]
  - Allow only full packet to be transmitted
    - If packet size > the fair share (quantum), the deficit is remembered.
    - If the fair share + deficit > the packet size, the packet is transmitted and the deficit is updated.

Example of DRR

- 4 Mobile Stations (MSs)
- Packet size = 125B
- Frame capacity = 300B
- Quantum (fair share)= 300/4 =75
- RED = transmitted packets
- Waste 50B each frame



#Transmitted Packet Size/ Deficit Counter

Frame	1			2	3			4
Round	1	2			3	4		
MS_1	0/75	0/150	125/25	0/25	0/100	0/175	125/50	0/50
MS_2	0/75	0/150	125/25	0/25	0/100	0/175	125/50	0/50
MS_3	0/75	0/150	0/150	125/25	0/100	0/175	0/175	125/50
MS_4	0/75	0/150	0/150	125/25	0/100	0/175	0/175	125/50

DRR with Fragmentation Awareness

- Mobile WiMAX allows fragmentation.
- DRR with fragmentation (DRRF)
  - Similar to DRR: Transmit full packet
    → Reduce overhead: MAC and fragmentation headers
  - In case there are some left-over spaces + none of full packets are eligible, DRRF allocates those left-over spaces to some MSs. → Achieve full frame utilization

Metric/Scheduling	GPS	DRR	DRRF
Fairness	Perfect	Perfect	Perfect
Frame Utilization	High	Low	High
Overhead	Highest	Lowest	Low

Example of DRRF

#Transmitted Packet Size/ Deficit Counter

Frame	1			2				3
Round	1	2			3	4		
MS_1	0/75	0/150	125/25	0/25	0/100	0/175	**100**/75	**25**/50
MS_2	0/75	0/150	125/25	0/25	0/100	0/175	0/175	125/50
MS_3	0/75	0/150	**50**/100	**75**/25	0/100	0/175	0/175	125/50
MS_4	0/75	0/150	0/150	125/25	0/100	0/175	0/175	**25**/150

Frame	3		
Round		5	
MS_1	0/50	0/125	125/0
MS_2	0/50	0/125	**75**/50
MS_3	0/50	0/125	0/125
MS_4	**100**/50	0/125	0/125

RED = transmitted packets

BOLD RED = transmitted fragmented packets

Throughput Fair Allocation

- Broadband Wireless Networks
  - Link Capacity is not constant over time/distance.
  - WiMAX allows different Modulation and Coding (MCS) for different condition.
  - Slot capacity → variable (based on the channel condition)
- We uses #requested_slots not #requested_bytes (queue length) as an allocation unit

$$requested\_slots = \lceil queue\_length / MCS\_size \rceil$$

- *MCS_size* = #bytes/slot given MCS level
  E.g., Each slot QPSK1/2 results in 6B and 9B for QPSK3/4

Max-Min Fairness Algorithm

- Some MS may not have enough traffic and may not be able to use the fair share.

$$Maximize\{Min(requested\_slots(i))\}$$

- Pseuducode:

Calculate *#requested_slots/frame* for each MS given MCS

Sort active MSs in ascending order of *MS_requested_slots*

FOR each $active\_MS_i$

  - Calculate *#fair_slots* given MCS_i
  - Update *#granted_slots* for each $active\ MS_i$
  - Update *free_slots* and exit if *free_slots* == 0

END FOR

Max-Min Fairness (GPS and DRR(F))

- For GPS; we use *#granted_slots* as an actual allocation.
- For DRR(F); we use *#granted_slots* as a quantum.

