BGP with an adaptive minimal route advertisement interval

Nenad Lasković

nlaskovi@cs.sfu.ca

Communication Networks Laboratory

http://www.ensc.sfu.ca/research/cnl

School of Engineering Science

Simon Fraser University

communication networks laboratory

Road map

- Introduction and motivation
- Border Gateway Protocol (BGP)
- BGP with adaptive MRAI (Minimal Route Advertisement Interval)
  - empirical model for BGP processing delay
  - reusable MRAI timers
  - the adaptive MRAI algorithm
- Performance analysis of BGP with adaptive MRAI
- Conclusions

Introduction

- The Internet consists of numerous heterogeneous networks without centralized control
- An Autonomous System (AS) is a group of networks controlled by a common administrative entity
- ASs communicate using Border Gateway Protocol (BGP) version 4, RFC 1771
- BGP is the *de facto* standard inter-domain routing protocol in today's Internet

Motivation

- One of the major problems of BGP is its long convergence time
  - unreachable destinations
  - packet loss
- Solution: an algorithm that decreases BGP convergence time
- The proposed algorithm should not change BGP messages format or BGP functioning

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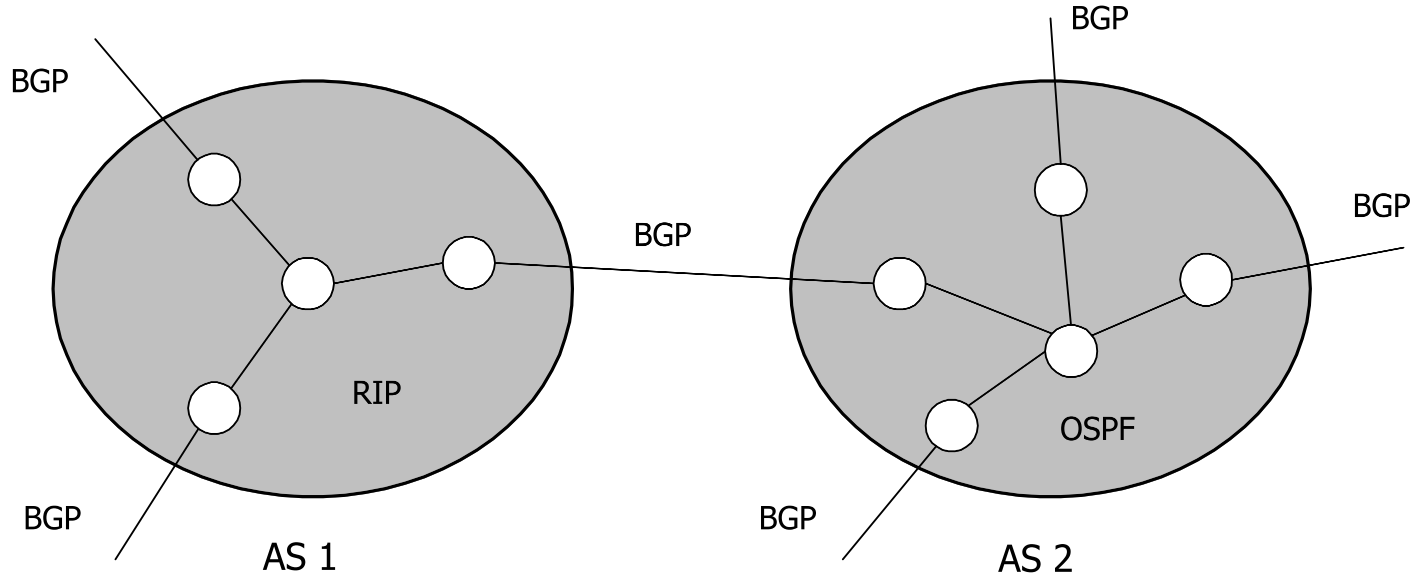
Routing in the Internet



AS: Autonomous System

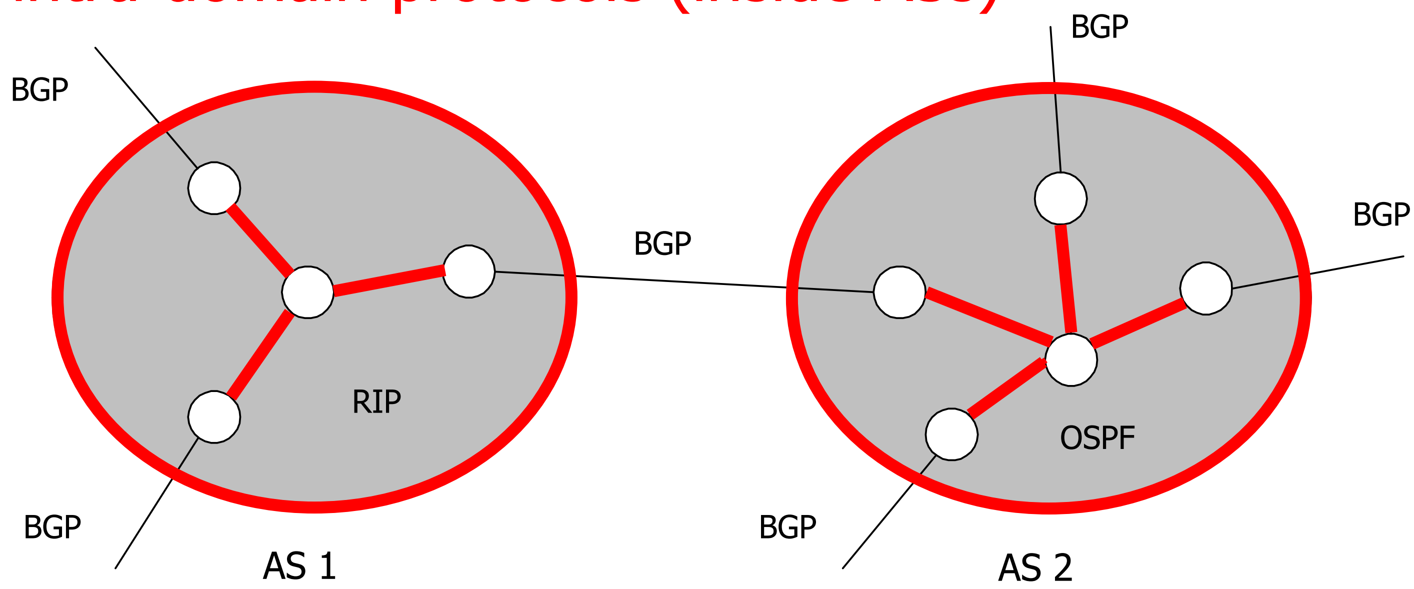
BGP: Border Gateway Protocol

RIP: Routing Information Protocol

OSPF: Open Shortest Path First

Routing in the Internet

intra-domain protocols (inside ASs)



AS: Autonomous System
BGP: Border Gateway Protocol

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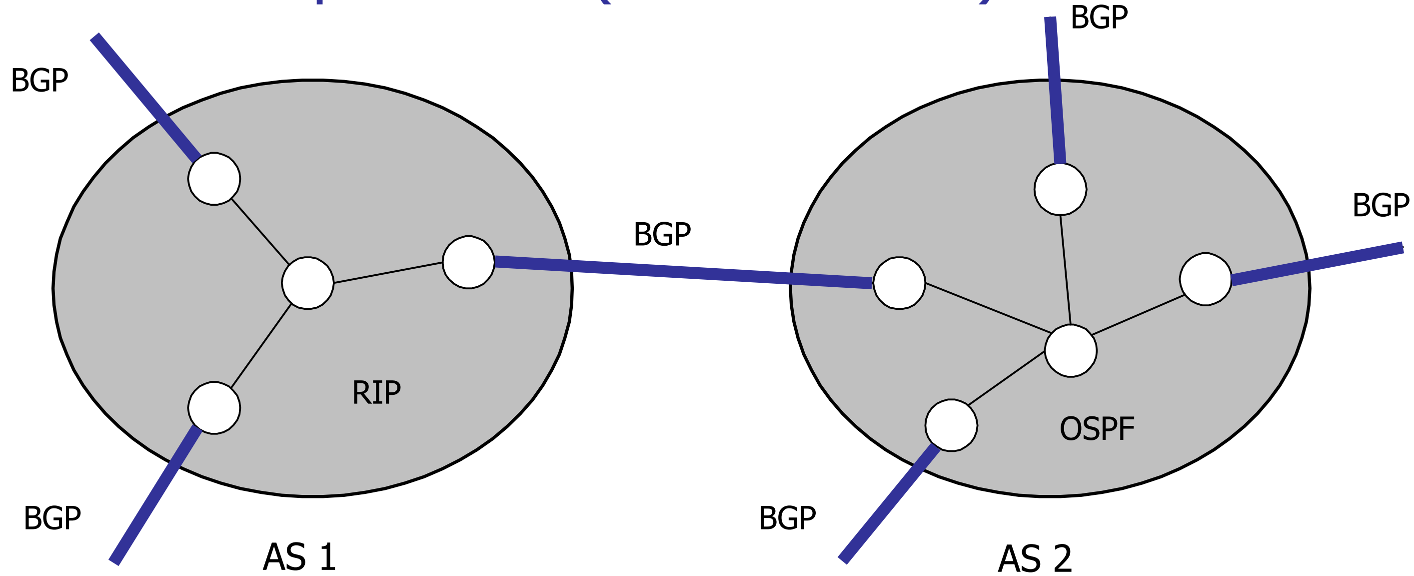
Routing in the Internet

inter-domain protocols (between ASs)



