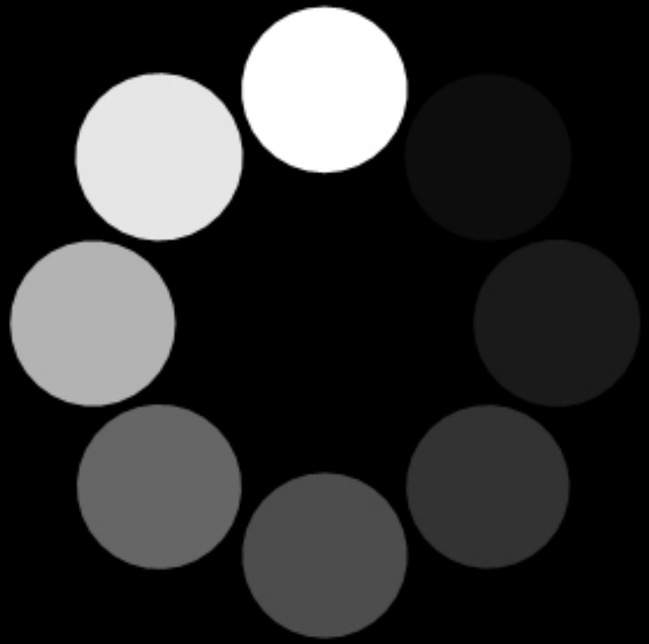
RouteScout

Performance-Driven Internet Path Selection



default Internet routing protocol

BGP

default Internet routing protocol

BGP statically routes traffic to each destination prefix via a single path despite Internet's path diversity, leading to sub-optimal performance.

Can we dynamically route traffic according to performance?

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…why now?

- sharper focus on reliably high network performance
- increasing diversity in available paths
- programmable devices allows scalable monitoring & flexible forwarding

RouteScout: Performance-Driven Internet Path Selection

Maria Apostolaki

Ankit Singla

Laurent Vanbever

RouteScout: Performance-Driven Internet Path Selection

RouteScout Operations

RouteScout Architecture

Data-Plane Design

Evaluation

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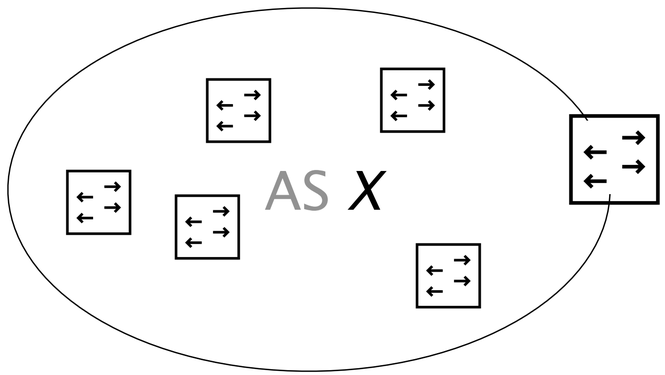
RouteScout selects the next hop per prefix



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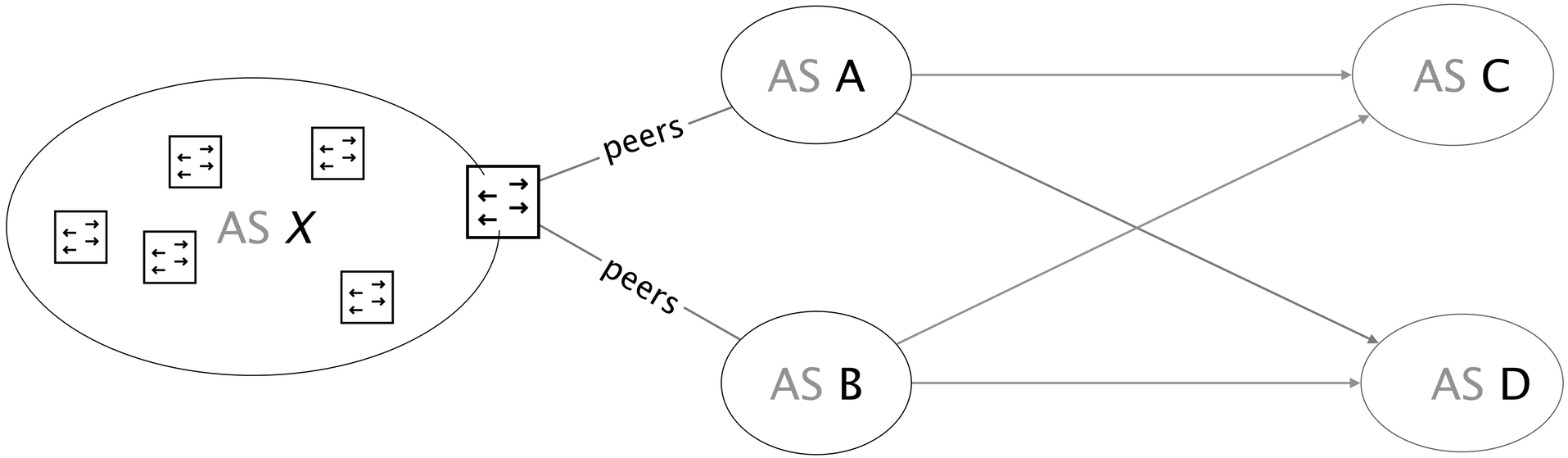
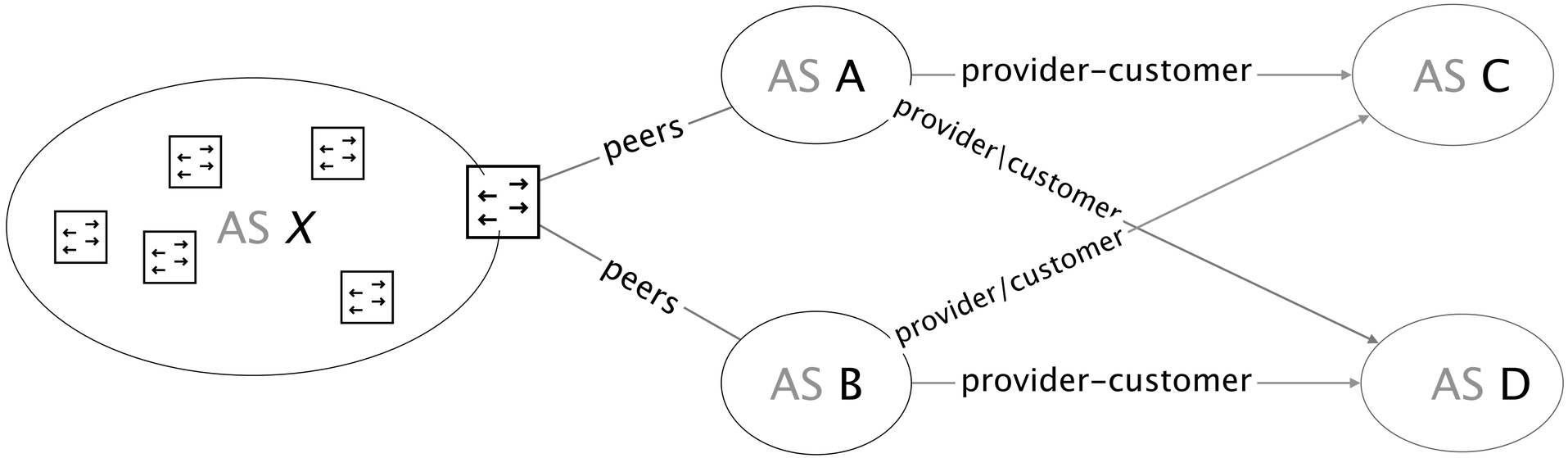
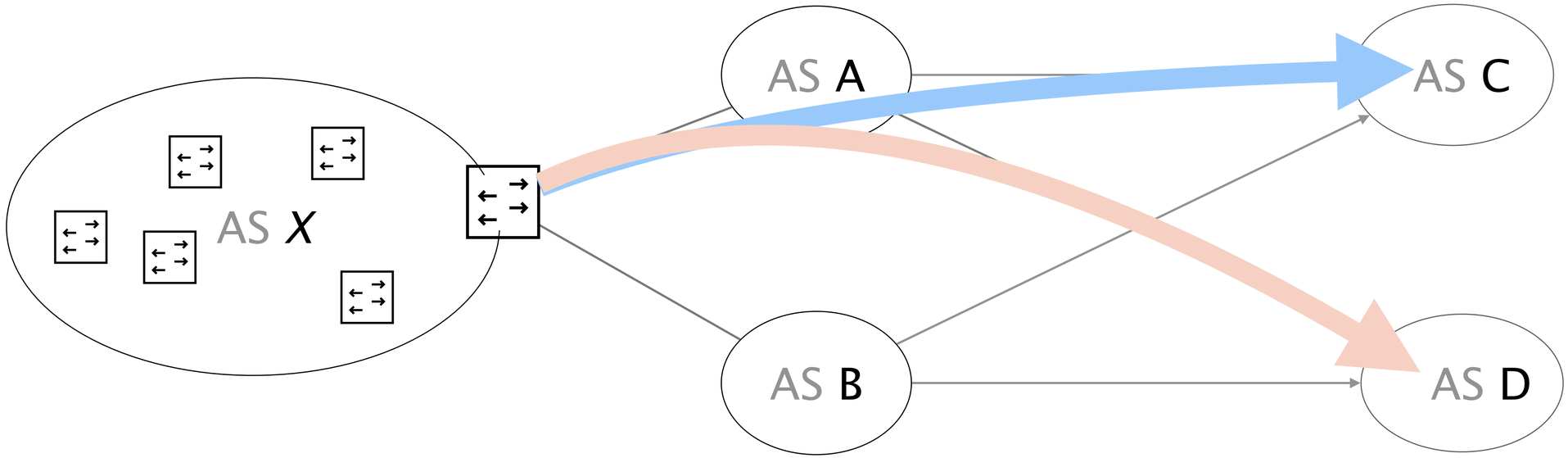


