

ON THE IMPACT OF IEEE 802.16 BANDWIDTH REQUEST-GRANT MECHANISMS ON TCP

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Agenda



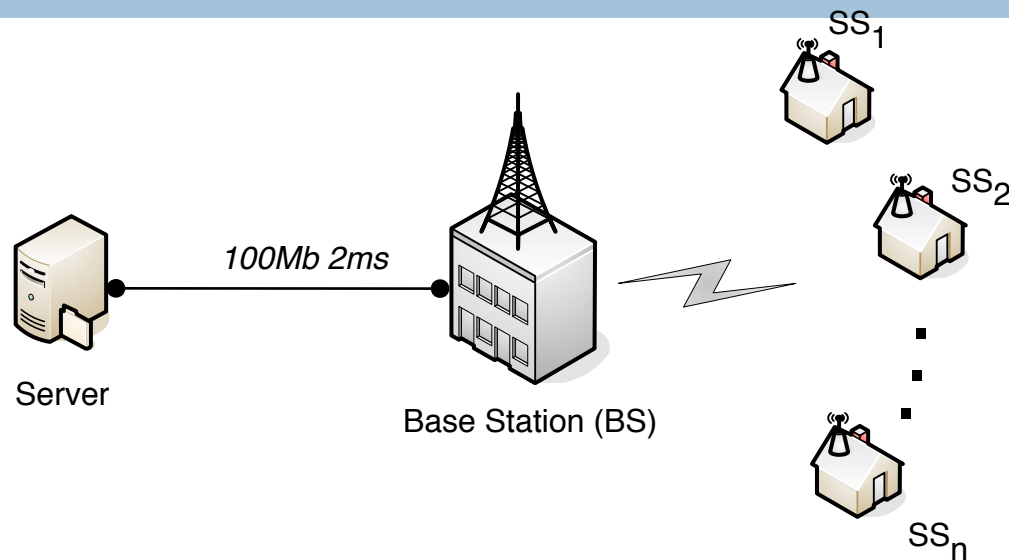
- Motivation
- Background
- Bandwidth Perception System for Best Effort Traffic
- Performance Model
- Simulation Results
- Conclusion & Future Work

Motivation



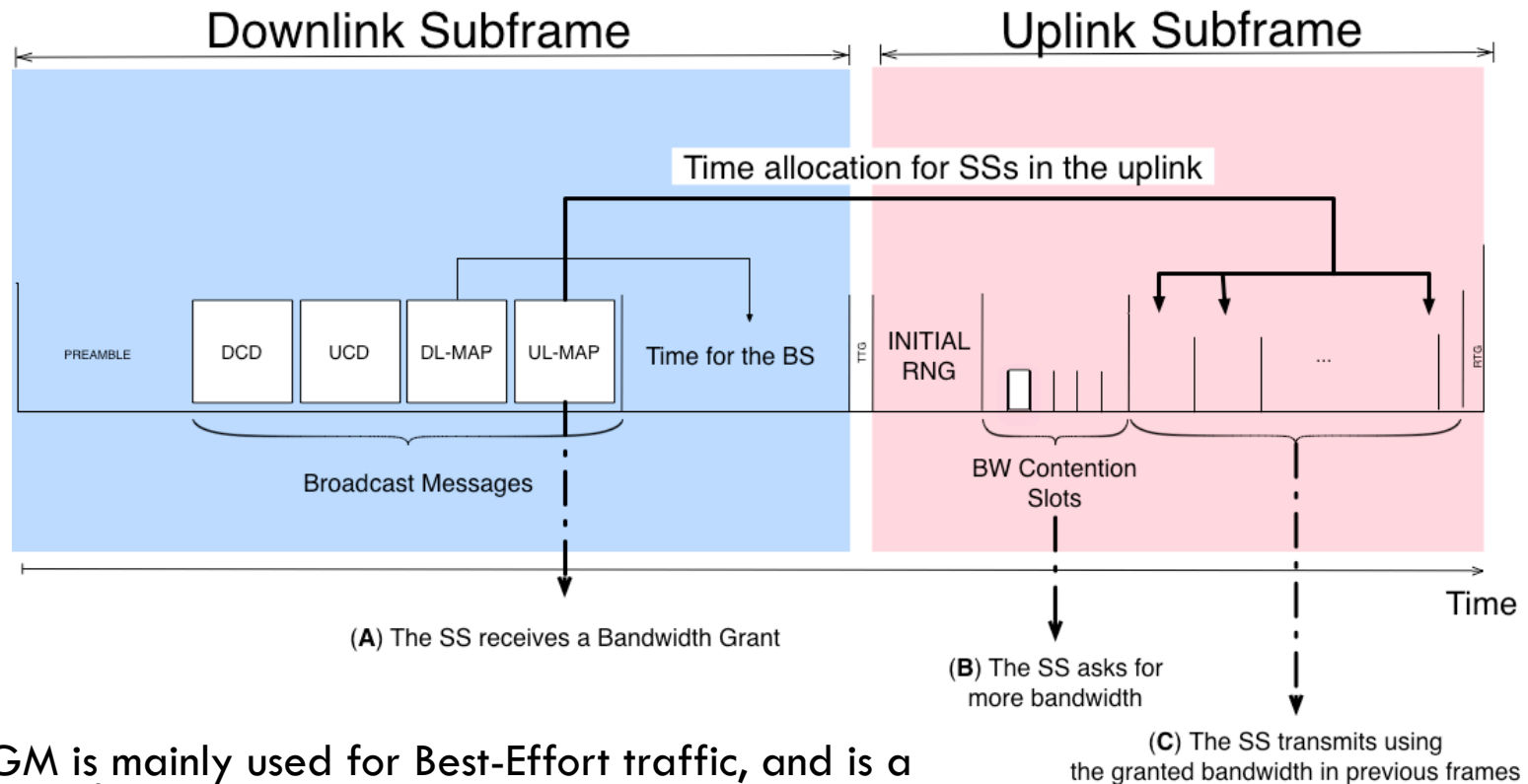
- TCP
 - ▣ Controls about 90% of the 200000 terabytes crossing the internet per second.
 - ▣ Transports up to 75% of on-demand and live streaming traffic.
- IEEE 802.16 Standards
 - ▣ Next generation Wireless broadband solution
 - ▣ Provide high speed internet access for mobile and residential users.
- In IEEE 802.16 networks, Uplink traffic also has significant impact on downlink TCP traffic.
 - ▣ ACKs that regulate TCP traffic
 - ▣ Data packets that cause HoL blocking of ACKs.