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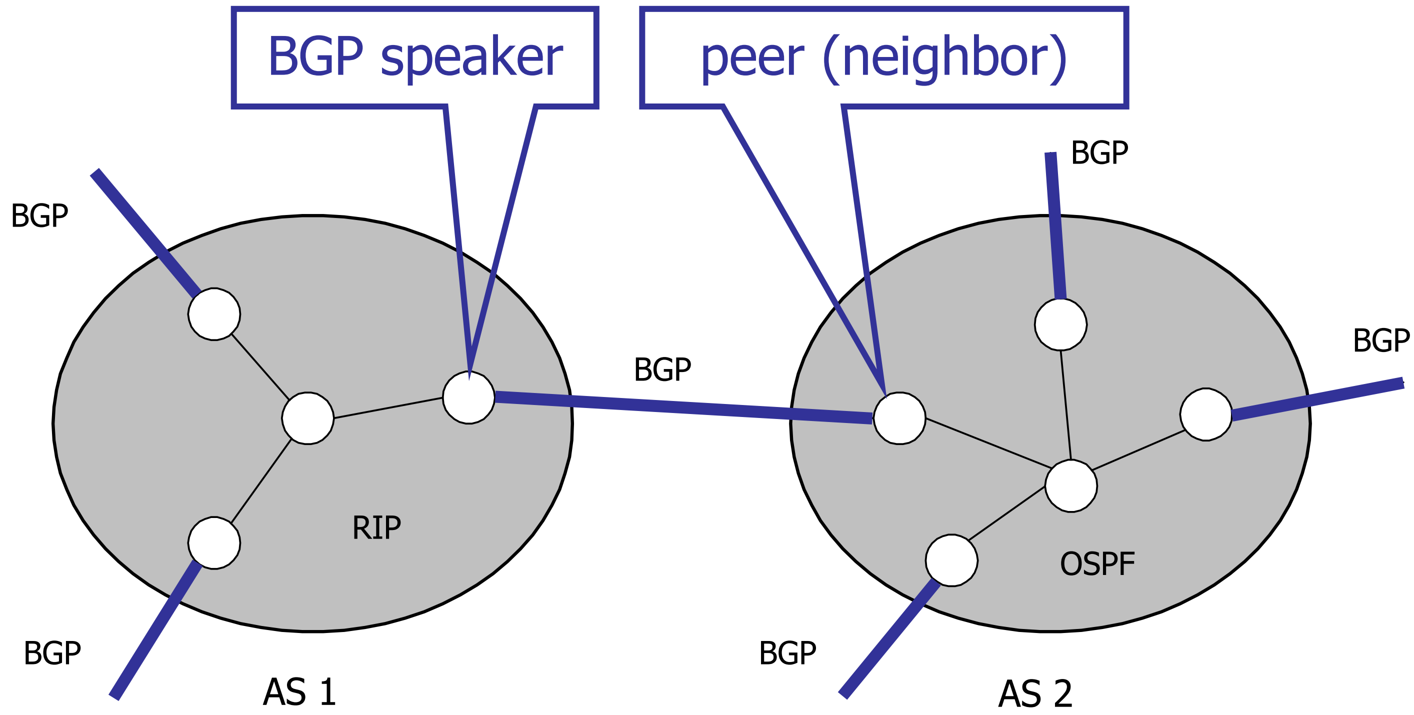
Routing in the Internet



AS: Autonomous System
BGP: Border Gateway Protocol

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Exchange of routing information

- Two main functions of BGP:
  - establishing routes (paths) between ASs
  - routing packets to their destinations (ASs)
- BGP distance metric: length of route in hops
- BGP speakers exchange information only when changes cause a replacement of the best routes
  - advertisements: new best path to a destination
  - withdrawals: destination unreachable

Dynamical behavior of BGP

- Changes of the Internet topology result in:
  - frequent changes of BGP routing tables
  - a large number of update messages
- BGP convergence time: from the time when the first update message is sent, until all update messages that are a consequence of the original update are received

Advertisement rate limiting

- Two conflicting requirements for BGP speakers:
  - minimize the number of sent update messages
  - react to changes in a timely manner
- Minimal Route Advertisement Interval (MRAI):
  - minimal time interval that must elapse between two consecutive advertisements of the same destination sent from one BGP speaker
  - controlled by use of MRAI timers
  - MRAI round is 30 s (RFC 1771)

MRAI timers

- Per-destination MRAI timers (RFC 1771):
  - one timer is associated with one destination
  - independent rate limiting for each destination
  - unfeasible: ~100,000 destinations per router
- Per-peer MRAI timers (RFC 1771):
  - one timer is associated with one peer
  - BGP speakers have less than 100 peers
  - disadvantage: all advertisements are delayed

$$\textit{average delay of an advertisement} = \frac{MRAI}{2}$$

BGP convergence time

- up (advertisement) phase, a new destination is introduced to a network
  - convergence time T_{up} (estimation):

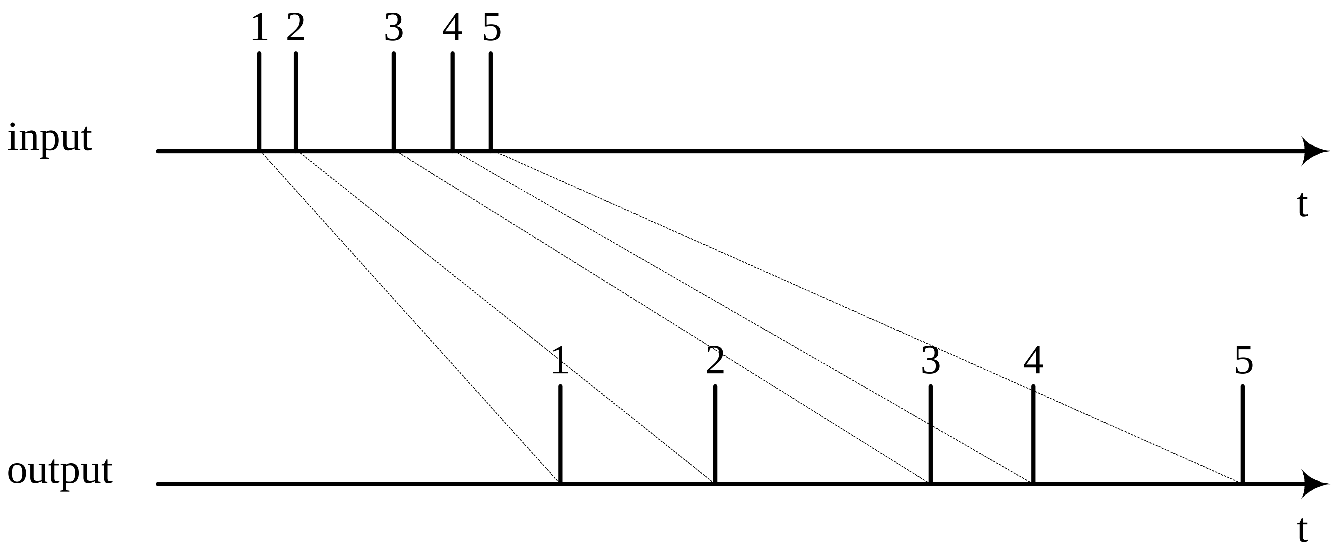
$$T_{up} \approx |length\ of\ the\ shortest\ path| \times \frac{MRAI}{2}$$

- down (withdrawal) phase, the only route to a destination is withdrawn from a network
  - convergence time T_{down} (upper bound):

$$T_{down} \leqslant |length\ of\ the\ longest\ path| \times \frac{MRAI}{2}$$

BGP processing delay: uniform model

- update messages are processed independently
- delay of each message is modeled with a uniformly distributed random variable



T. Griffin and B. Premore, "An experimental analysis of BGP convergence time," in *Proc. ICNP*, Riverside, CA, Nov. 2001, pp. 53–61.

BGP processing delay: measurements

- BGP speakers process groups of update messages in fixed 200 ms processing cycles
- 95% of messages are processed within 210 ms
  - BGP processing delay is independent of the number of received updates
- The uniform model estimates unrealistically high processing delays
  - Example: 20 messages -> ~10 s delay

A. Feldmann, H. Kong, O. Maennel, and A. Tudor, "Measuring BGP pass-through times," in *Proc. PAM*, Antibes Juan-les-Pins, France, Apr. 2004, pp. 267–277.

Previous work

- Each network has an optimal MRAI value that minimizes BGP convergence time
- Optimal MRAI values depend on:
  - network topology
  - traffic load
- A global MRAI value cannot be determined for the entire Internet

T. Griffin and B. Premore, "An experimental analysis of BGP convergence time," in *Proc. ICNP*, Riverside, CA, Nov. 2001, pp. 53–61.

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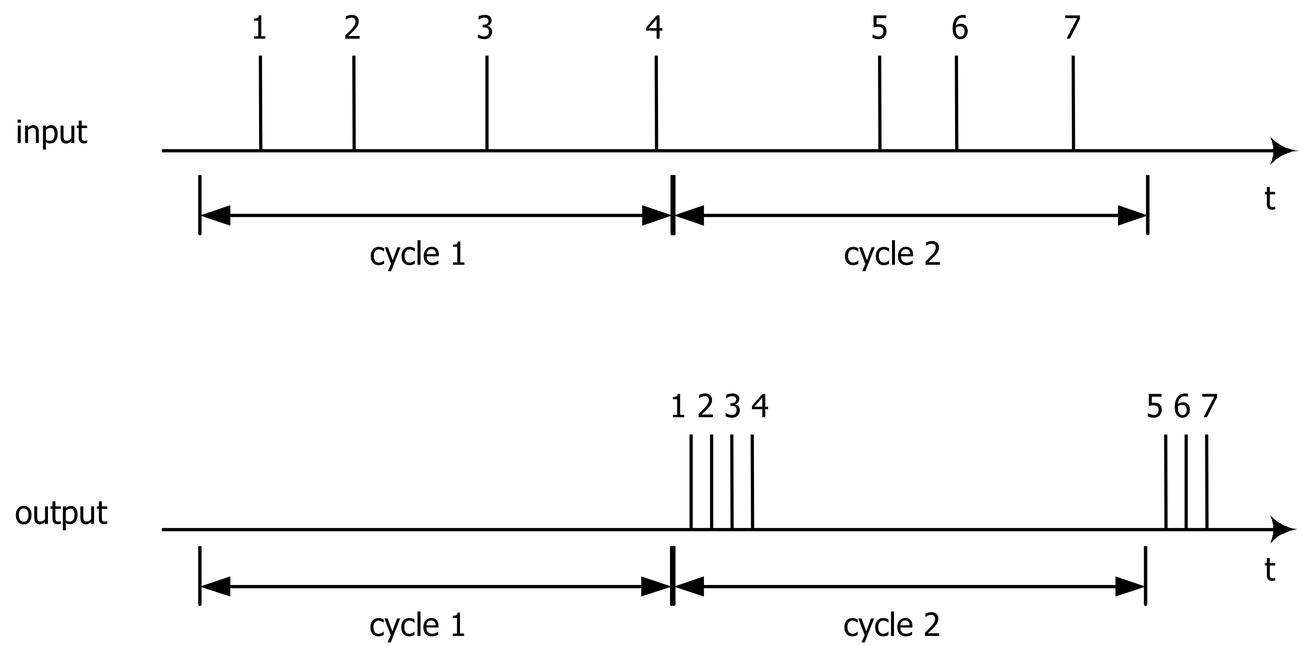
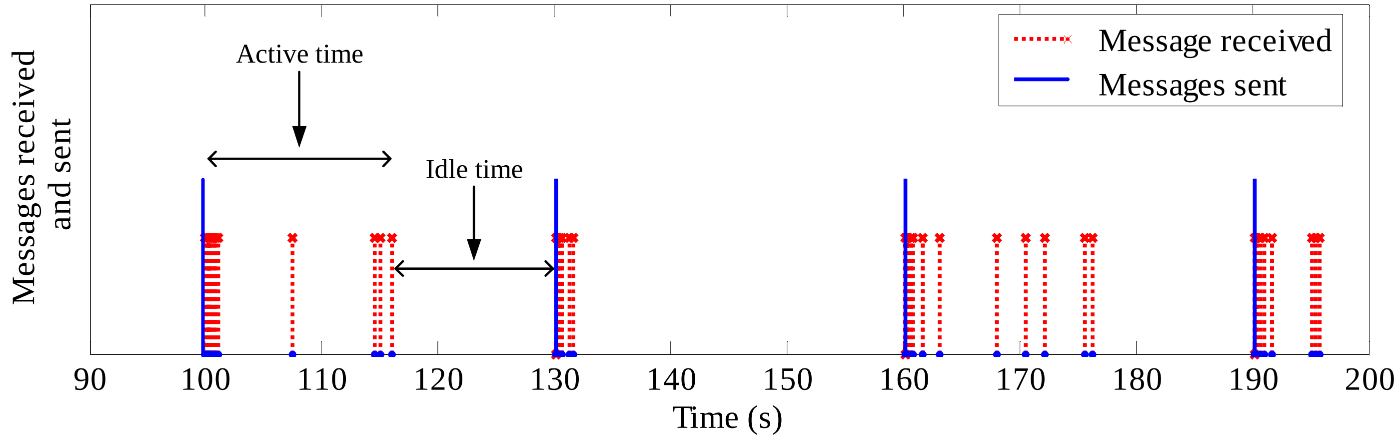
BGP processing delay: empirical model