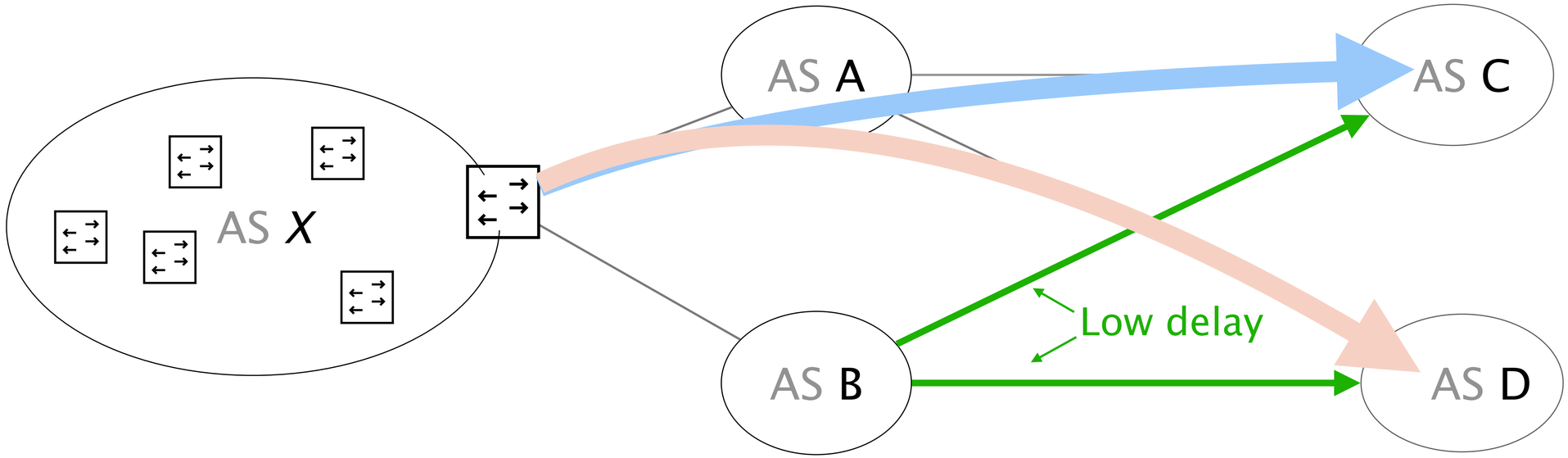
Routes via AS A and via AS B to AS C and AS D are equally preferred



BGP routes to both destinations via AS A

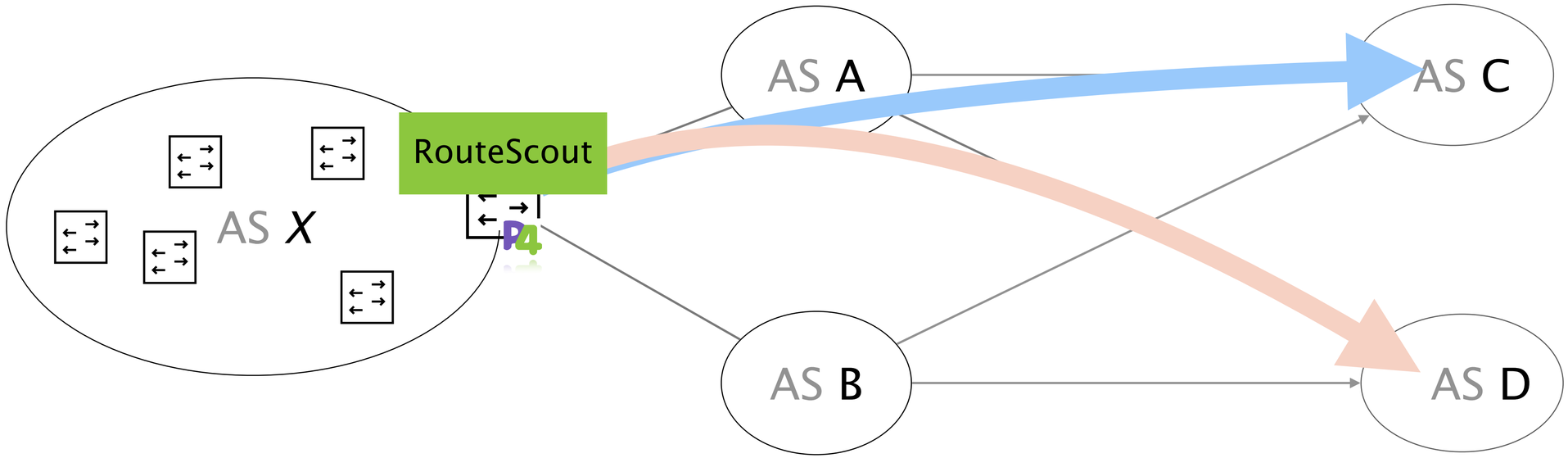


Unbeknownst to AS X Routes via AS B have much lower delay



What does RouteScout need to explore and exploit this opportunity?