TCP over WiMAX Networks



- Point to Multipoint topology as in 802.16d and 802.16e
- TCP traffic transported by BE Class of Service
 - ▣ Uses contention based bandwidth requesting
- Bandwidth Control:
 - ▣ Downlink by central BS scheduler
 - ▣ Uplink Mixed Scheduler One Part Controlled by SS another by BS

IEEE 802.16 Frame



- The BRGM is mainly used for Best-Effort traffic, and is a compound of:
 - (A) The bandwidth needs perception at the BS driven by the processing of BR-REQ.
 - (B) The contention period to pass the BW-REQs
 - (C) The administration of the granted bandwidth at the SS.

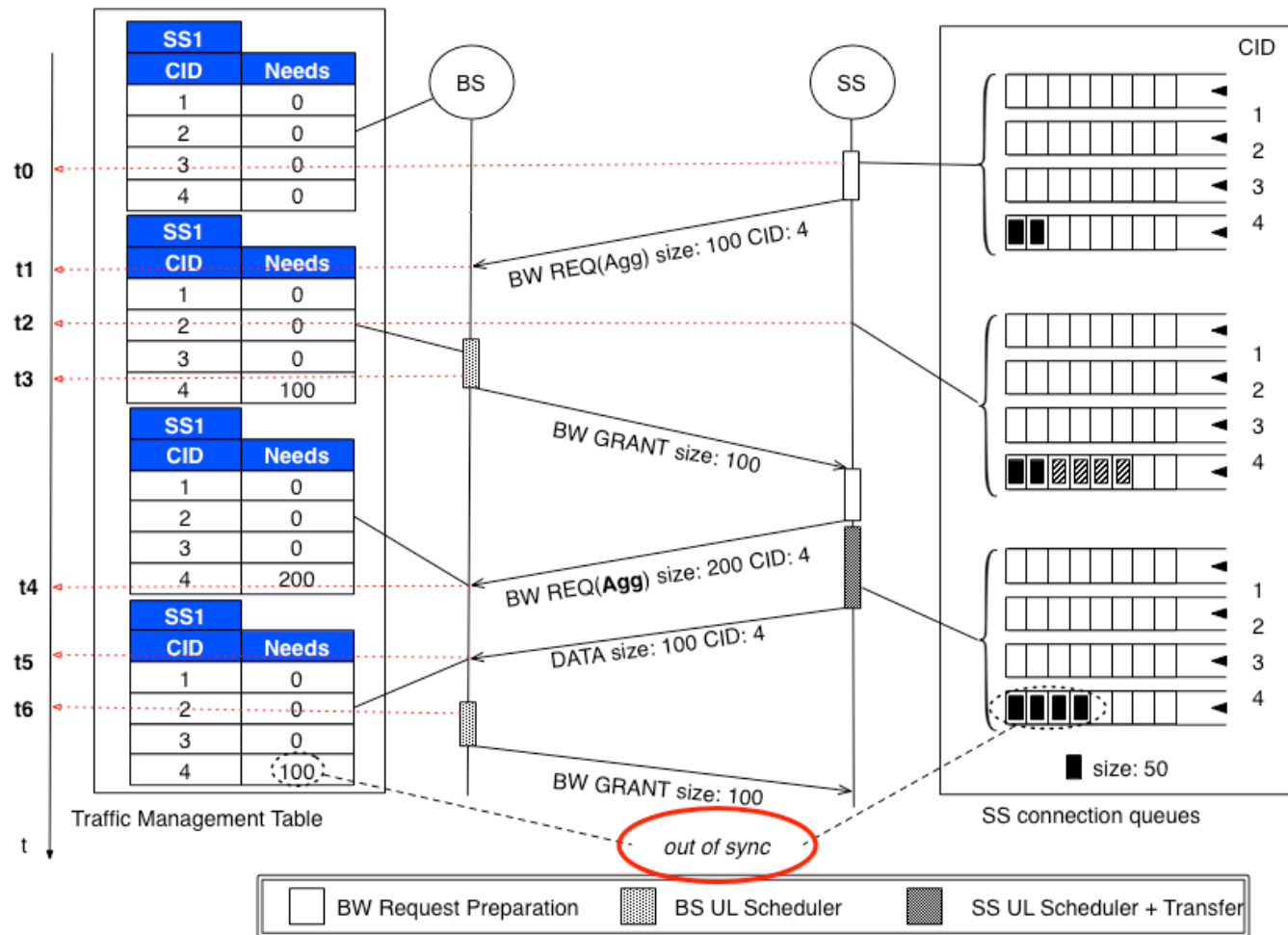
Uplink Bandwidth REQUEST-GRANT Scheme

- a) Data and ACK Packets arrive in SSs' CID queue
- b) SSs contend to transmit **BW-REQ** packets to BS.
- c) **Uplink Bandwidth Perception**: BS processes received **BW-REQs** and calculates the bandwidth needs.
- d) BS allocates uplink bandwidth according to the perceived bandwidth demand of SSs.