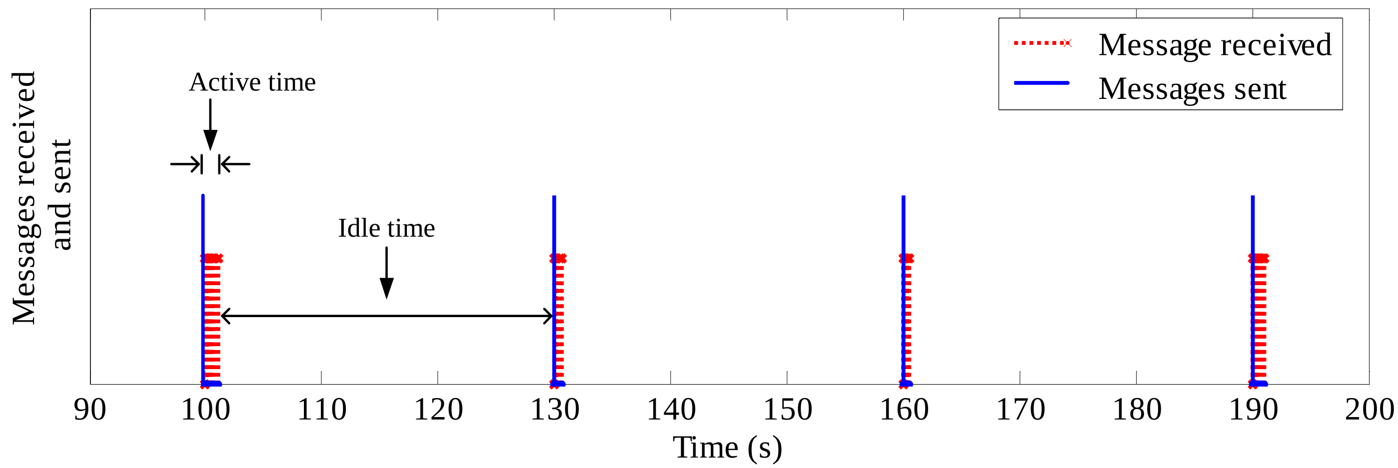
- Model based on measurements
- BGP speaker completes processing of all received updates at the end of the 200 ms processing cycle



Uniform vs. empirical model



Uniform model



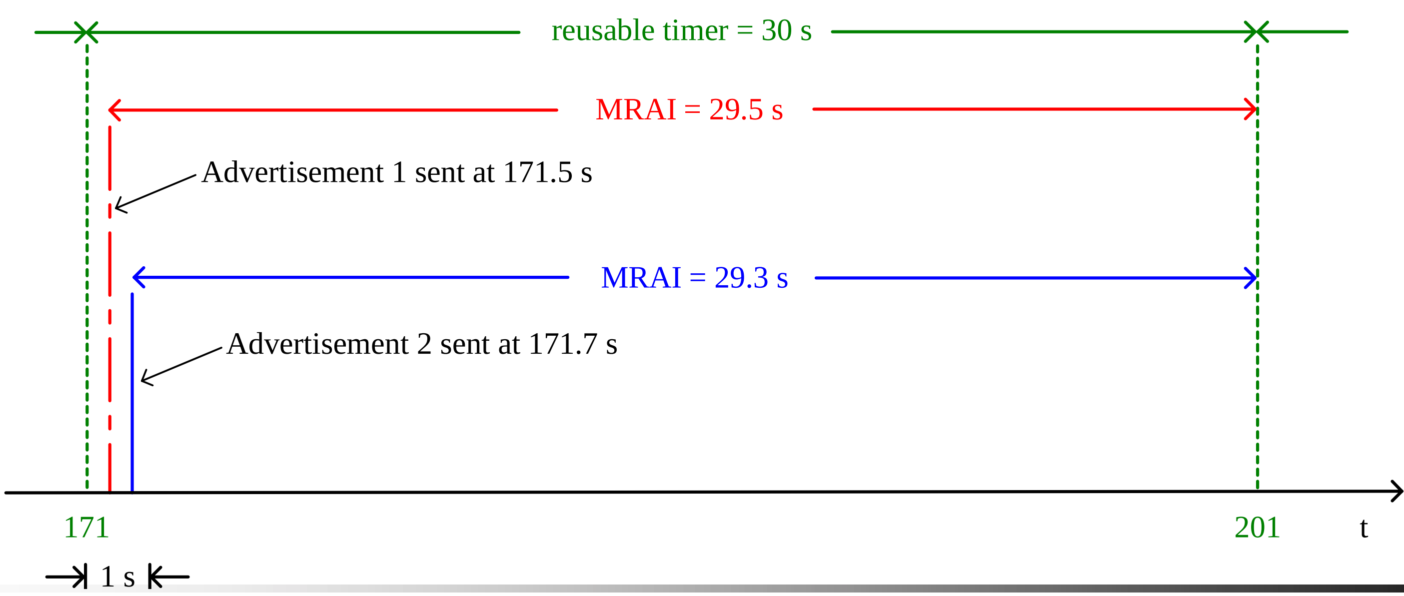
Empirical model

BGP with adaptive MRAI

- Goal: minimizing the idle time for each destination
  - MRAI round for each destination has to be equal to the active time
  - independent rate limiting for each destination
- BGP needs new MRAI timers and a new algorithm that adaptively adjusts the duration of MRAI rounds
- Solution: BGP with adaptive MRAI

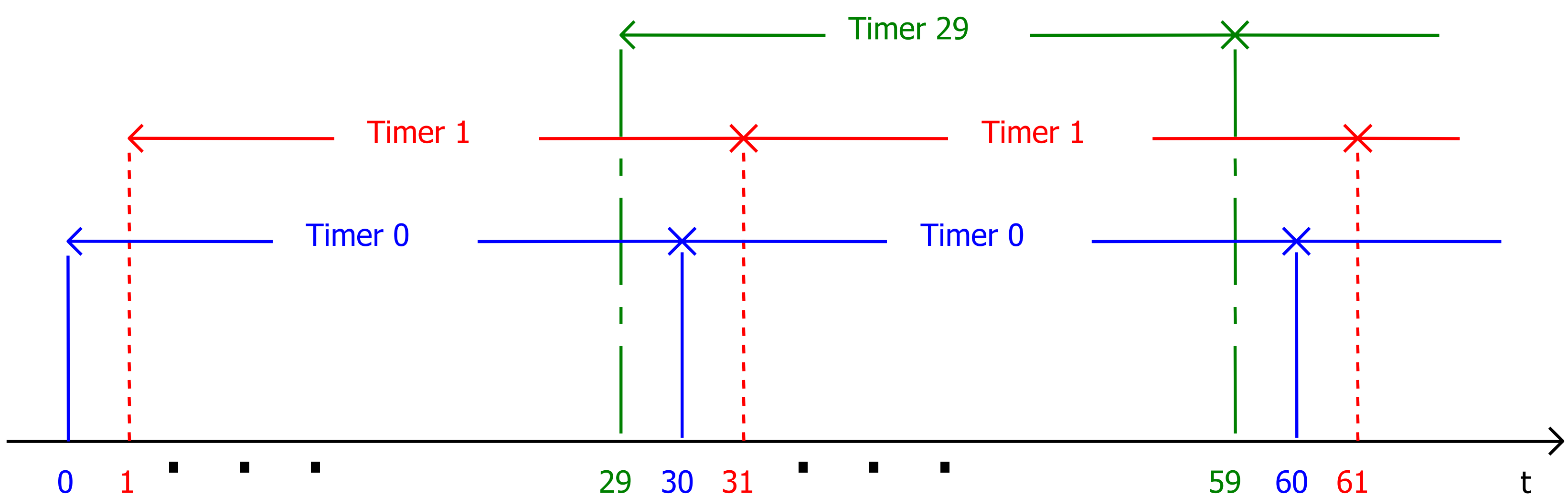
Reusable MRAI timers

- Associating all route advertisements sent during a one second interval with a single reusable MRAI timer
- Instead of being exactly 30 s, an MRAI round belongs to an interval between 29 and 30 s



Reusable MRAI timers

- A BGP speaker needs only 30 reusable MRAI timers for all destinations and all peers
- Reusable MRAI timers achieve independent rate limiting