RouteScout runs at the network edge on a programmable switch and controls the paths of outgoing traffic



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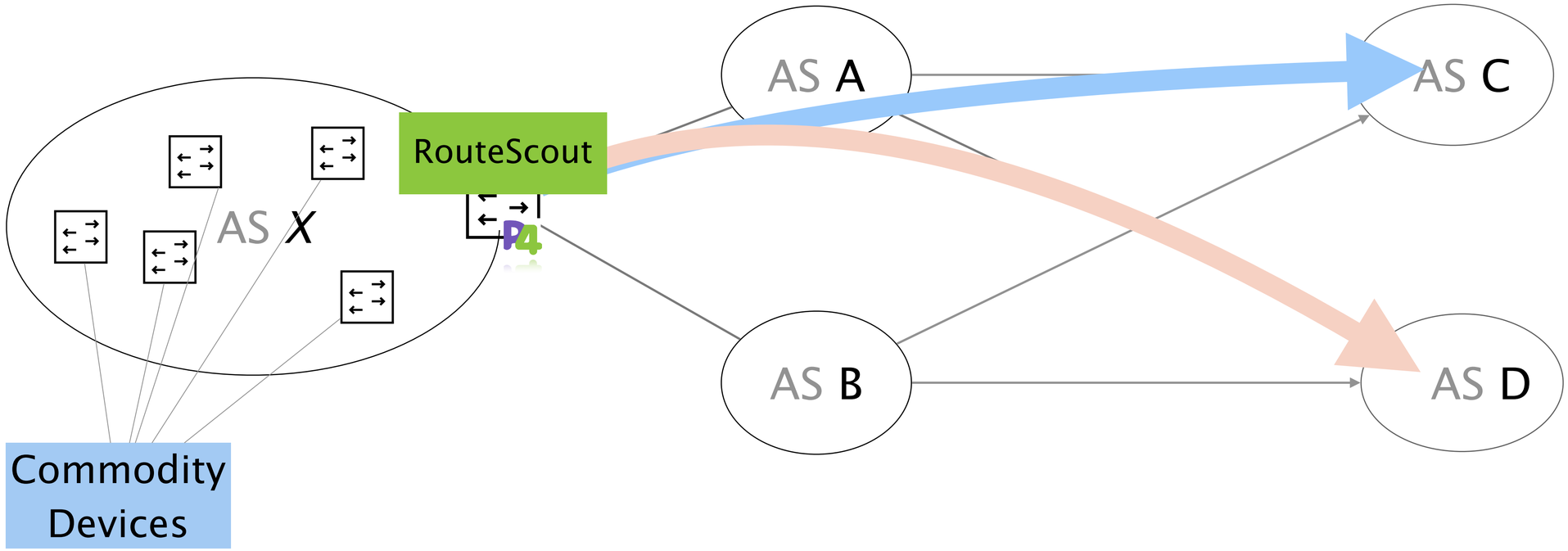
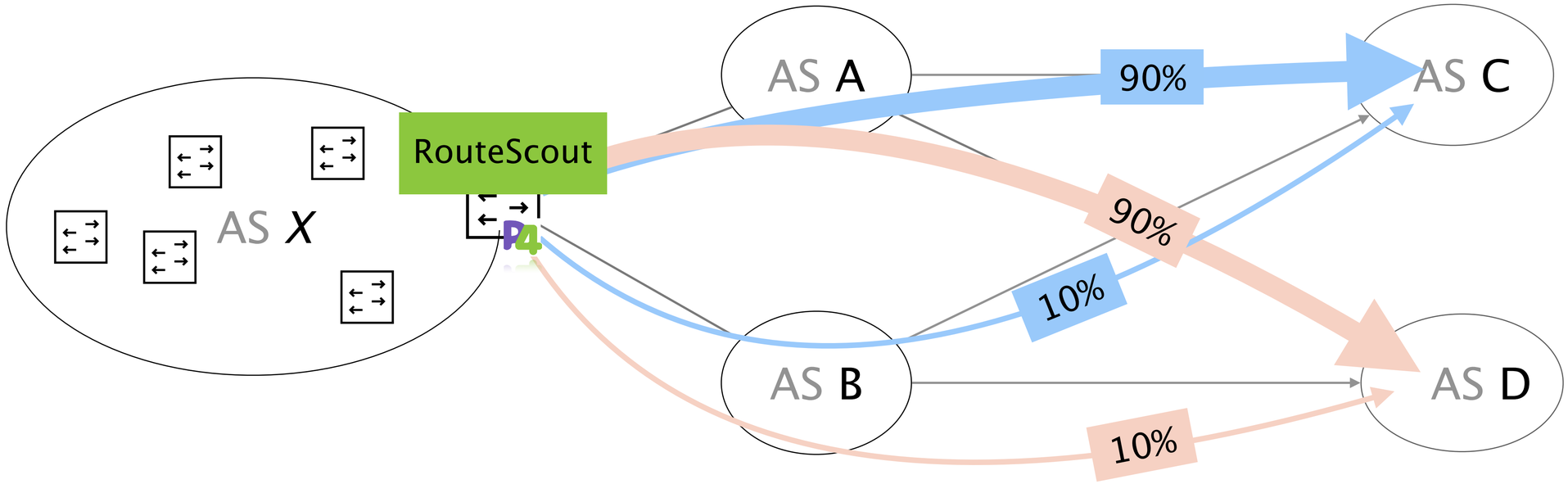
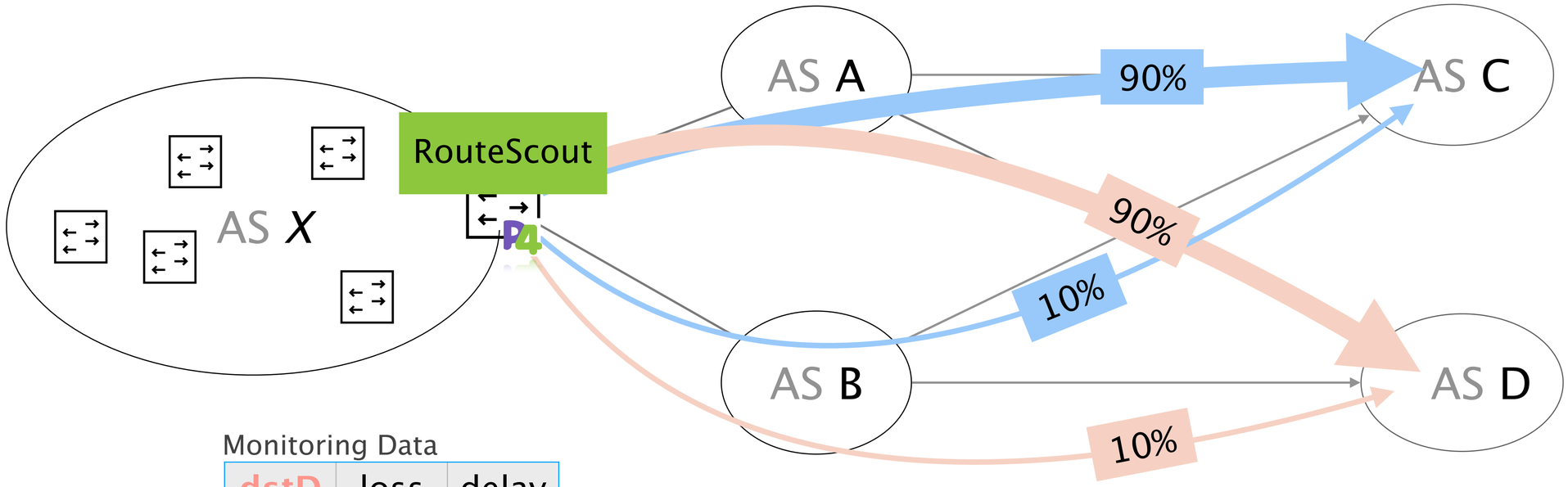