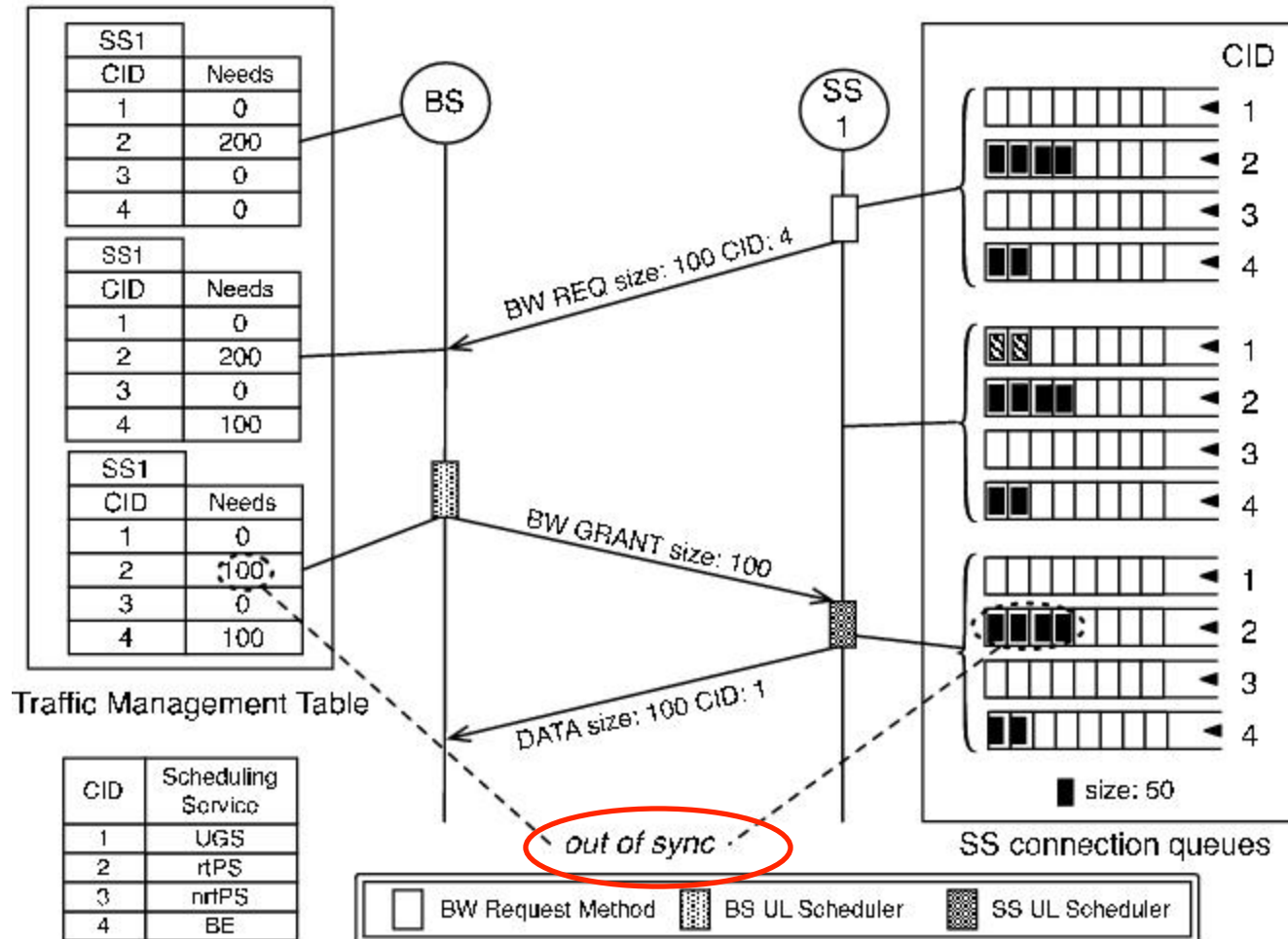
Bandwidth Perception at BS

- Previous work bandwidth perception schemes
 - RPG: Reset per grant
 - BS reset bandwidth perception to zero after granting
 - DPG: Decrease per grant
 - BS decrease bandwidth perception after granting
 - DDA: Decrease at data arrival.
 - BS decrease bandwidth perception after receiving uplink data
 - BS set bandwidth perception immediate after receiving BW-REQ packet