Adaptive MRAI algorithm

- Finding the optimal MRAI requires knowledge of the active time during an MRAI round
- BGP speakers may estimate the active time of the next round using information from previous rounds
- Durations of the adaptive MRAI rounds are estimated for each destination separately:

$$adaptiveMRAI_{n+1}(D) = avg\_active_n(D) + 3 \times deviation_n(D)$$

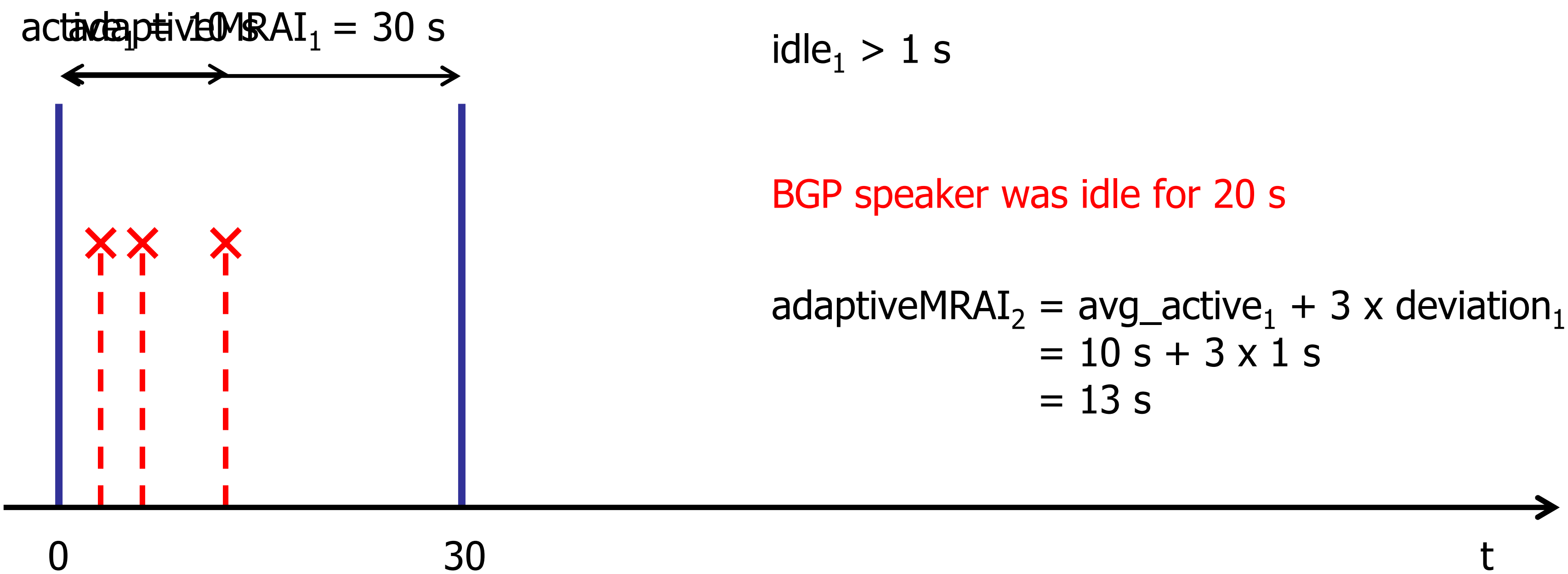
Adaptive MRAI algorithm: round 1

$idle_1 = adaptiveMRAI_1 - active_1$
$= 30 - 10$ s
$= 20$ s

$idle_1 > 1$ s

BGP speaker was idle for 20 s

$adaptiveMRAI_2 = avg\_active_1 + 3 \times deviation_1$
$= 10$ s $+ 3 \times 1$ s
$= 13$ s

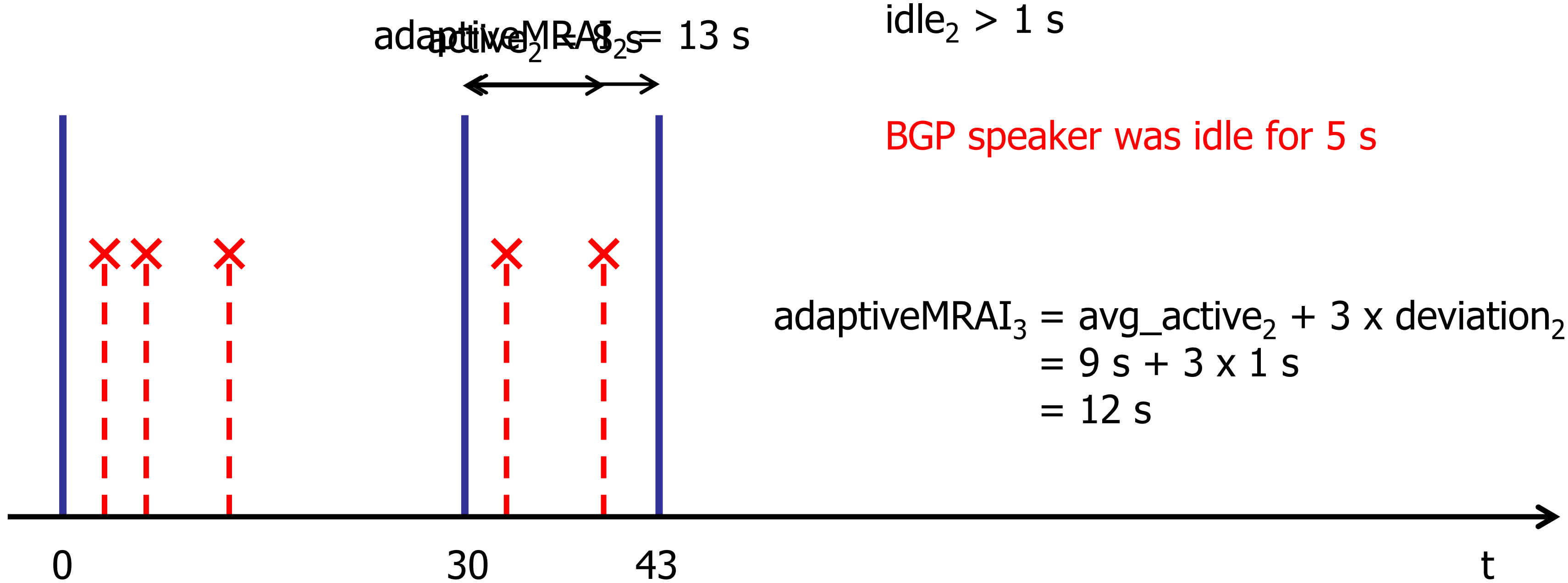


Adaptive MRAI algorithm: round 2

$idle_2 = adaptiveMRAI_2 - active_2$
$= 13 - 8$ s
$= 5$ s

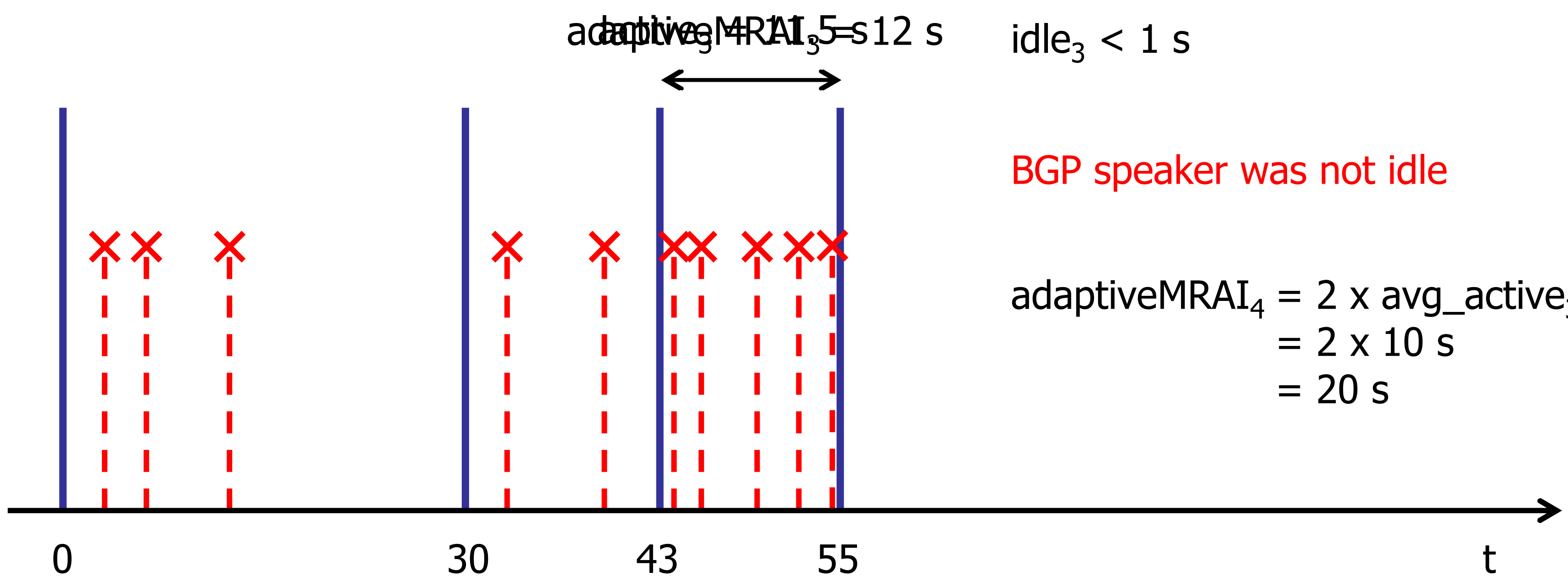
$idle_2 > 1$ s

BGP speaker was idle for 5 s



$adaptiveMRAI_3 = avg\_active_2 + 3 \times deviation_2$
$= 9$ s $+ 3 \times 1$ s
$= 12$ s

Adaptive MRAI algorithm: round 3



$idle_3 = adaptiveMRAI_3 - active_3$
$= 12 - 11.5$ s
$= 0.5$ s

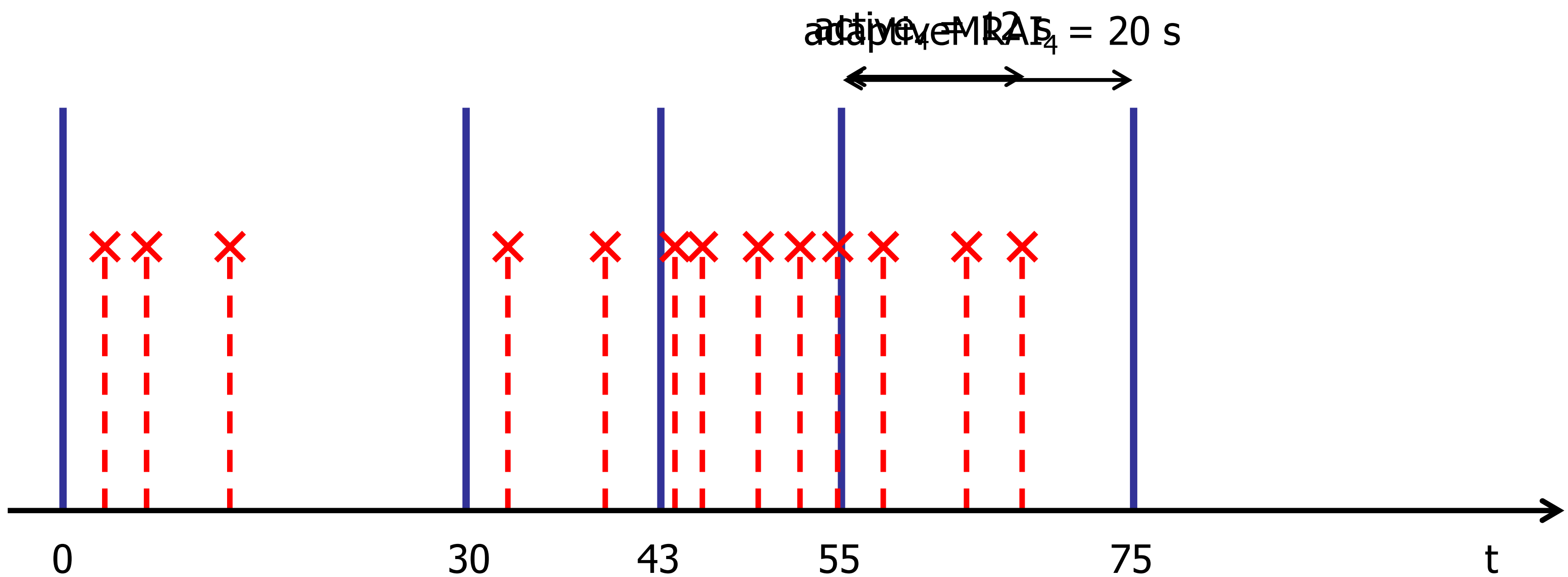
$idle_3 < 1$ s

BGP speaker was not idle

$adaptiveMRAI_4 = 2 \times avg\_active_3$
$= 2 \times 10$ s
$= 20$ s

Adaptive MRAI algorithm: round 4

$$\text{adaptiveMRAI}_5 = \text{avg\_active}_4 + 3 \times \text{deviation}_4$$
$$= 10.5\text{ s} + 3 \times 2\text{ s}$$
$$= 16\text{ s}$$