Minimum Guaranteed Rate Extension

- Some users may need to be favored over others.

$$r\_\min\_slots(i) = \lceil r\_\min(i) \times t\_frame / MCS\_size(i) \rceil$$

  - *r_min(i)* = minimum guaranteed rate of mobile station *i*
  - *t_frame* = WiMAX frame duration (5ms)
  - *MCS_size(i)* = #bytes/slot given MCS level of MS_i

$$quantum(i) = Min[requested\_slots(i), r\_\min\_slot(i)]$$

- For DRR and DRRF; quantum *i* is used as an initial deficit number for MS_i
- For GPS; quantum *i* is used as a minimum number of granted slots for MS_i

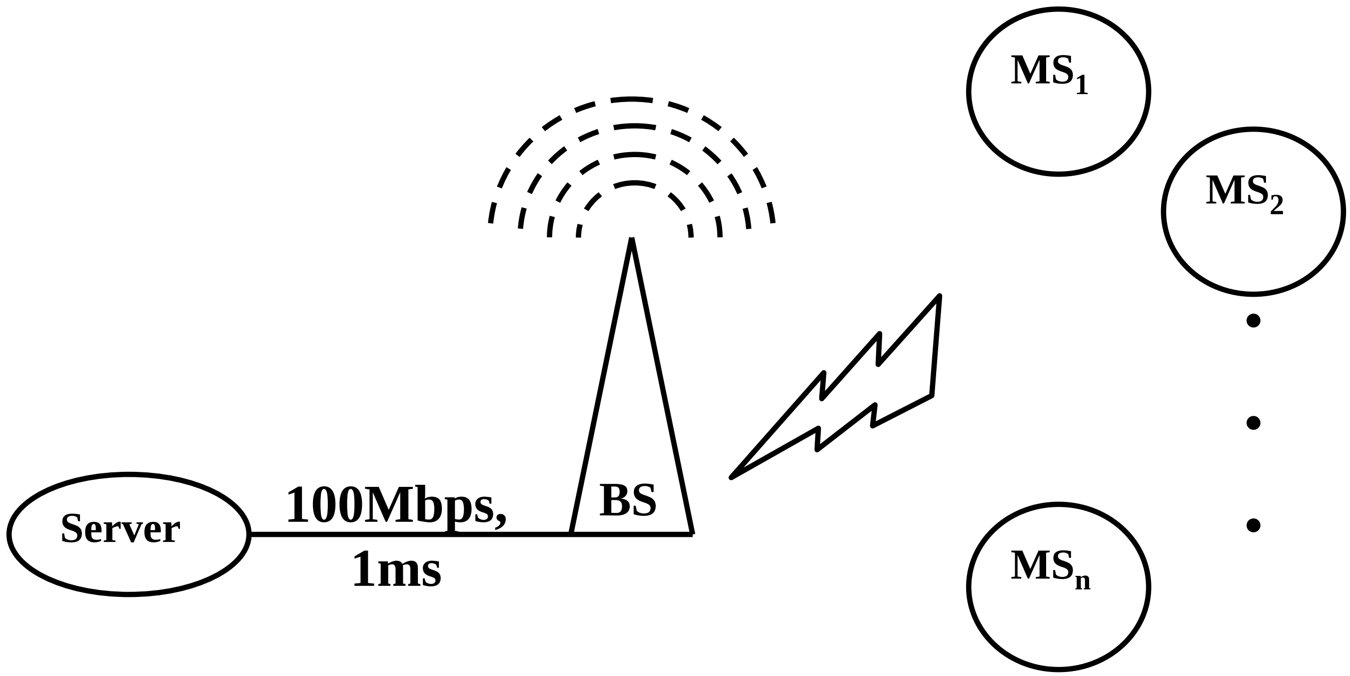
Max-Min Fairness with r_{min}

- For DRR(F), use *r_min_slot* to update deficit counter
- For GPS, use *r_min_slot* for minimum granted slots
  - We update *free_slots* given *r_min_slot* and then we also update *requested_slots.*
- We apply Max-Min Fairness Algorithm

Simulation Parameters/ Configuration

- WiMAX Methodology [1] and NS2 Simulator [3, 4]
- Frame Duration: 5ms
- Bandwidth: 10 MHz (FFT: 1024), total symbols = 48.6
- TTG + RTG = 1.6; left-over symbols = 47
- Downlink ratio: 0.66 (DL 66%, UL 34%) ~ 2:1 [1]
  - #downlink symbols = 29 and 18 for #uplink symbols
- PUSC #DL Subchannels: 30, #UL Subchannels: 35
- ARQ and Packing are disabled.
- Downlink Preamble: 1 column-symbol