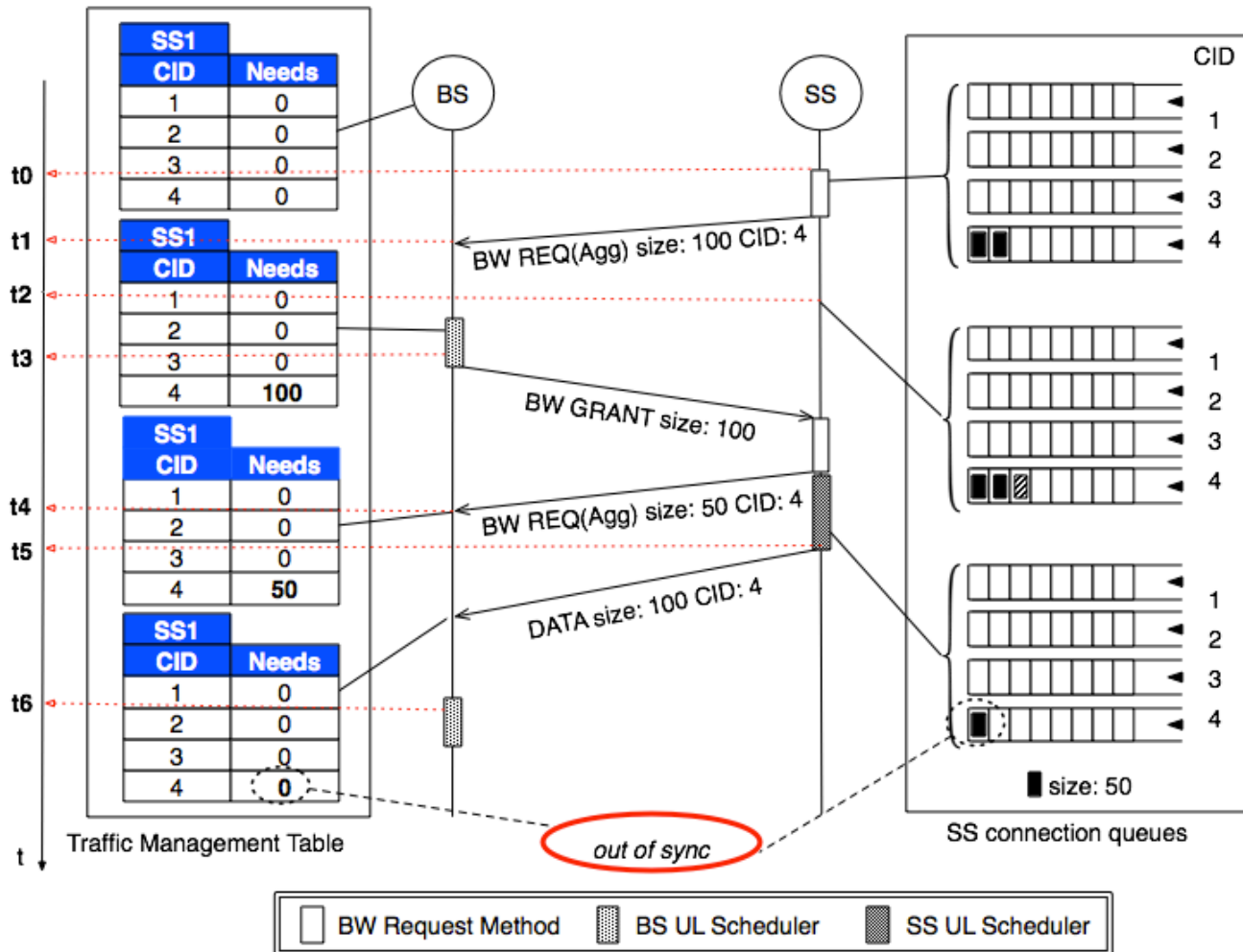
Getting out of synchronization-RPG



Get out of synchronization-DPG



Get out of synchronization-DDA-i

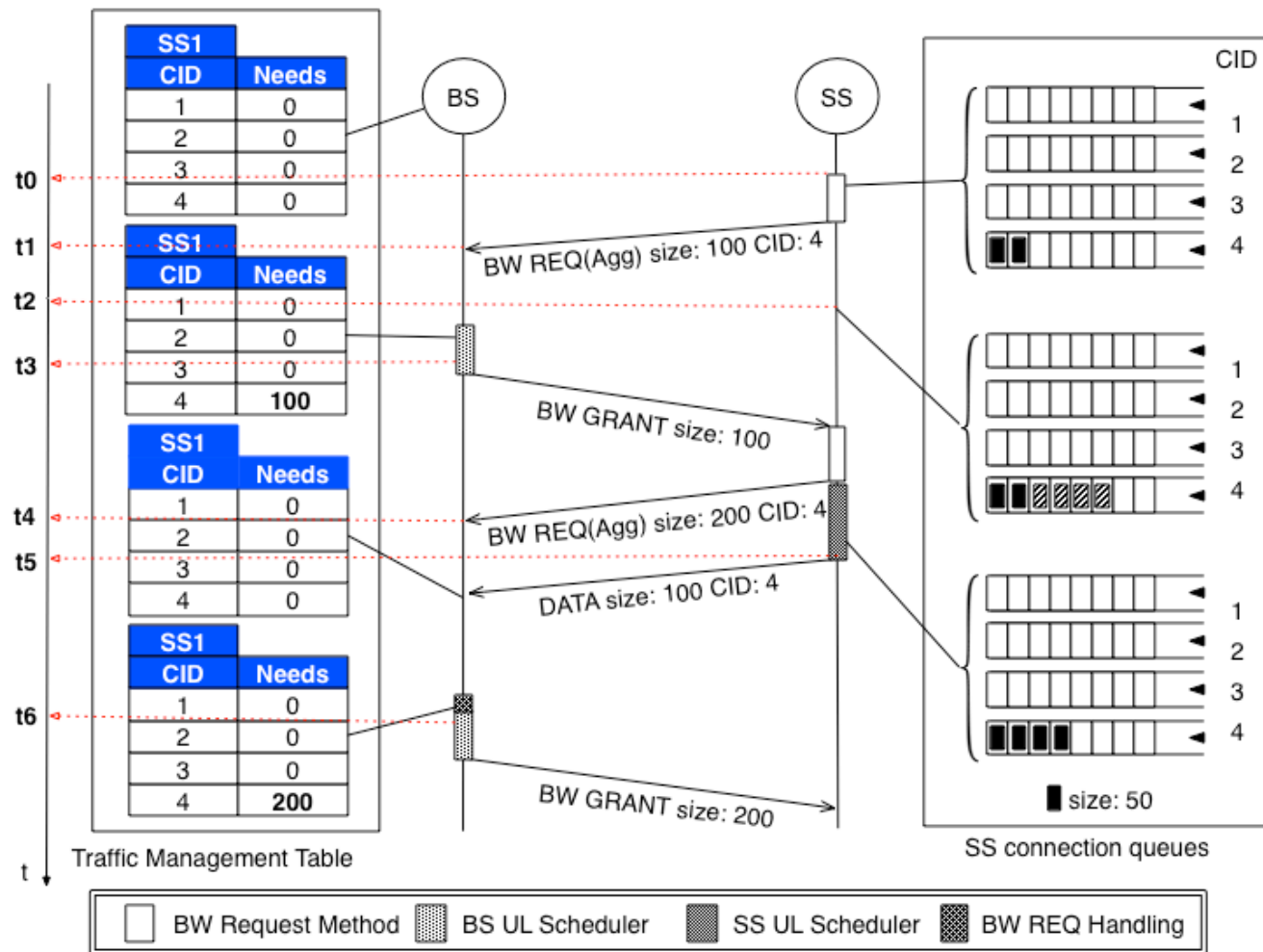


Proposed bandwidth perception management: DDA-d



- Main idea
 - **BW-REQs** are **delayed** until the end of the frame to be processed.
 - Perception of the BW should adapt to the dynamical demand/use of BW by SSs.

Proposed bandwidth perception management: DDA-d



Scenario Configuration



- WiMAX
 - ▣ Point to Multipoint Topology
 - ▣ DL:UL ratio is set to 1:1
 - ▣ Frame duration is set to 5ms
- TCP
 - ▣ Randomly launched long-lived TCP NewReno flows
 - ▣ Segment size 1000 Bytes
 - ▣ Delayed ACKs
 - ▣ Simulation time: 1000 sec
 - ▣ 10 repetitions for every point

Simulation Results

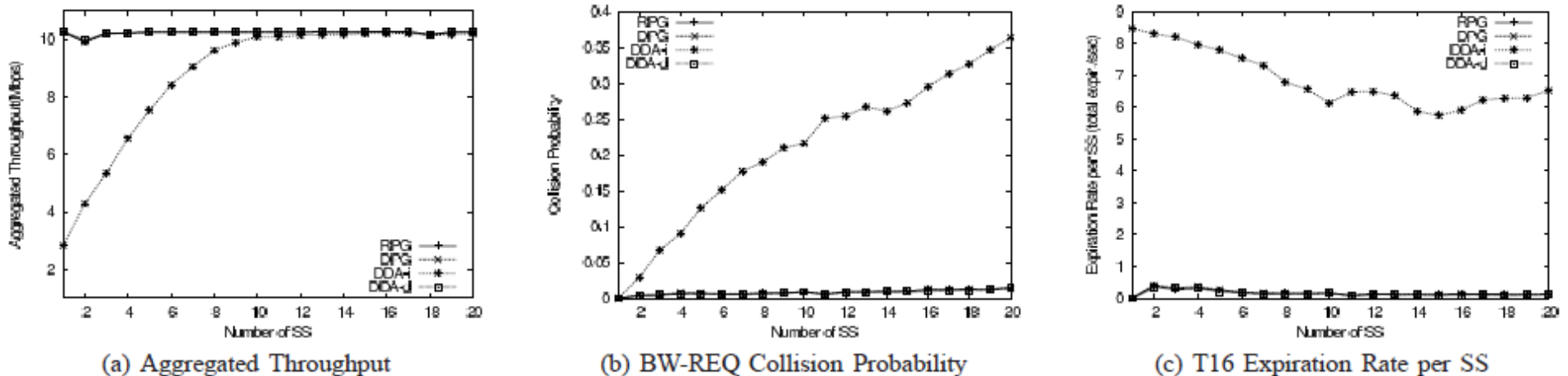


Figure 9. Download-only traffic scenario, using exclusively aggregate requests (BW-REQs) for asking for uplink bandwidth.