RouteScout directs traffic to alternative BGP-compliant next-hops



RouteScout monitors performance across prefix, next-hop pairs



Monitoring Data

dstD	loss	delay
A	0	5
B	0	4

dstC	loss	delay
A	0	13
B	0	7

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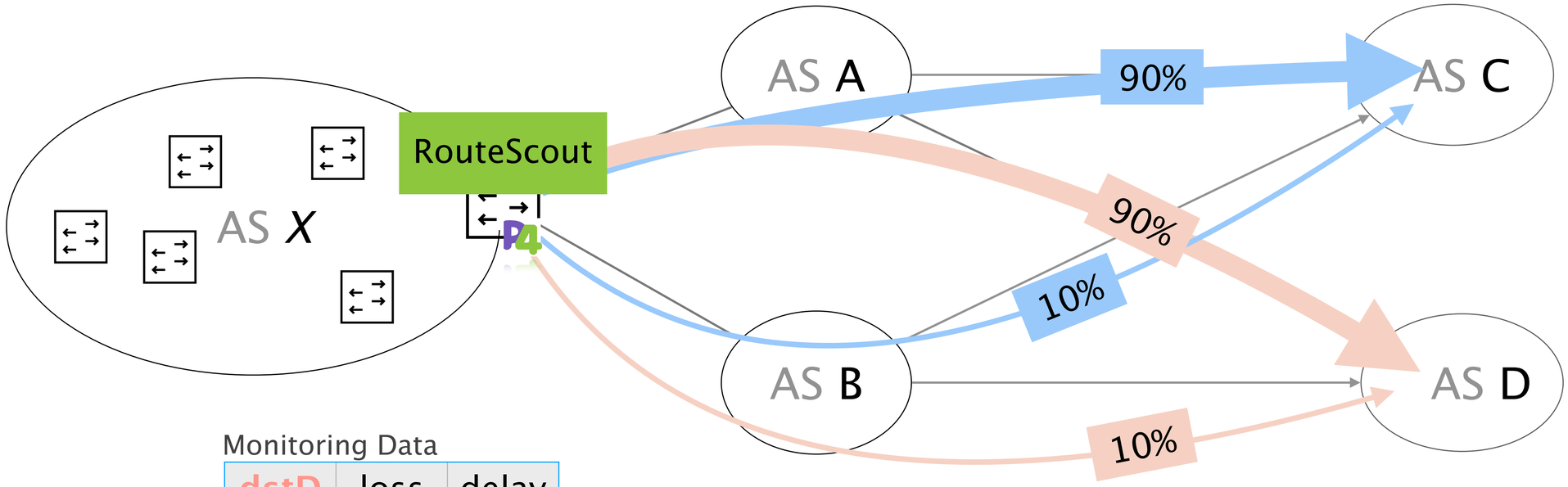

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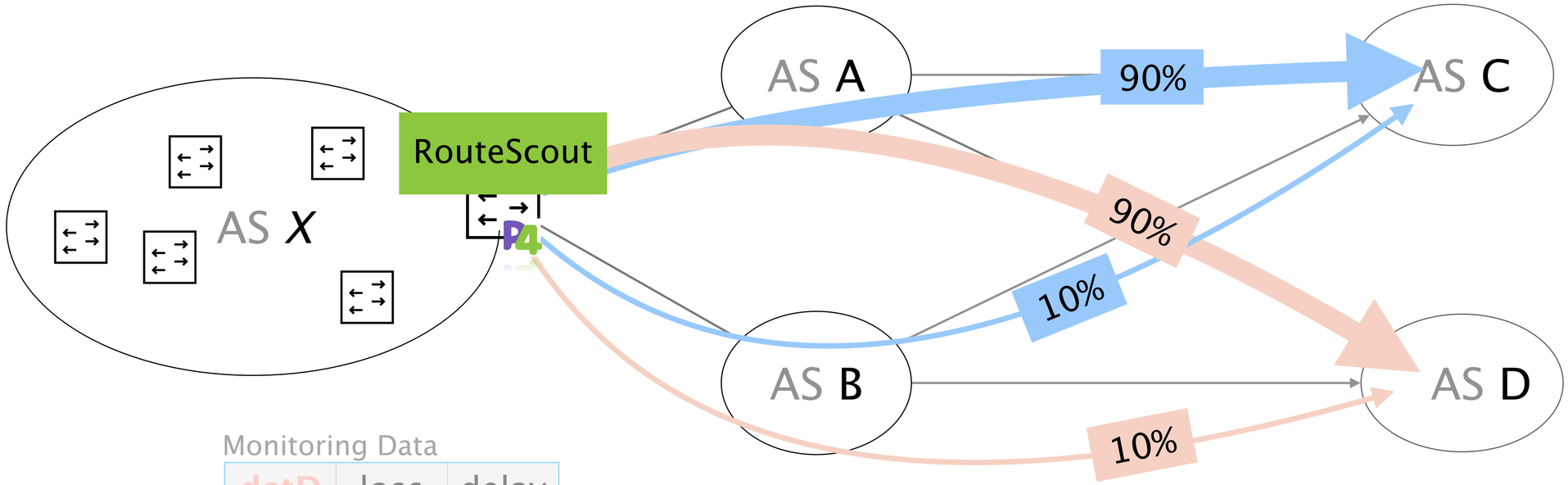

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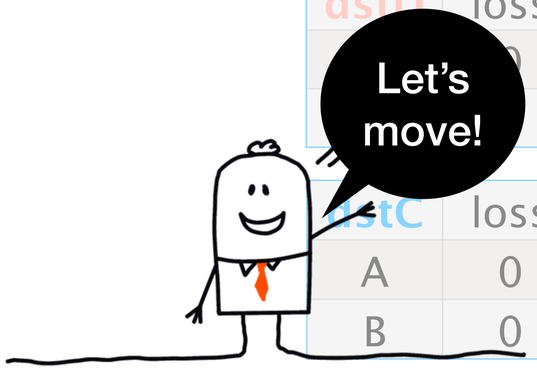

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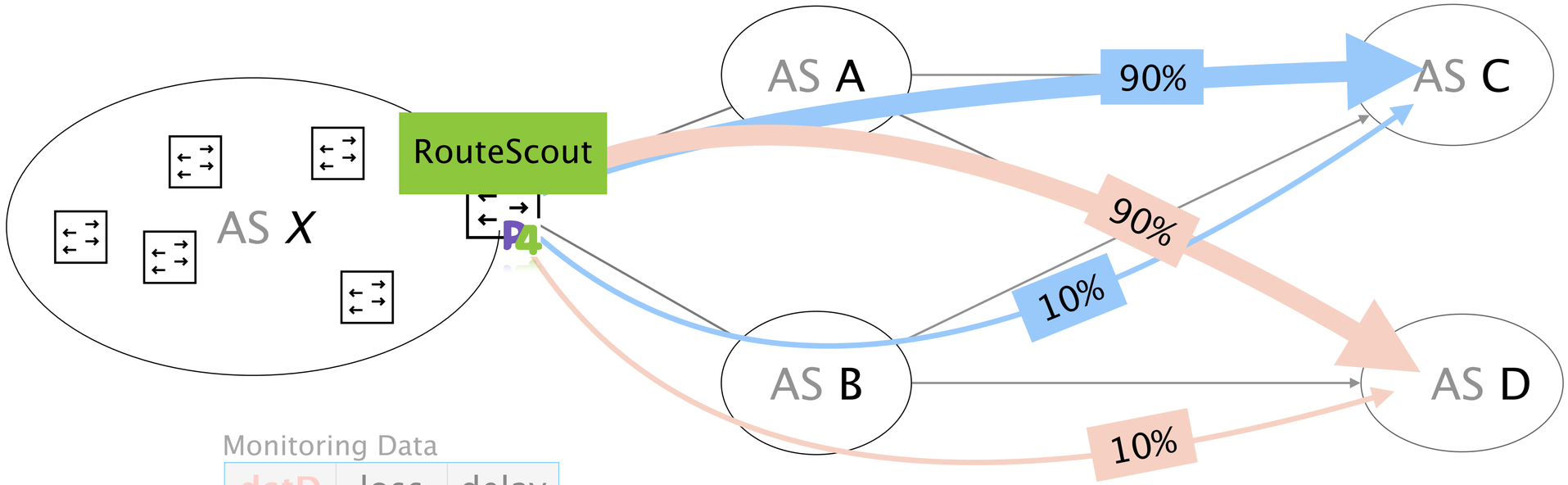