Simulation Topology

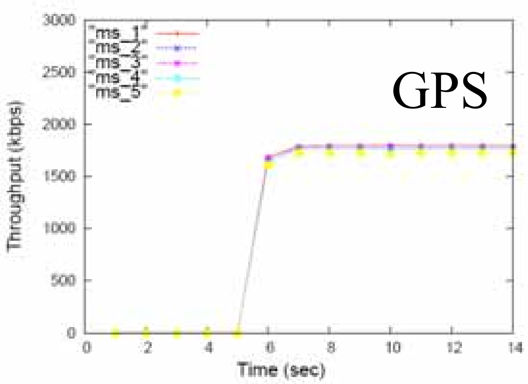


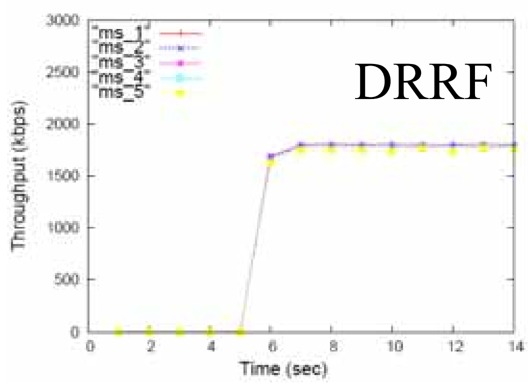
- Single BS with multiple MSs

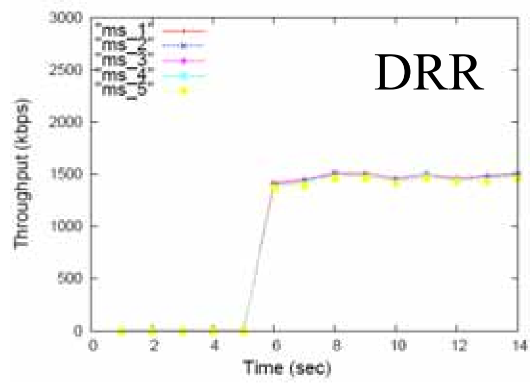
Workload/ Metrics/ Scenarios

- Traffic: UDP (CBR) at 0.3 and 3 Mbps (1500B packet size)
- 5 and 30 MSs or flows (3Mbps and 0.3Mbps in each scenario)
- Simulation starts from 0 sec to 15 sec (5 sec. setup process).
  - Flows start at 5+0.005*n* sec, *n* = 0, 1, 2, .., 30, end at 14 sec.
- Metrics: Throughput (kbps), %overhead and fairness
- Scenarios:
  - Throughput Fairness: 5 flows (QPSK3/4, 16QAM1/2, 16QAM3/4 and 64QAM1/2, 64QAM3/4)
  - Rate Guarantee: 5 flows (QPSK3/4) with 1 flow 2Mbps rate guaranteed
  - Throughput vs. overhead: 30 flows (QPSK3/4)