□ Downlink performance:

- Maximum throughput limited by the correct treatment of BW-REQ.
- Unnecessary BW-REQ generation due to wrong BW needs perception
- Significant number of episodes BW concession deadlock.

Performance Model



- Our model aims at:
 - ▣ Modeling the effect of the desynchronization of bandwidth perception
 - ▣ Finding an expression for TCP throughput considering:
 - Queue size at the BS
 - Different number of SSs
 - Variations on T16

Modeling Uplink Delay (1 / 5)

- Uplink delay depends on passing the BW-REQ, which depends in turn on the BW-perception scheme
 - ▣ Let's define q as a measure for the desynchronization, i.e., a probability of being in such state. The probability of failure a single BW-REQ is:

$$p_f = p + (1 - p)q$$

- ▣ The probability of a BW-REQ being successfully received at the i^{th} attempt:

$$p_f^{i-1} (1 - p_f)$$

Modeling Uplink Delay (2/5)

- Thus, the average number of transmissions of a single successful BW-REQ is:

$$N_{tx} = \sum_{i=1}^M i p_f^{i-1} (1 - p_f) + M p_f^M$$

$$N_{tx} = \sum_{i=1}^M p_f^{i-1}$$

Being M the maximum number of retransmissions.

Modeling Uplink Delay (3/5)

- Assuming that a collision has the same probability to happen on any slot, and T_f frame duration in which there are n slots for contention. The avg. number of slots for a successfully received BW-REQ:

$$N_{s,i} = \frac{nT_{16}}{T_f} (i - 1) + \frac{W_0}{2} (2^i - 1)$$

- Thus, the avg. number of waiting slots until the end of a single contention process is:

$$N_s = \sum_{i=1}^M (p_f^{i-1} (1 - p_f) N_{s,i}) + p_f^M \left(\frac{nT_{16}}{T_f} M + \frac{W_0}{2} (2^M - 1) \right)$$

Modeling Uplink Delay (4/5)

- The probability of transmitting a successful BW-REQ in a given slot:

$$p_{tr} = \frac{N_{tx}}{N_s + T_{idle}}$$

- Finally, we obtain \mathbf{N}_s and therefore the Uplink Delay:

$$E[D_u] = \frac{N_s T_f}{n}.$$

Modeling Downlink Delay

- Given r_k the sending rate for user k , N the number of active SS, P_l the packet size and Q_{BS} the BS queue length. We can calculate the expectation as follows:

$$E[D_d] = \frac{P_l}{r_k/N} \frac{Q_{BS}}{2}$$

- And the expectation of the maximum window size:

$$N_{CW} = \frac{Q_{BS}}{2} + \frac{r_k}{NP_l} (D_u + D_{wired})$$

- Also, the probability of a single packet loss is (b is the delayed ack factor):

$$p_{lost} = \frac{1}{\frac{3}{4} b N_{CW} \left(\frac{N_{CW}}{2} + 1 \right)}$$

Modeling the TCP throughput.

- Based on previous results we can derive an expression for TCP throughput based on Padhye's model:

$$B = \frac{P_l(E[Y] + Q * E[Y_{TO}])}{E[A] + Q * E[A_{TO}]}$$
$$= \frac{P_l\left(\frac{1-p_{lost}}{p_{lost}} + N_{CW} + Q \frac{1}{1-p_{lost}}\right)}{T_{RTT}(N_{CW} + 1) + QT_{RTO} \frac{f(p_{lost})}{1-p_{lost}}}$$

- Where Y is the number of packets and A the duration of the RTT.

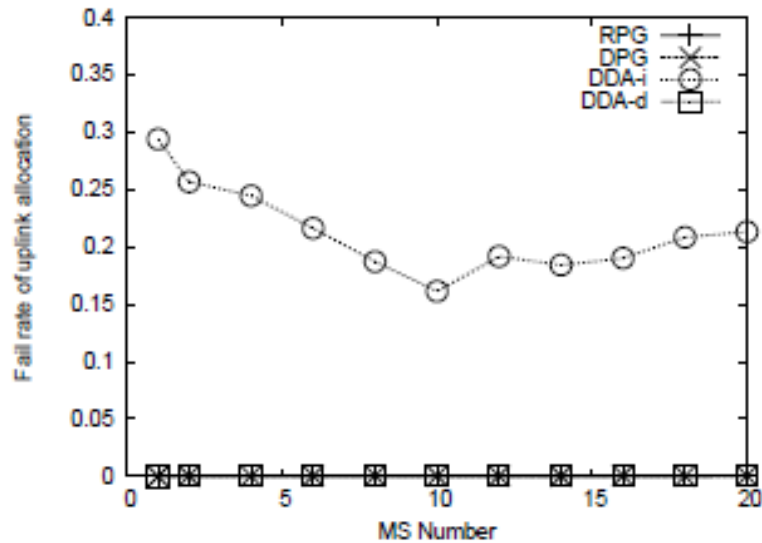
Assessing the impact of BS mac queue length

- From the performance model, when BS queue length is big enough, TCP throughput is limited by the sending rate of the user:

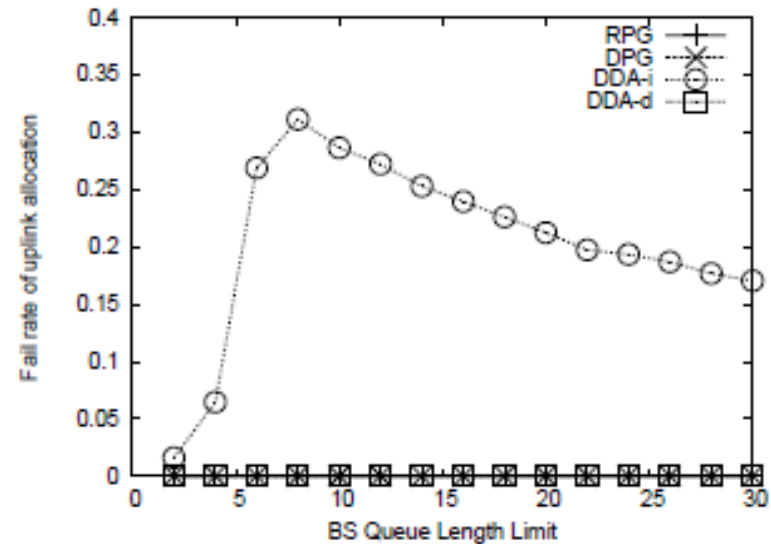
$$\lim_{Q_{BS} \rightarrow \infty} B_k = \frac{3}{4} \frac{r_k}{N}$$

- Besides:
 - ▣ When BS queue size is small, and link is underutilized.
 - ▣ When queue size large enough, TCP throughput is constrained by **scheduled** transmitting rate and delay increases.

Performance Model: Uplink Delay



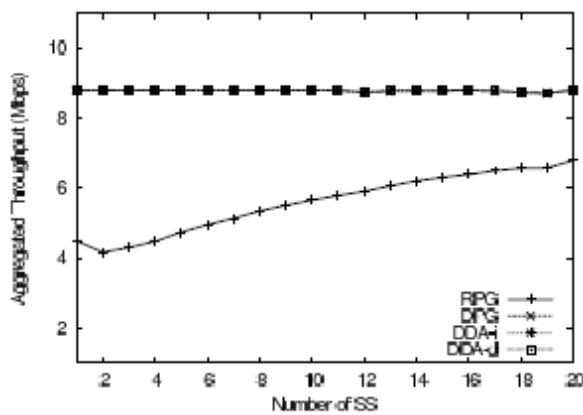
(a) Failure rate q vs. MS num



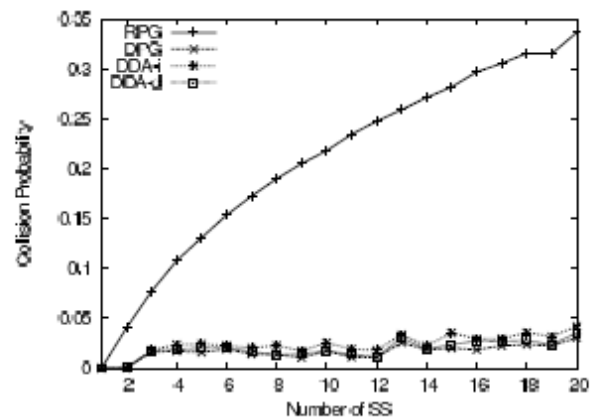
(b) Failure rate q vs. BS Queue Length Limit

We've obtained by simulation differences among bandwidth perception schemes that can be characterized by **bandwidth allocation failure rate q** .

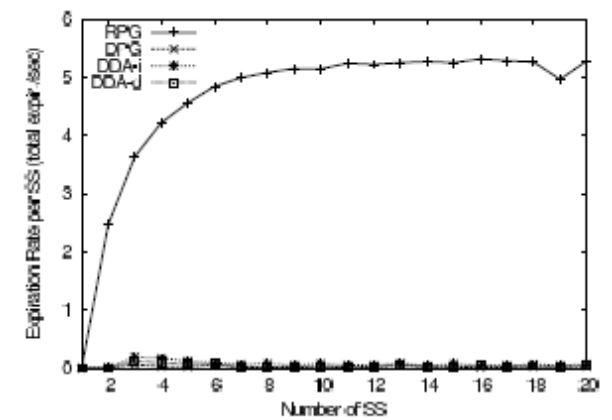
Simulation Results



(a) Aggregated Throughput



(b) BW-REQ Collision Probability

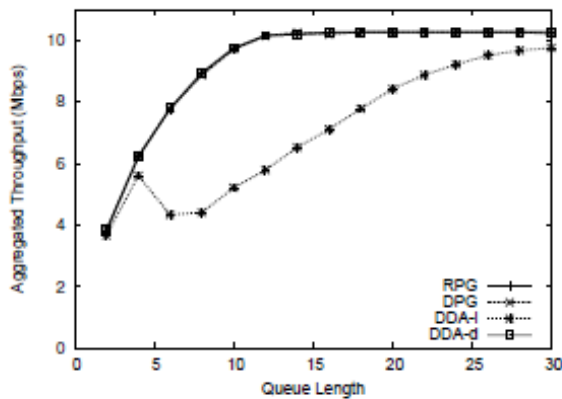


(c) T16 Expiration Rate per SS

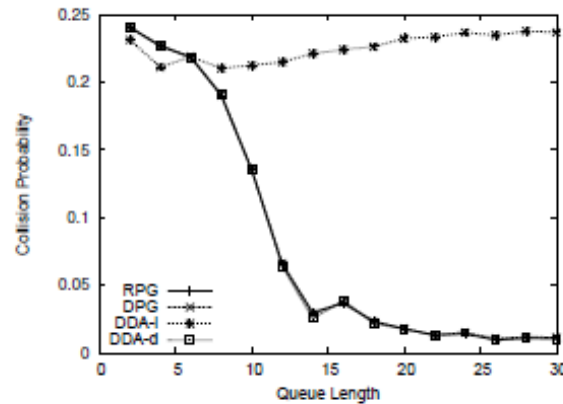
Figure 10. Upload-only traffic scenario, using one aggregate bandwidth request per 50 incremental bandwidth requests (BW-REQs).