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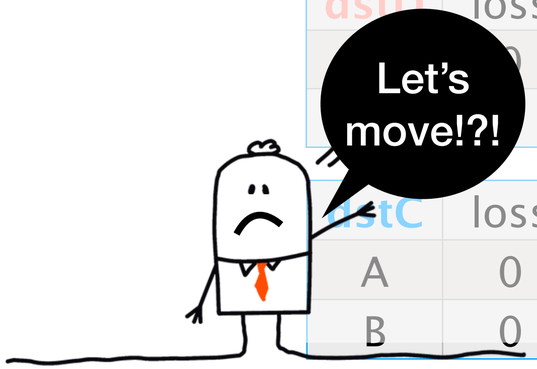

RouteScout using performance monitoring as input,
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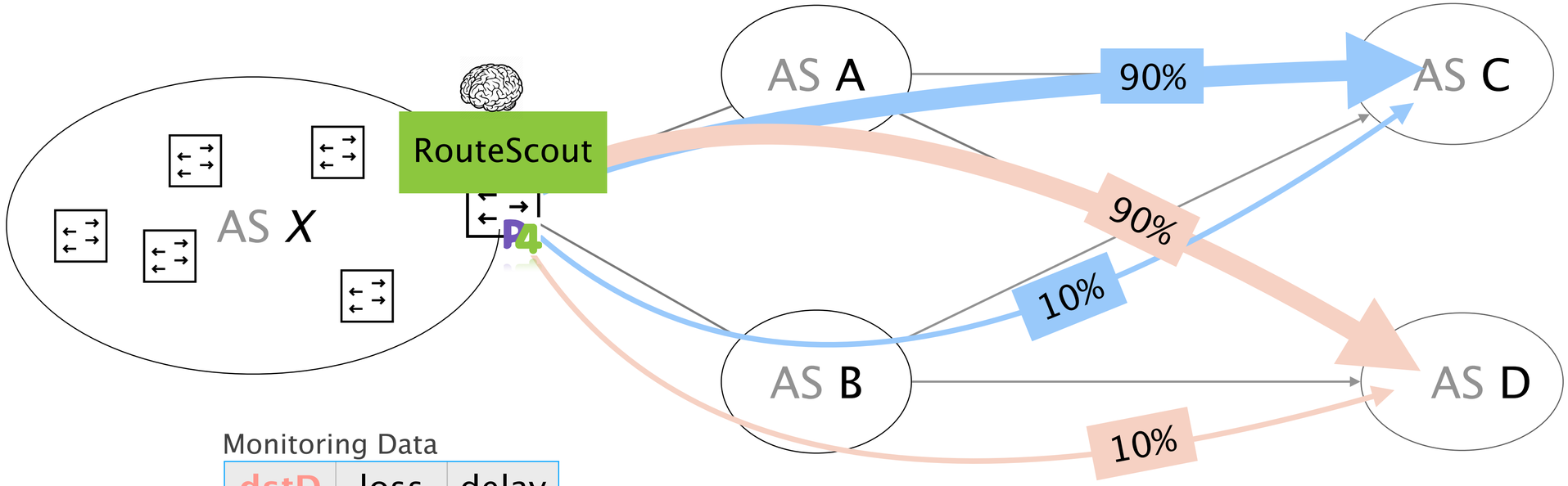

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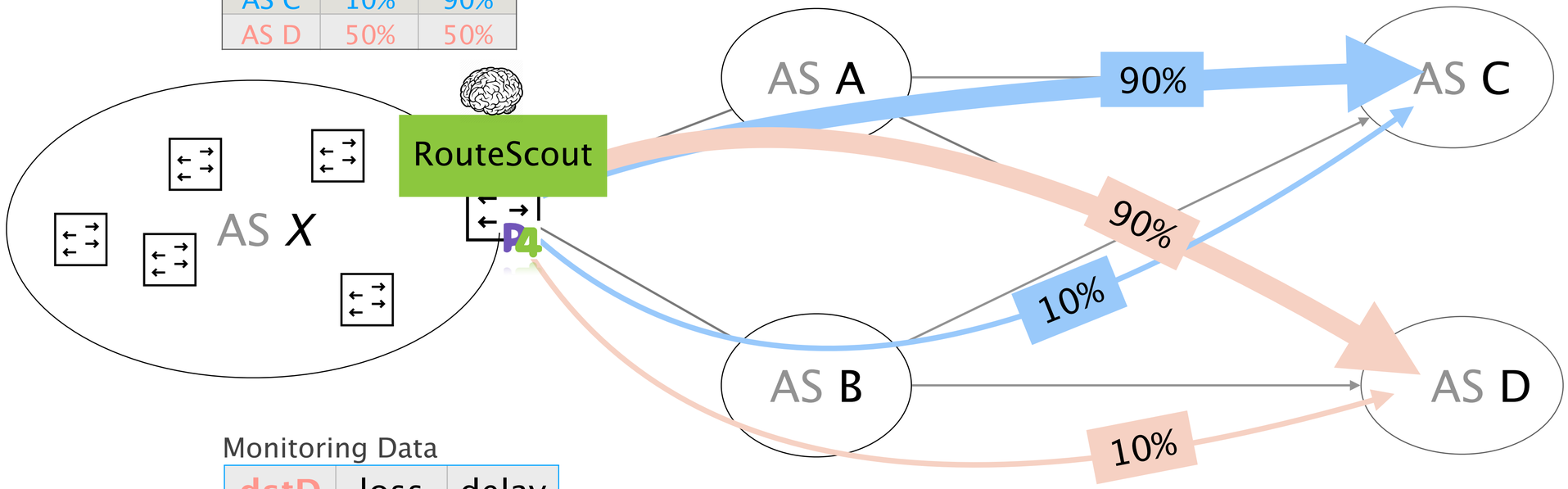
Forwarding Plan

	AS A	AS B
AS C	10%	90%
AS D	50%	50%



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RouteScout actuates appropriate traffic shifts in the data plane

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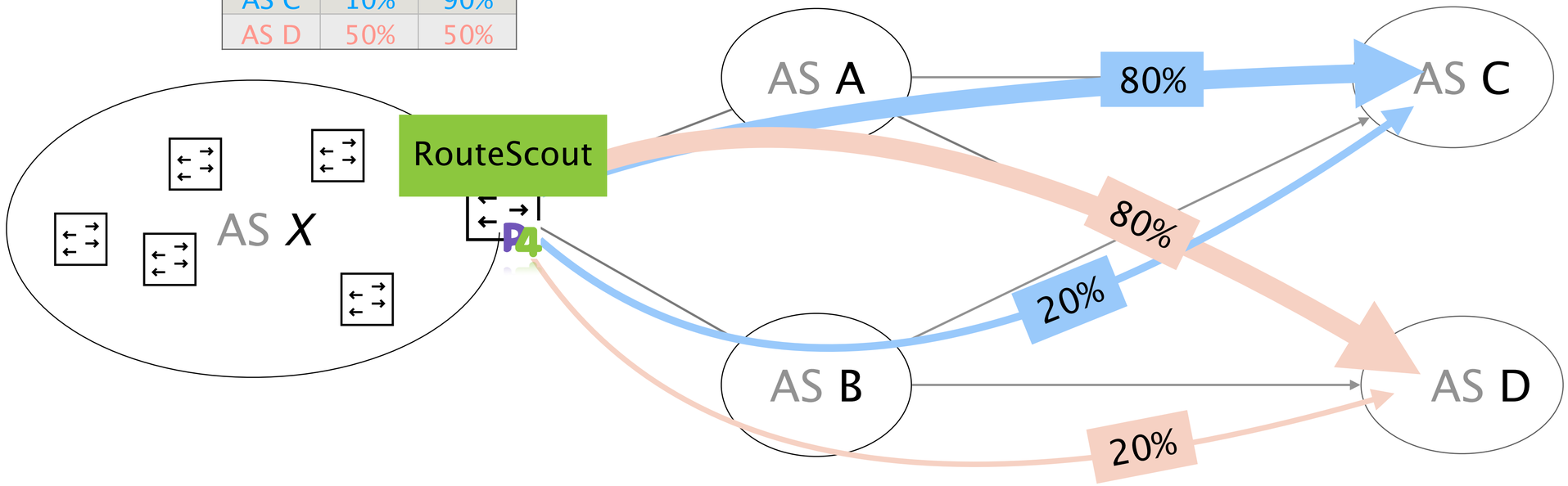