The algorithm overhead

- Memory requirements:
  - reusable MRAI timers: 30 timers + pointer for each non-converged route (~100)
  - adaptive MRAI algorithm: 4 integers for each non-converged route
- Computational overhead of the adaptive algorithm:
  - 13 operations at the end of a MRAI round
  - the number of MRAI rounds ~ the number of non-converged routes
  - computational complexity depends linearly on the number of non-converged routes

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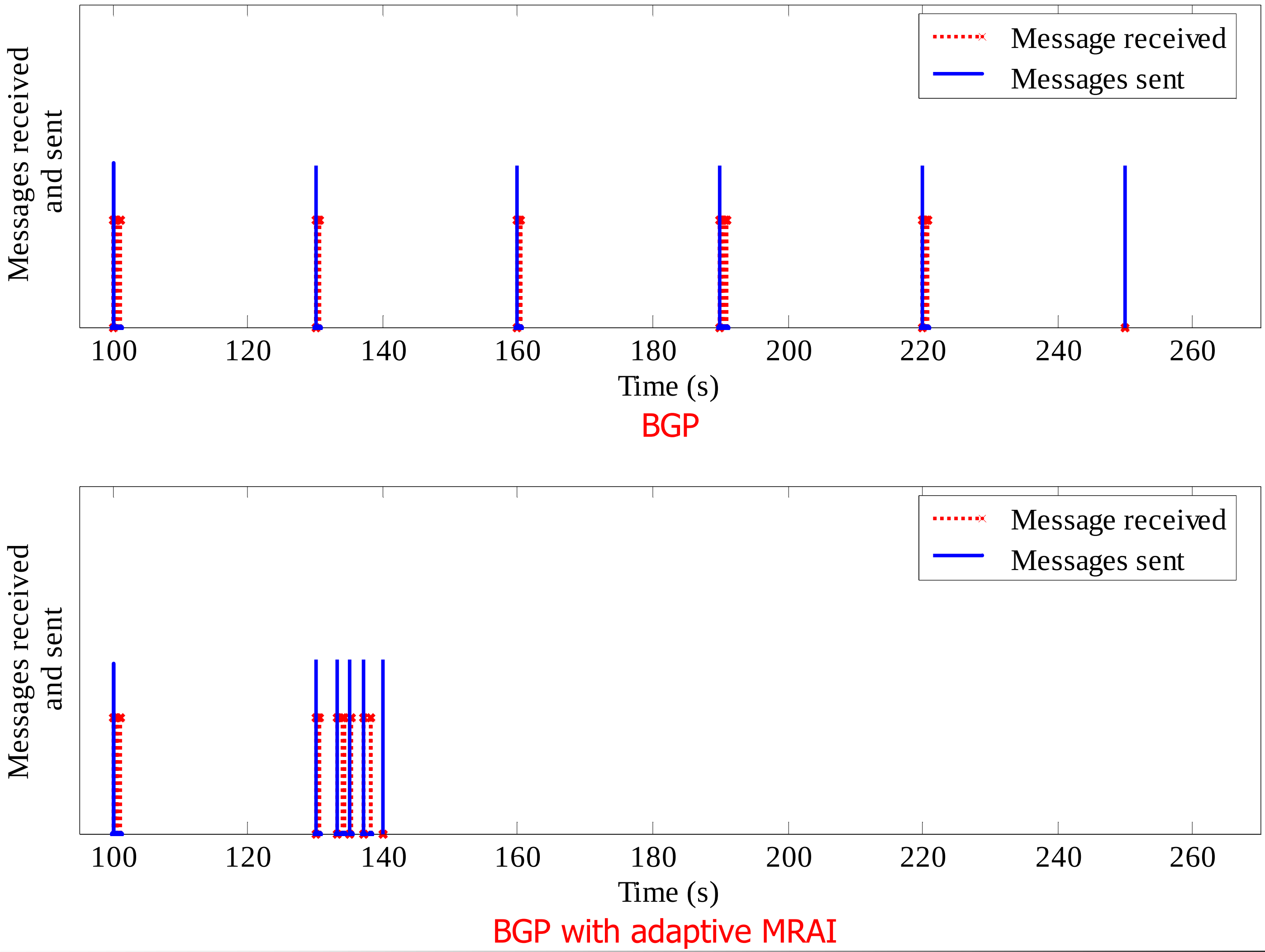
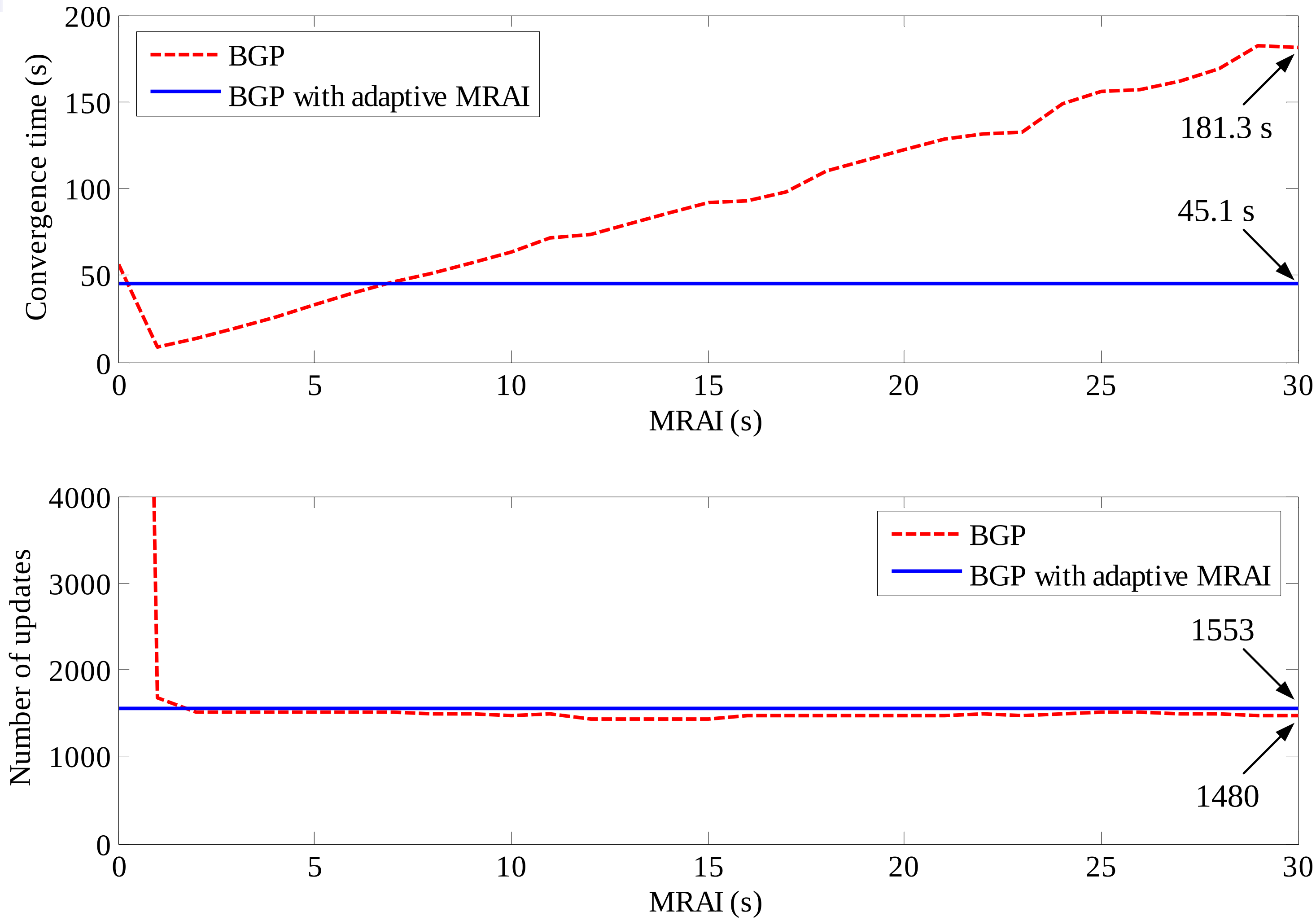
Simulation scenarios

- We implemented the algorithm using ns-2 and its BGP module (ns-BGP 2.0)
- Topologies:
  - completely connected graph with 15 nodes
  - two topologies (29 and 110 nodes) derived from the BGP routing tables (Route Views Project)
  - topology with 200 nodes obtained using topology generator BRITE
- Each simulation scenario is repeated 30 times using 30 unique random number generator seeds