□ Uplink performance

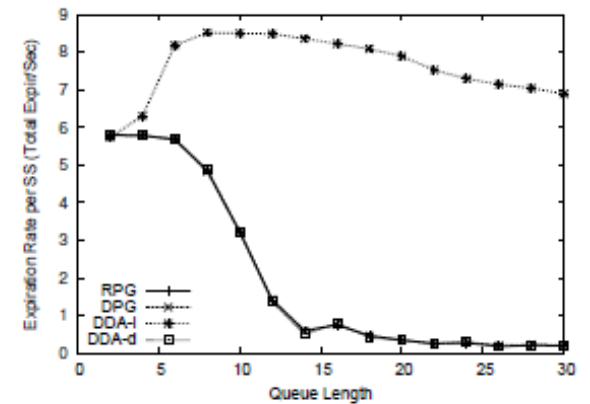
Simulation Results



(a) Aggregated Throughput



(b) BW-REQ Collision Probability



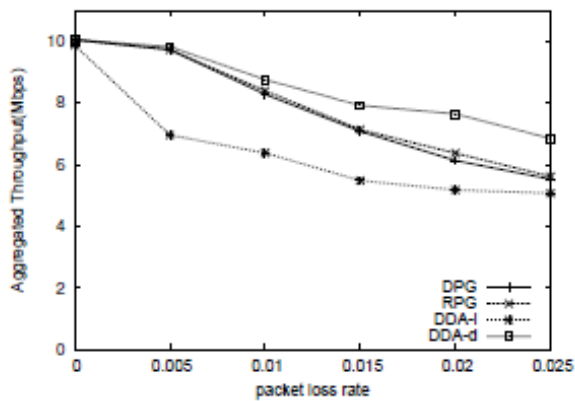
(c) T16 Expiration Rate per SS

Figure 11. Downlink only traffic, Performance with different queue length limit, MS number is 10.

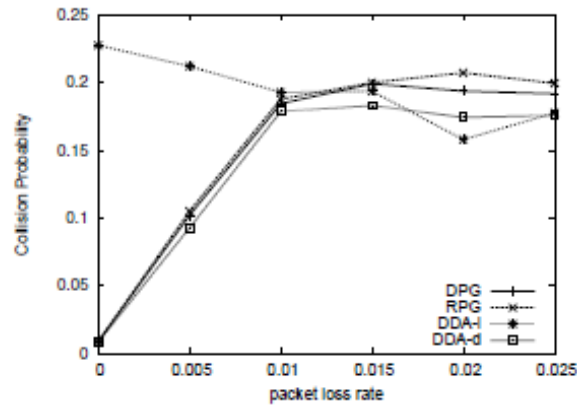
□ Impacts of MAC queue length

Simulation Results

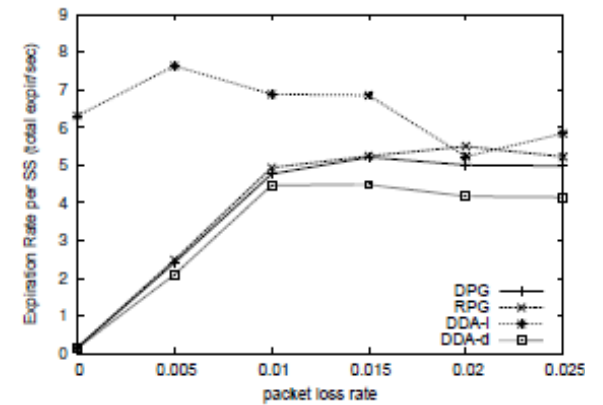
Impacts of wireless losses



(a) Aggregated Throughput



(b) BW-REQ Collision and Wireless Loss Probability

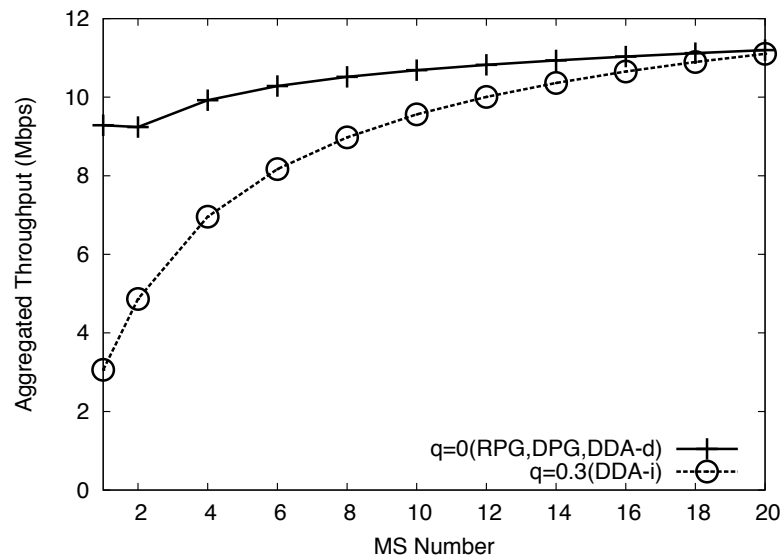


(c) T16 Expiration Rate per SS

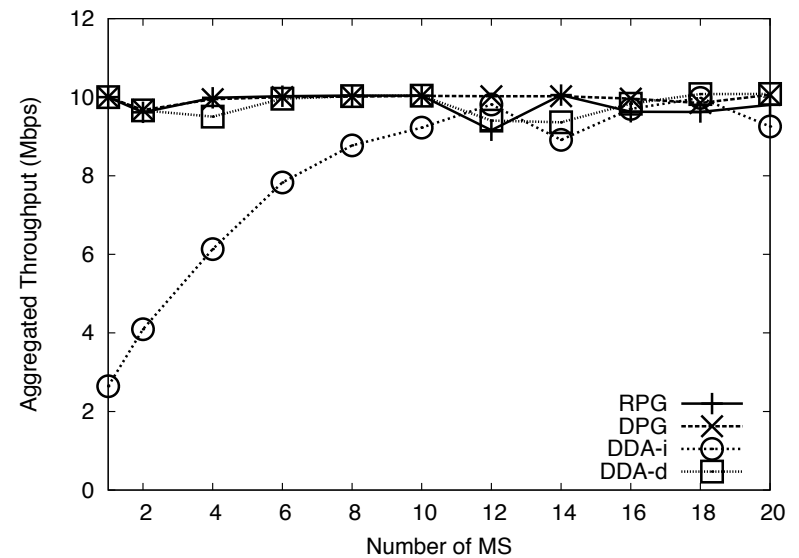
Figure 12. Downlink only traffic. Performance with different wireless loss rate. MS number is 10.