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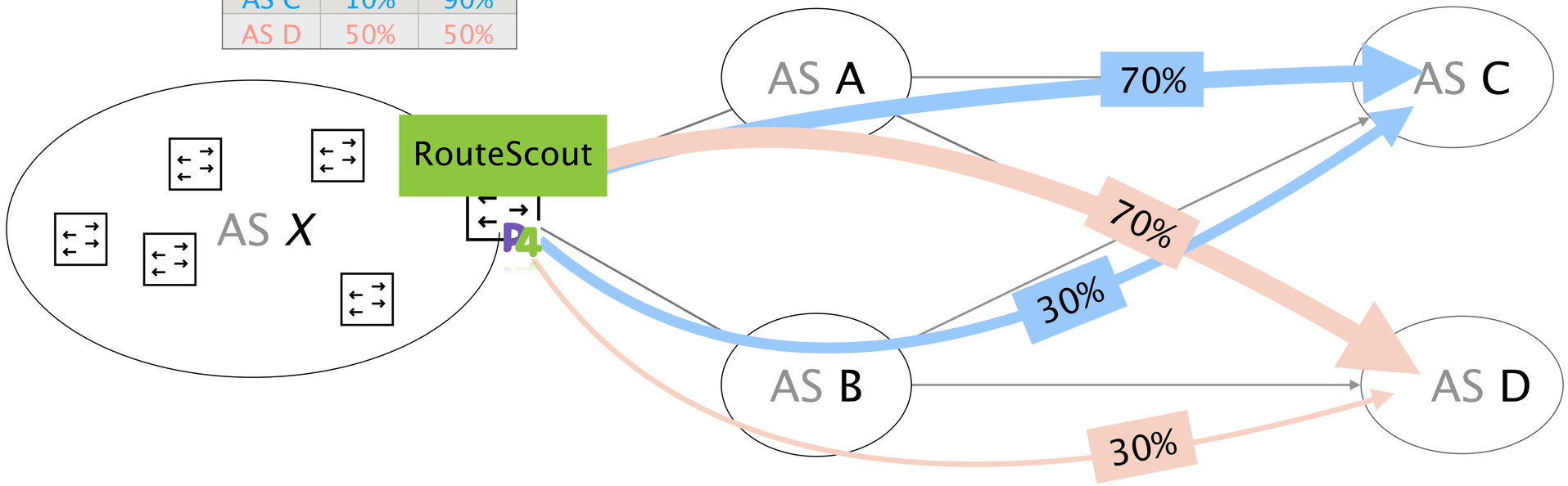

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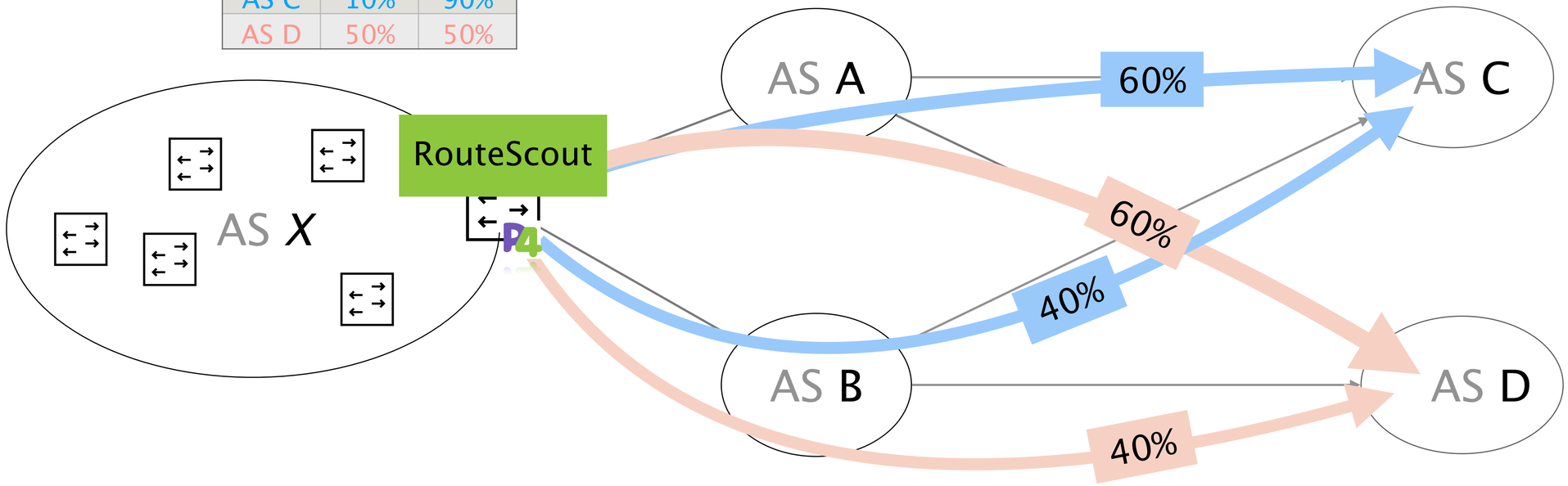

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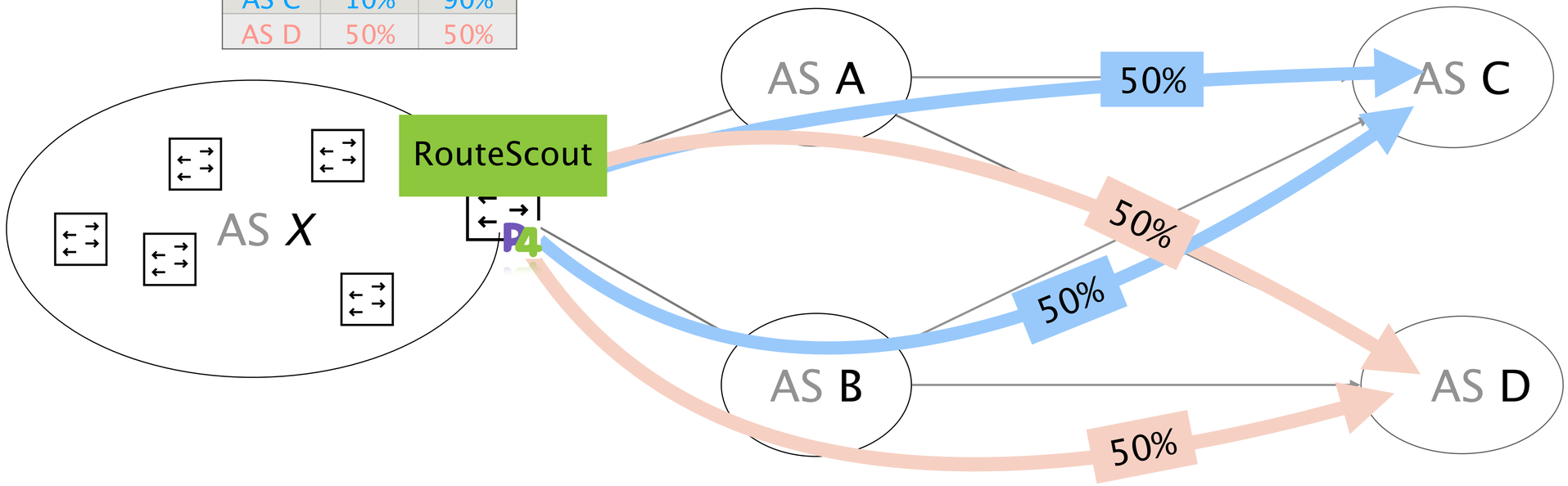