Scenario I: 5 Flows with Various MCSs

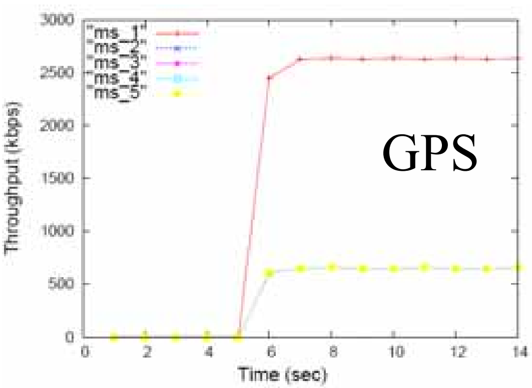


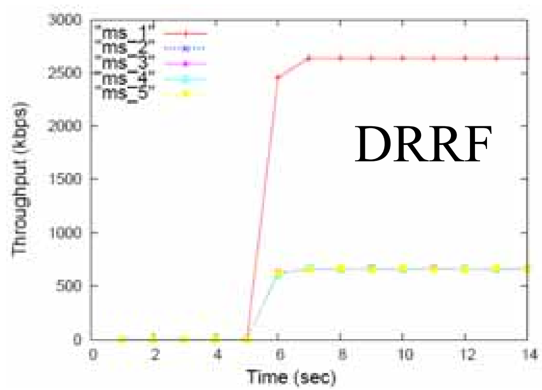


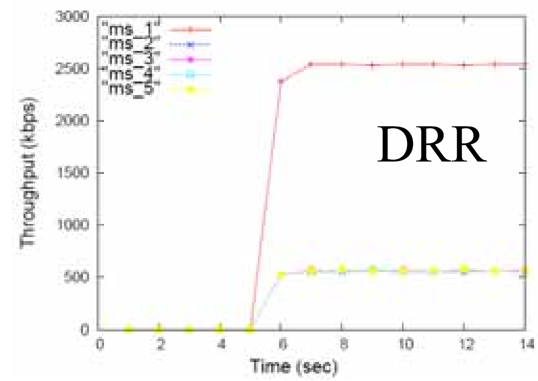


- With the modification by taking MCS into account; all three algorithm can achieve perfect throughput fairness.
- Fairness Index = 1 for all three algorithms

Scenario II: 5 Flows with 2Mbps (r_{min})







- With the modification by taking r_{min} into account; all three algorithms support minimum bandwidth guaranteed (2 Mbps)
  - The left-over bandwidth is distributed fairly. E.g., ≈ 2.6 Mbps for MS_1 and 600 Kbps for MS_2 to MS_5 with GPS or DRRF

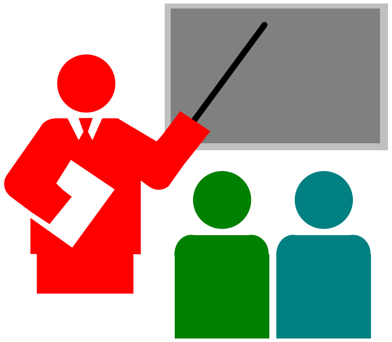
Scenario III: Large Topology (30 flows)

Algorithms	System Throughput (kbps)	%Overhead	Fairness Index
GPS	3,649	**10.26**[1]	1
DRRF	**3,652**[2]	**0.85**[1]	1
DRR	**2,409**[2]	0.39	1

- All three algorithms achieve perfect fairness.
  - Jain Fairness [6]

$$f(x_1, x_2, \ldots, x_n) = \left(\sum_{i=1}^{n} x_i\right)^2 / n\sum_{i=1}^{n} x_i^{\;2}$$

- [1] GPS: High link utilization BUT more overhead
- [2] DRR: less overhead BUT also less throughput
- DRRF = GPS (High link utilization) + DRR (less overhead)



Summary

- Deficit Round Robin (DRR) with Fragmentation = Full frame utilization (similar to GPS)+ less overhead (similar to DRR)
- With MCS consideration, GPS, DRR and DRRF achieve perfect fairness (throughput).
- By taking r_{min} into account, GPS, DRR and DRRF can support minimum bandwidth guarantee
- WiMAX Forum NS2 model is usable for realistic problems

References

- [1] WiMAX Forum, "WiMAX System Evaluation Methodology V2.1", 230 pp, July 2008, available at http://www.wimaxforum.org/technology/documents
- [2] UCB/LBNL/VINT, "Network Simulator – ns (version 2)," June 2007. http://www.isi.edu/nsnam/ns/index.html
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- [4] Parekh, A. K., and Gallager, R. G., "A Generalized Processor Sharing approach to Flow control in Integrated Services Networks: The Single Node Case," IEEE/ACM Transaction in Networking, vol. 1, no. 3, pp. 334 – 337, June 1993.
- [5] Shreedhar, M. and Varghese, G., "Efficient fair queueing using deficit round robin," ACM SIGCOMM Communication Review, vol. 25, no. 4, pp. 231 – 242, October 1995.
- [6] Jain, R., Chiu, D.M., and Hawe, W., "A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Systems," DEC Research Report TR-301, 1984, http://www.cse.wustl.edu/~jain/papers/fairness.htm .