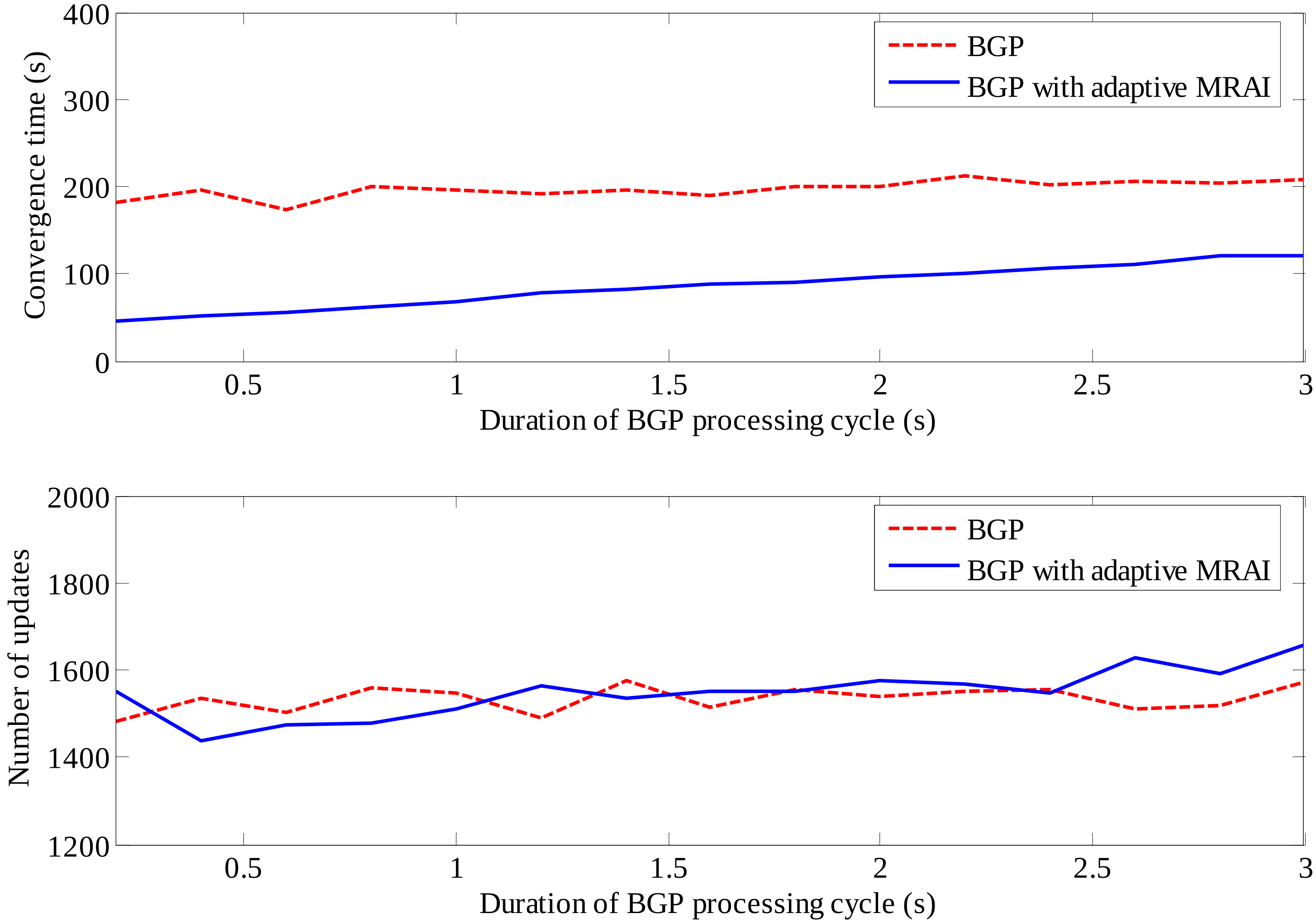
Time series of update messages



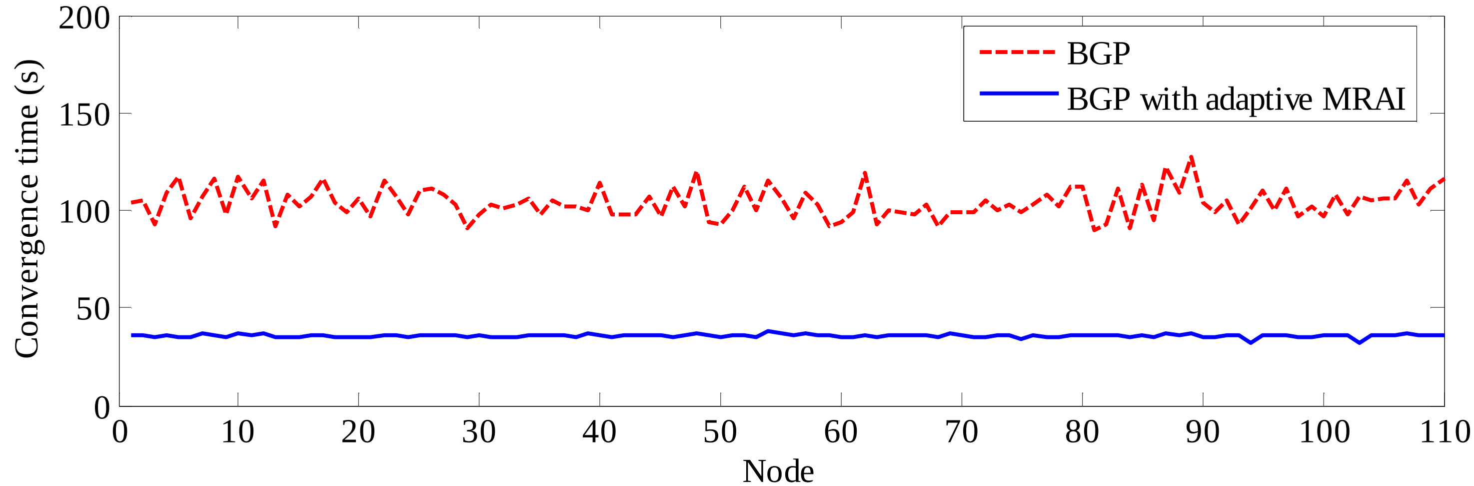
Completely connected graph

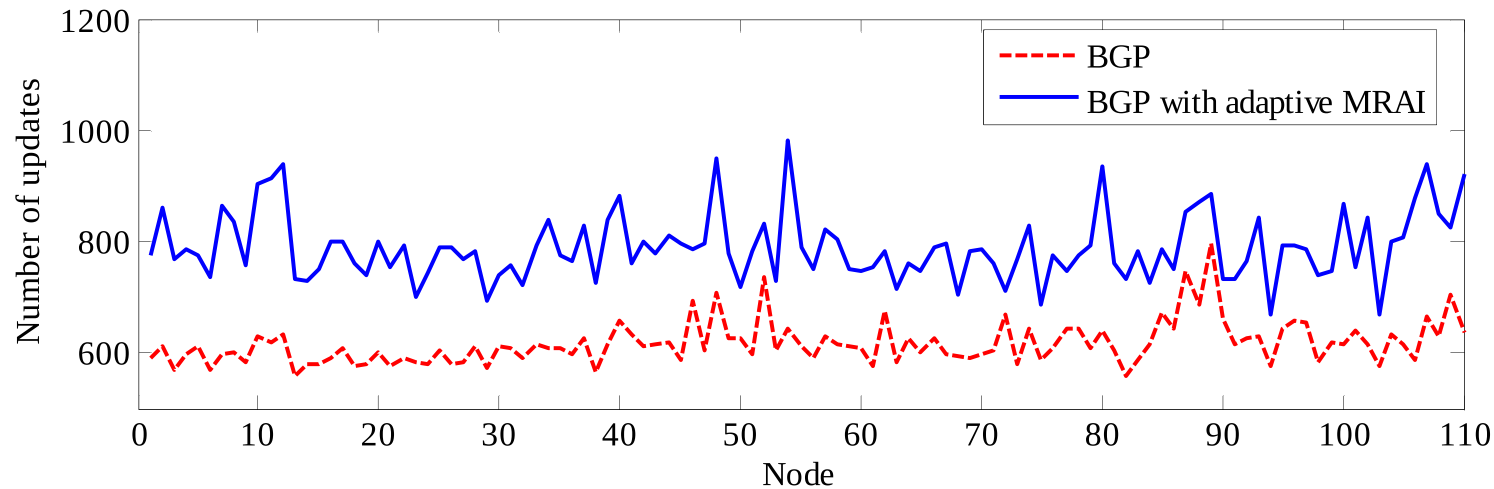


BGP processing cycles

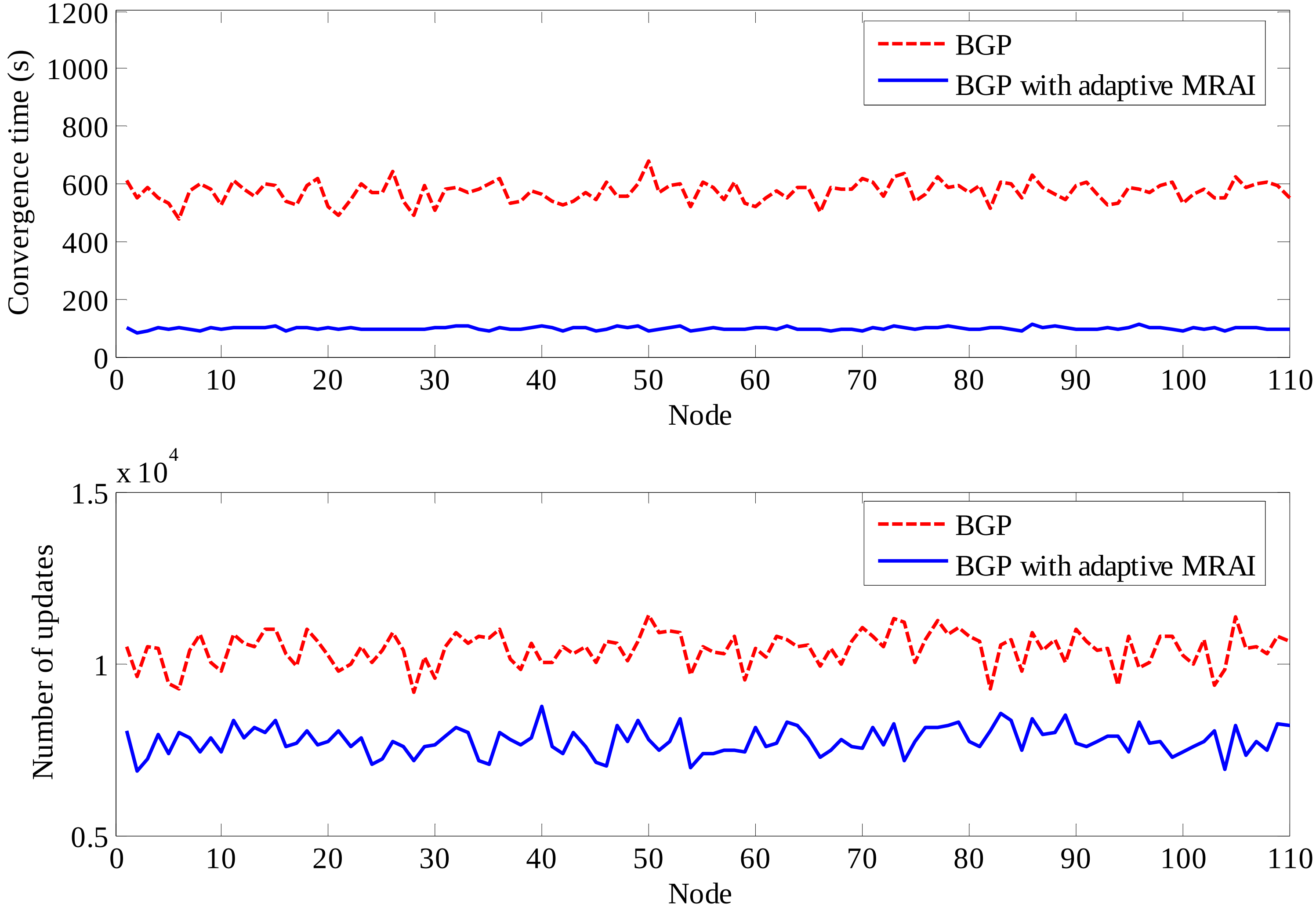


Network with 110 nodes: up phase





Network with 110 nodes: down phase



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Conclusions

- We introduced the empirical delay model for the BGP processing delay
- We proposed BGP with adaptive MRAI
  - reusable MRAI timers
  - the adaptive MRAI algorithm
- BGP with adaptive MRAI results in shorter BGP convergence times for four simulated topologies
  - BGP convergence time is a linear function of the average BGP processing delay (traffic load)

Future work

- Further analysis requires additional measurement of the processing delay and the active time in various network settings
  - new value for the duration of the first MRAI round
- If fluctuations of the average active time are not too rapid the algorithm may be simplified
  - the duration of the adaptive MRAI does not have to be calculated in each round and for each destination separately

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QUESTIONS?