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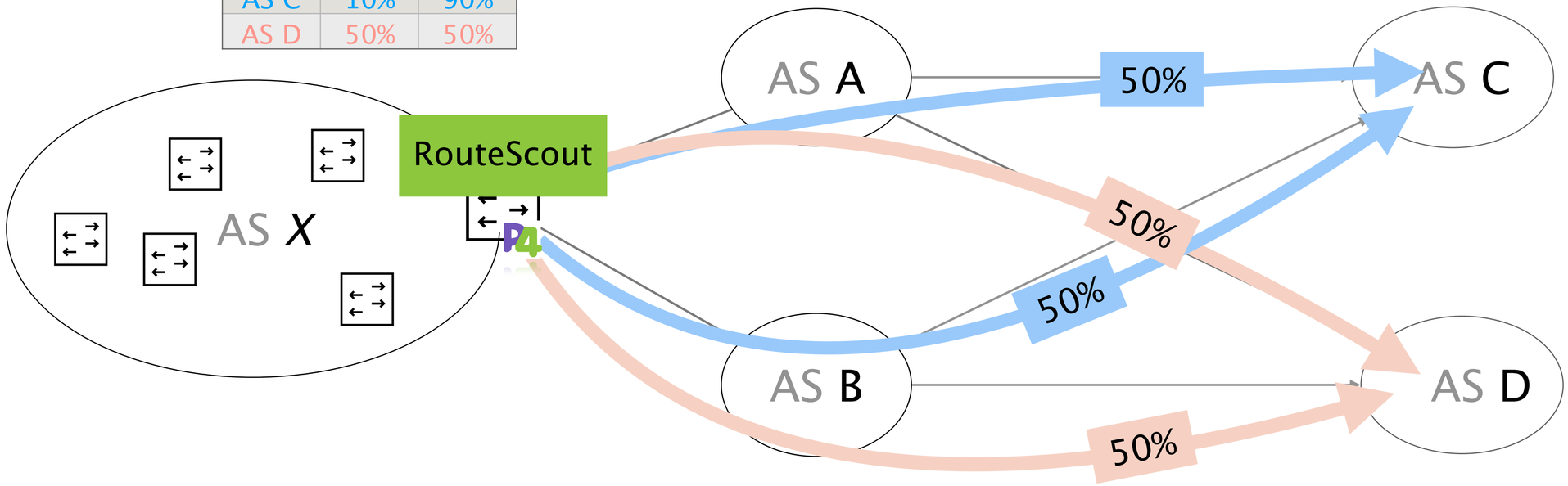

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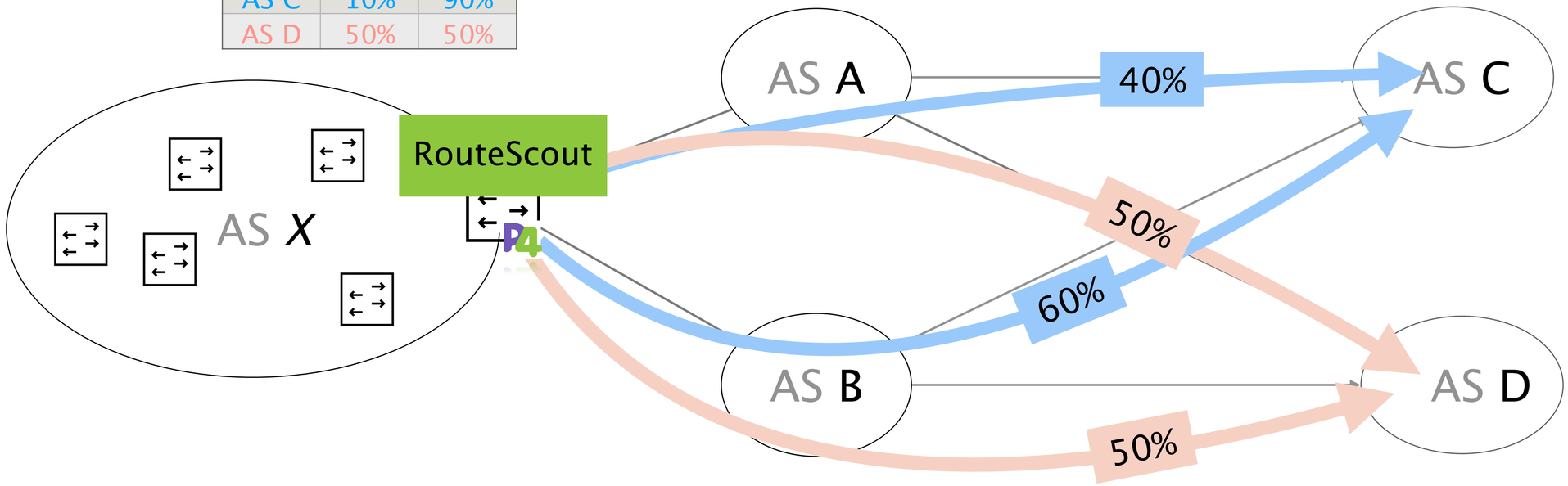

RouteScout optimizes aggregate performance while respecting constraints

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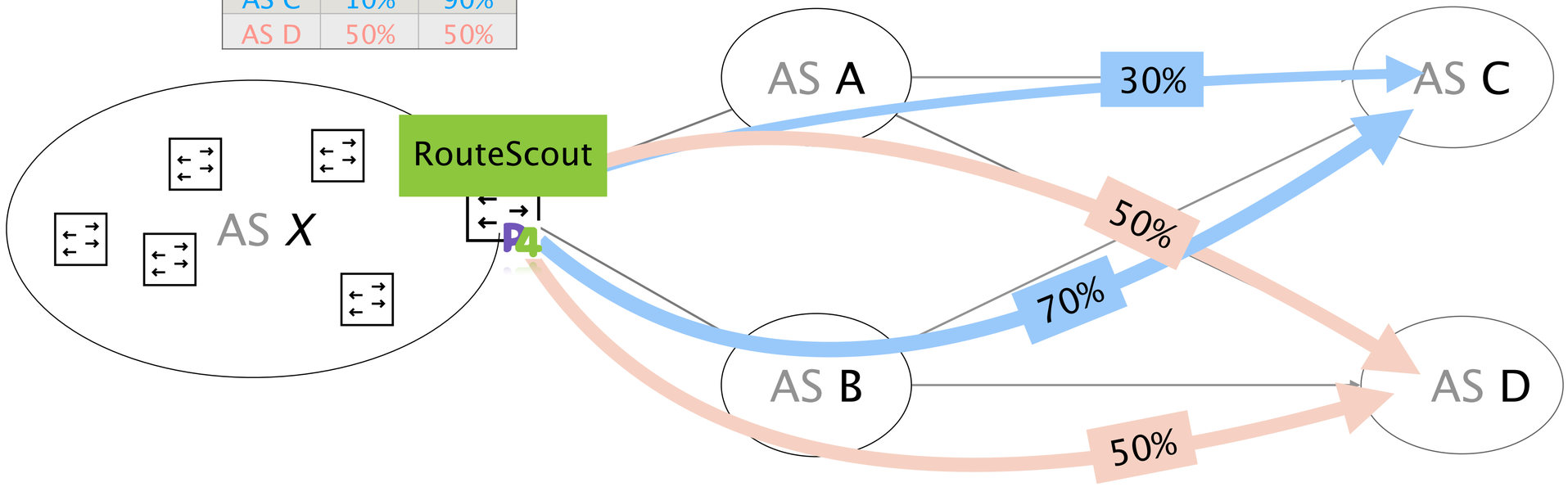