Aggregated Throughput vs. Number of MS

Model Based

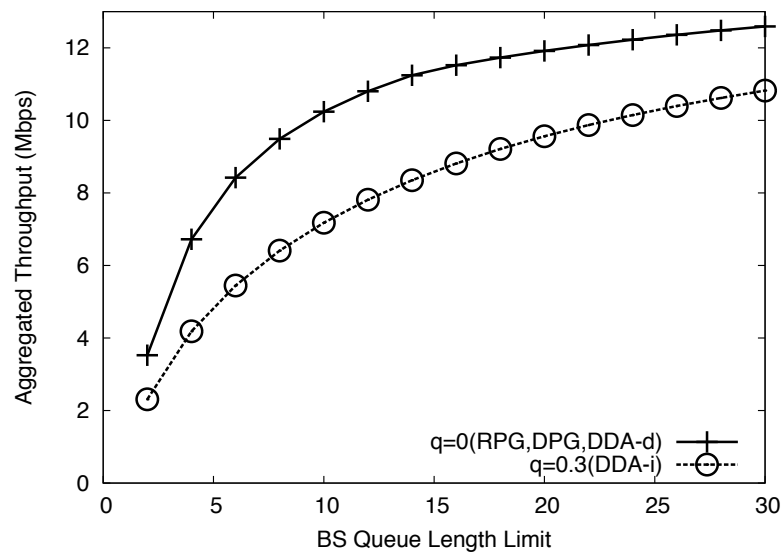


Simulation Results

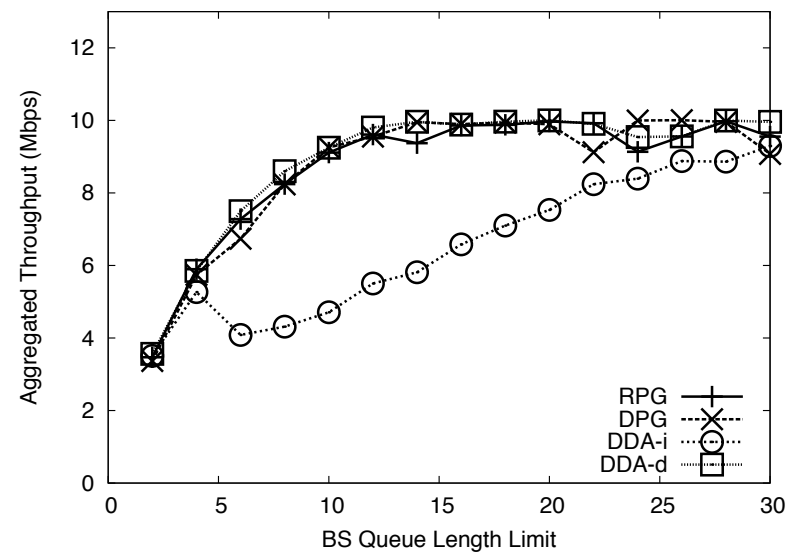


Aggregated Throughput vs. BS queue length

Model Based

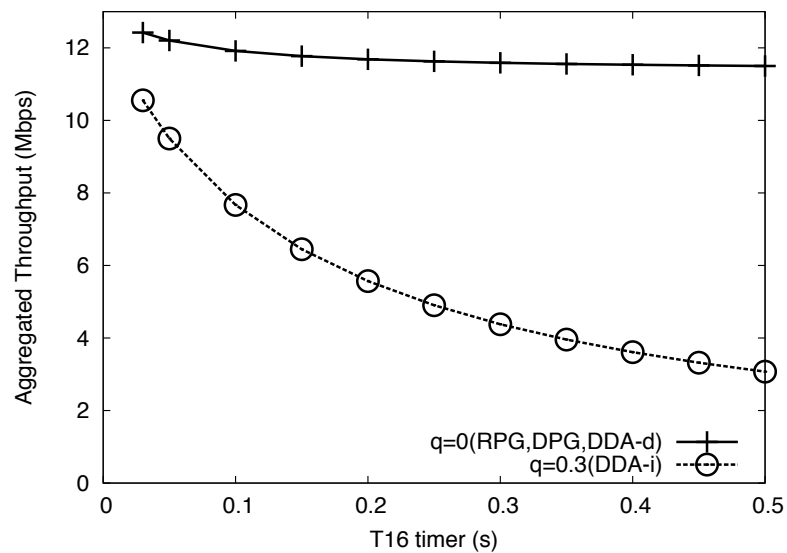


Simulation Results

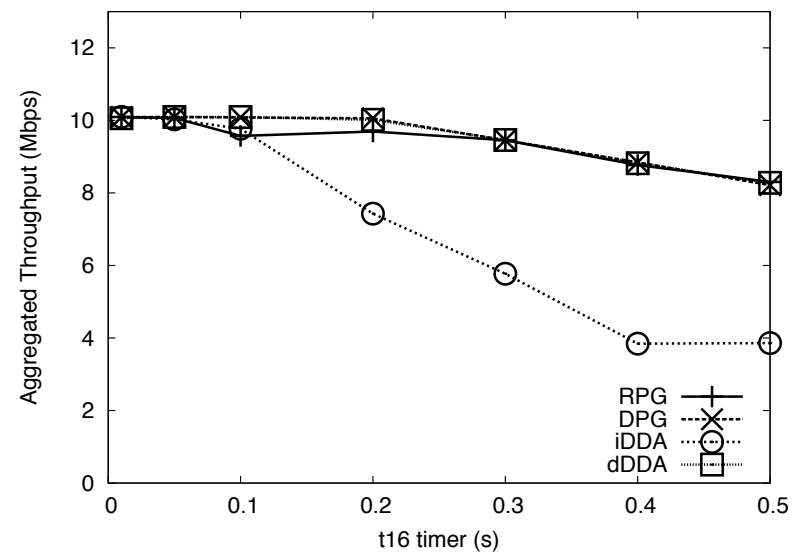


Aggregated throughput vs. T16 timer

Model based



Simulation Result



Conclusion



- Bandwidth request-grant mechanism is a critical subsystem
 - ▣ BS can misperceive the bandwidth needs of SSs, affecting the TCP performance.
 - ▣ The BRGM relies heavily on the BW-REQ treatment
- Deeper understanding of BW-REQ mechanism
 - ▣ Built a model that takes into account BS MAC queue, SS number, T16 timer.
 - ▣ We have synthesized the degree of desynchronization and modeled its impact of TCP performance.

Future Work



- Work on an extended version of the DDA-d mechanism that dynamically delays treatment of BW-REQs.
- Give precise rules on setting queue size and T16 timer (i.e., depending on the system's load).
- Investigate the impact of 'q' on timeout events of TCP.



Thank you.
Questions?