BGP routing table (RIB)

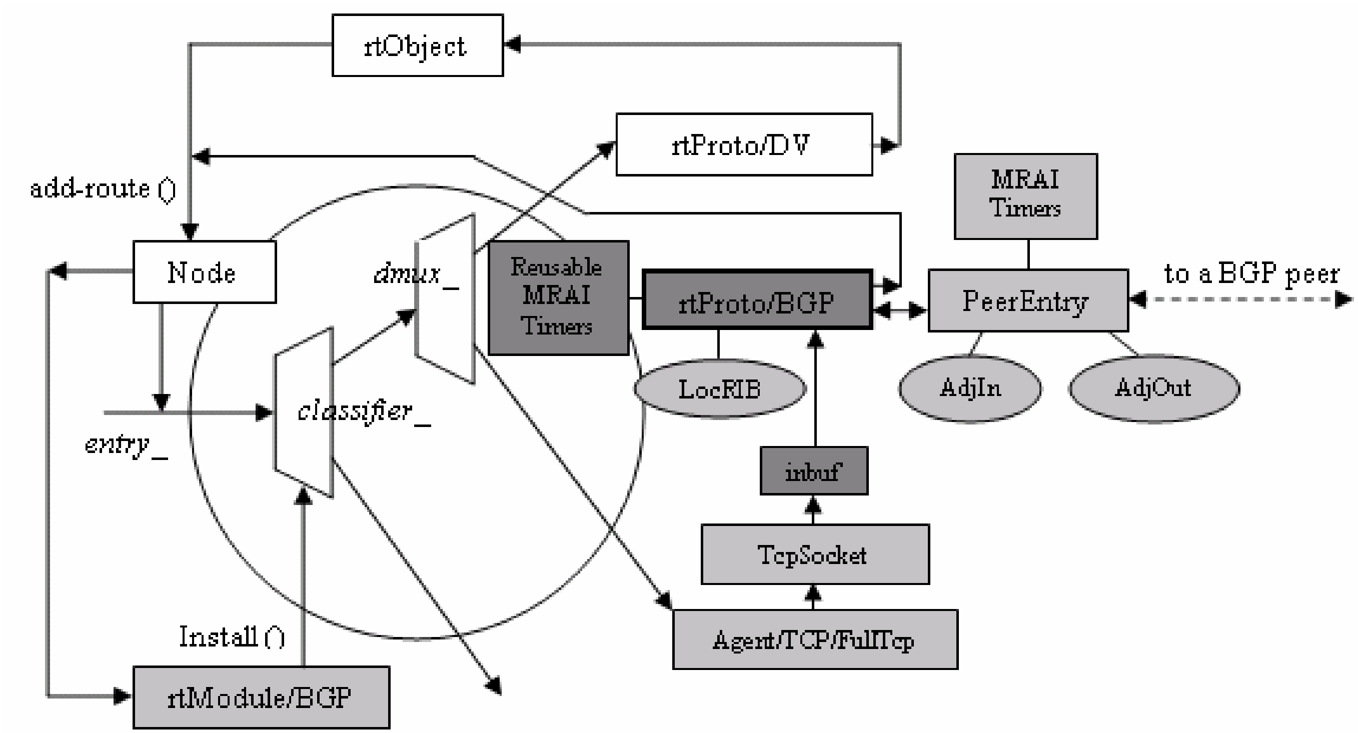
Prefix (destination)	Peer's AS	Peer's IP	AS path
3.0.0.0/8	1755	213.174.64.80	1755 701 80
3.0.0.0/8	3130	147.28.255.2	3130 7018 701 80
3.0.0.0/8	3130	147.28.255.1	3130 7018 701 80
3.1.0.0/8	701	64.200.199.3	701 80
3.1.0.0/8	715	157.22.9.7	715 1239 80
3.1.0.0/8	3561	208.172.146.2	3561 1239 80
3.1.0.0/8	6539	216.18.31.102	6539 701 80
3.1.0.0/8	8121	199.74.221.1	8121 6461 701 80

Granularity of reusable MRAI timers

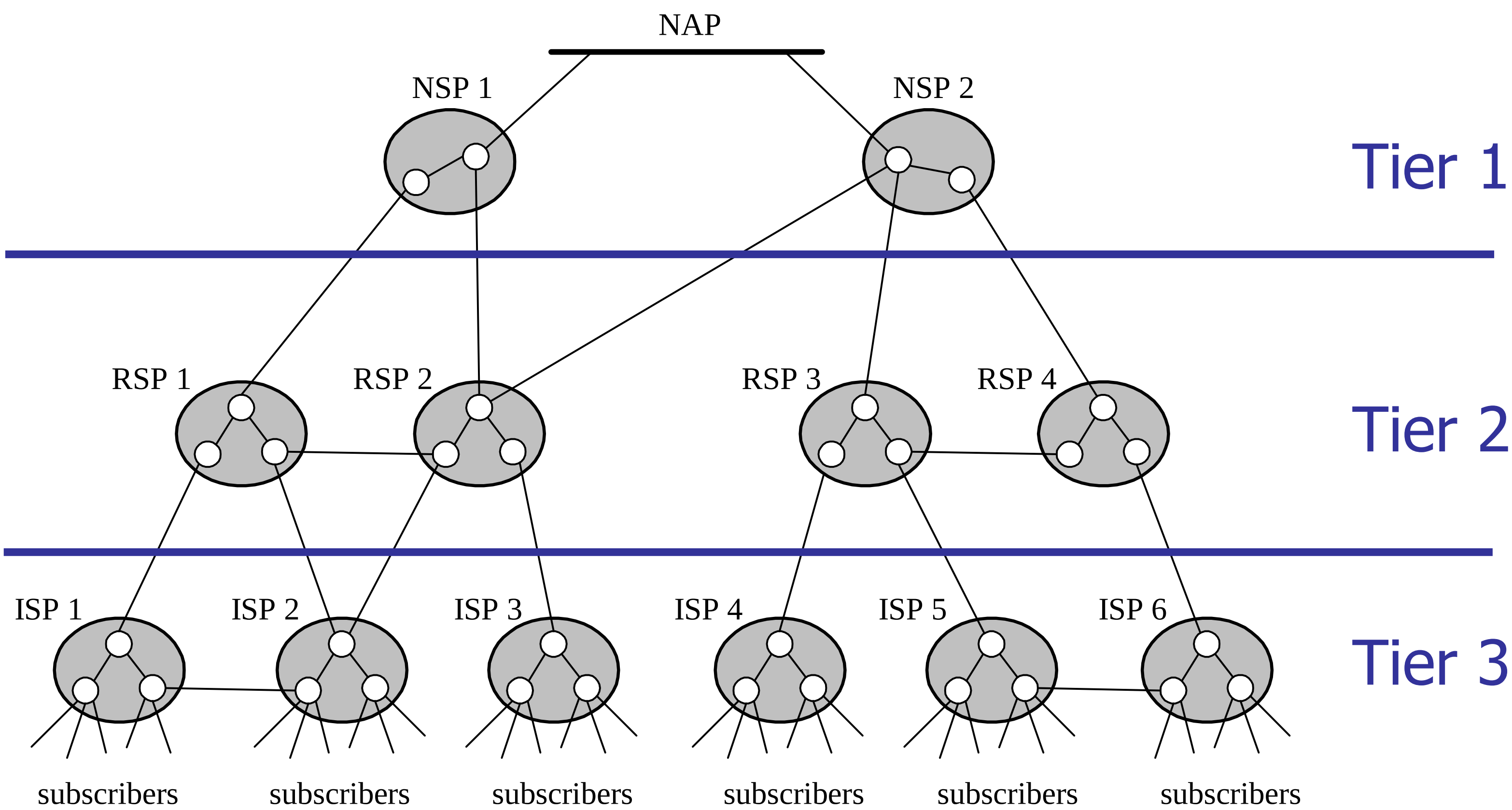
Reusable timers		BGP convergence time (sec)	Number of updates
Number of timers	Granularity (sec)		
10	3	56.2	1651.7
15	2	54.9	1659.8
30	1	45.1	1552.9
60	0.5	45.8	1489.0
120	0.25	45.7	1520.0

ns-2 implementation

- We used ns-2 network simulator and its BGP module ns-BGP 2.0

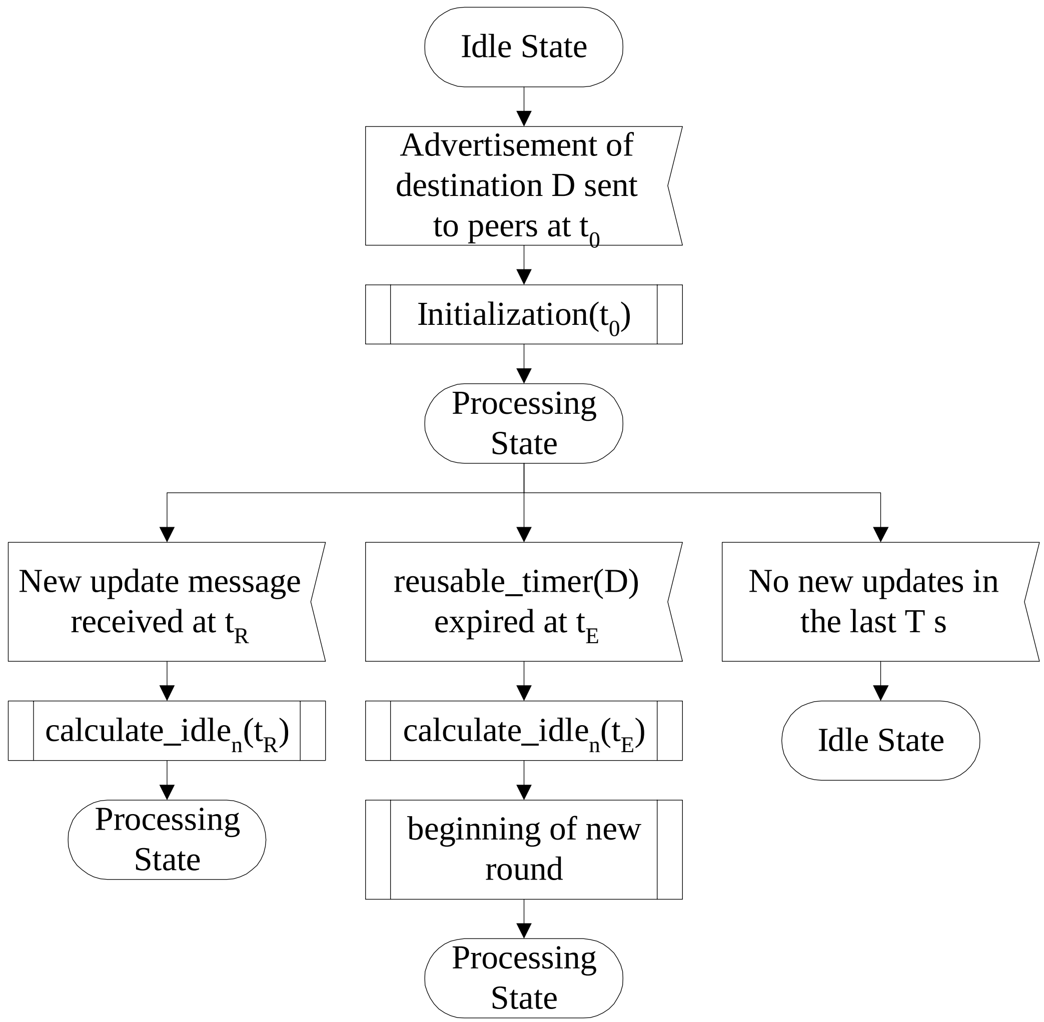


AS hierarchy



ISP: Internet Service Provider
RSP: Regional Service Provider
NSP: Network Service Provider
NAP: Network Access Point

Adaptive MRAI algorithm



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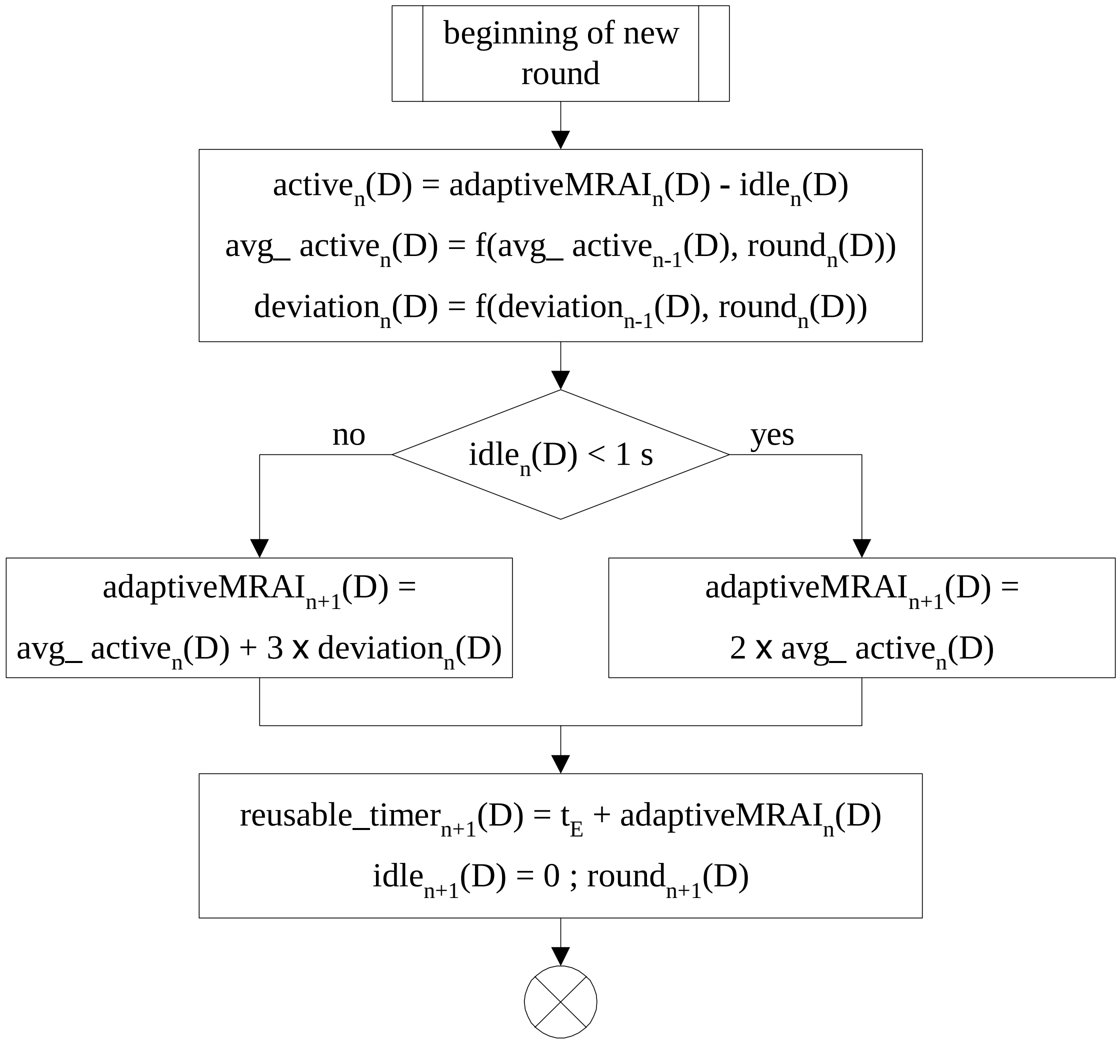
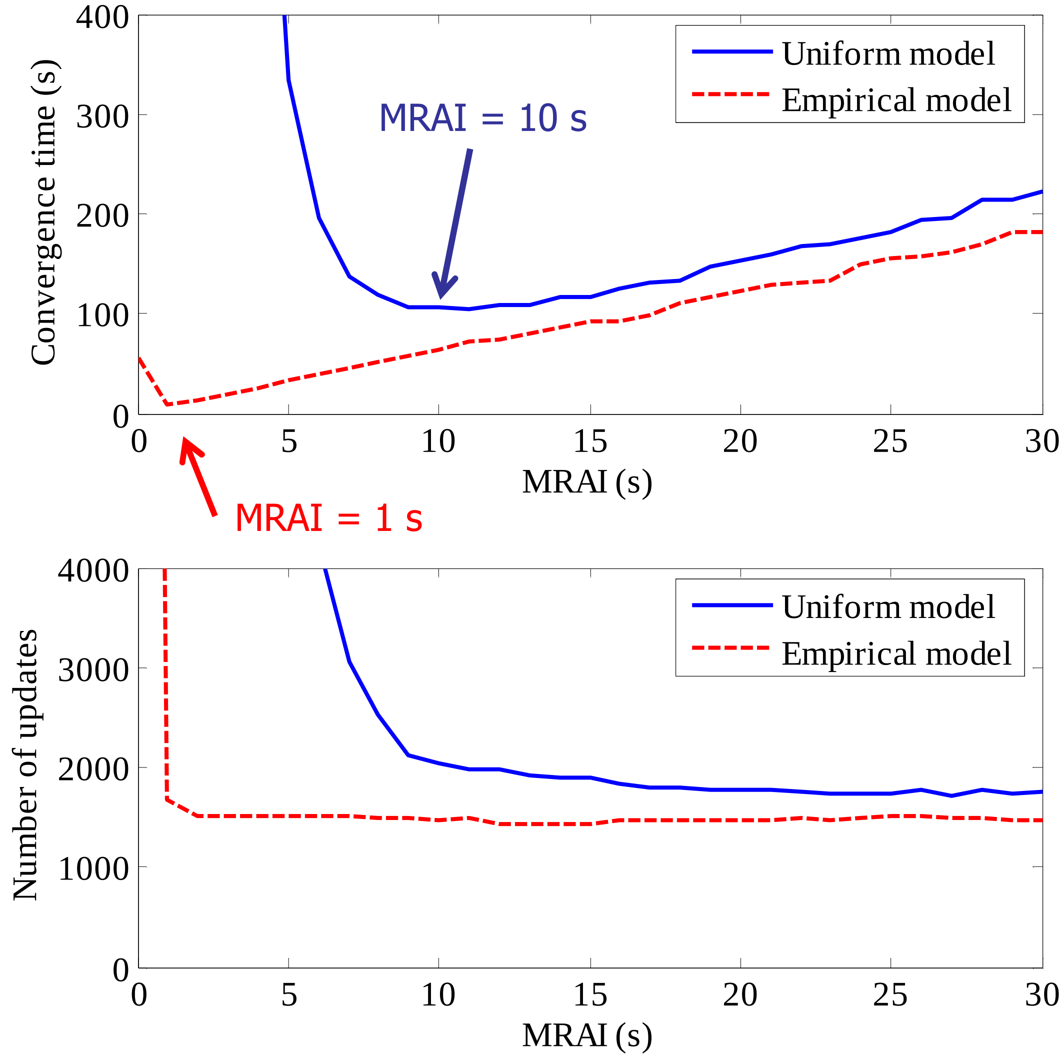


Empirical vs. uniform model



The average active time: calculation

$$avg\_active_n(D) = \sum_{i}^{n} \frac{active_i(D)}{n}$$

$$= \frac{1}{n}\left(\sum_{i}^{n-1} active_i(D) + active_n(D)\right)$$

$$= \frac{n-1}{n} \sum_{i}^{n-1} \frac{active_i(D)}{n-1} + \frac{1}{n} active_n(D)$$

$$= \left(1 - \frac{1}{n}\right) avg\_active_{n-1}(D) + \frac{1}{n} active_n(D)$$

$$= avg\_active_{n-1}(D) + \frac{(active_n(D) - avg\_active_{n-1}(D))}{n}$$

$$= avg\_active_{n-1}(D) + \frac{\Delta_n}{n}$$

The standard deviation of the active time

$$deviation_n(D) = \sqrt{\sum_{i}^{n} \frac{(active_i(D) - avg\_active_n(D))^2}{n}}$$

$$= \sqrt{\frac{1}{n}\left(\sum_{i}^{n-1}(active_i(D) - avg\_active_n(D))^2 + (active_n(D) - avg\_active_n(D))^2\right)}$$

$$= \sqrt{\frac{n-1}{n}\sum_{i}^{n-1}\frac{(active_i(D) - avg\_active_n(D))^2}{n-1} + \frac{\Delta_n{}^2}{n}}$$

$$= \sqrt{(1-\frac{1}{n})deviation^2{}_{n-1}(D) + \frac{\Delta_n{}^2}{n}}$$

$$= \sqrt{deviation^2{}_{n-1}(D) + \frac{(\Delta_n{}^2 - deviation^2{}_{n-1}(D))}{n}}$$