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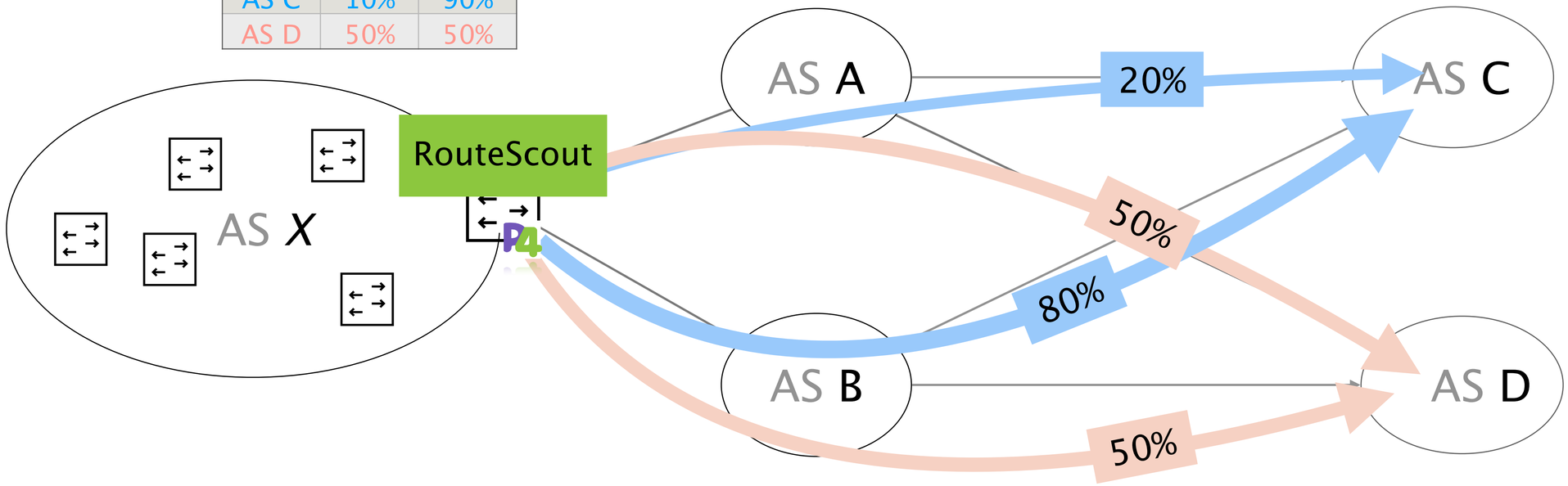

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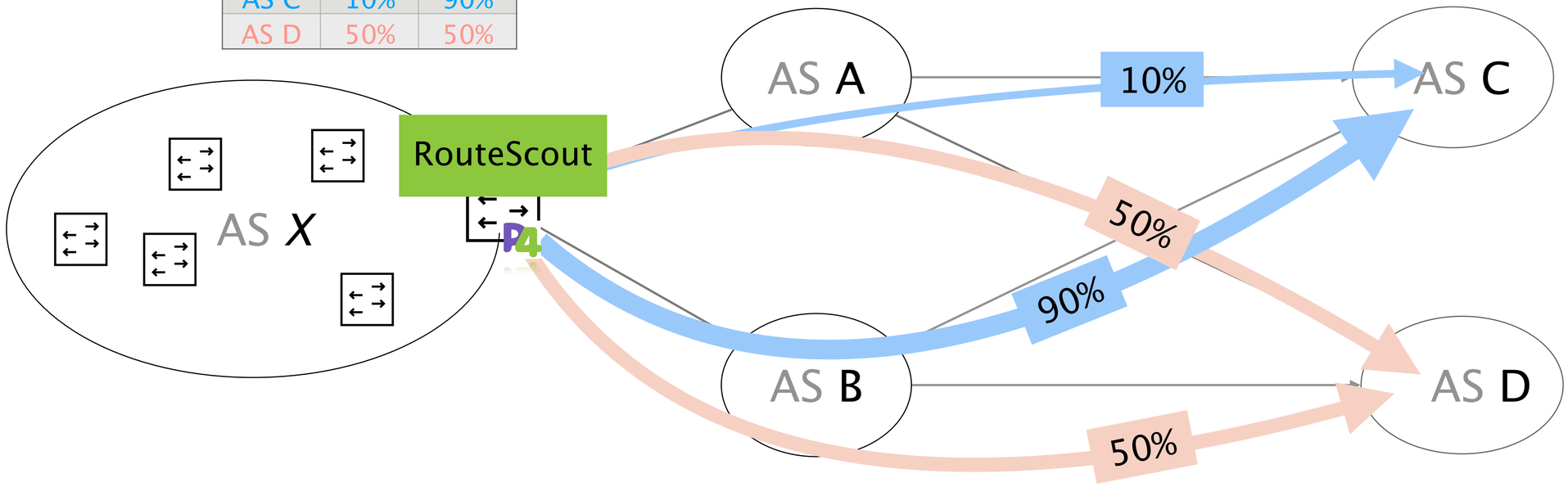


RouteScout: Performance-Driven Internet Path Selection

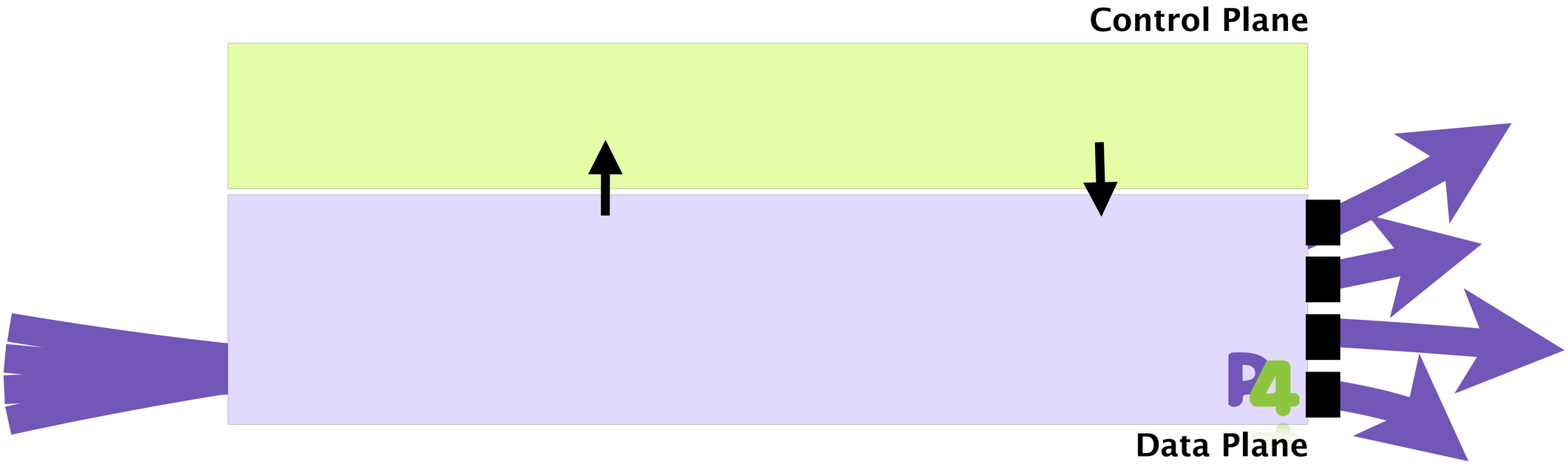
RouteScout Operations

RouteScout Architecture

Data-Plane Design

Evaluation

RouteScout is a closed-loop control system, implemented as a hardware-software design



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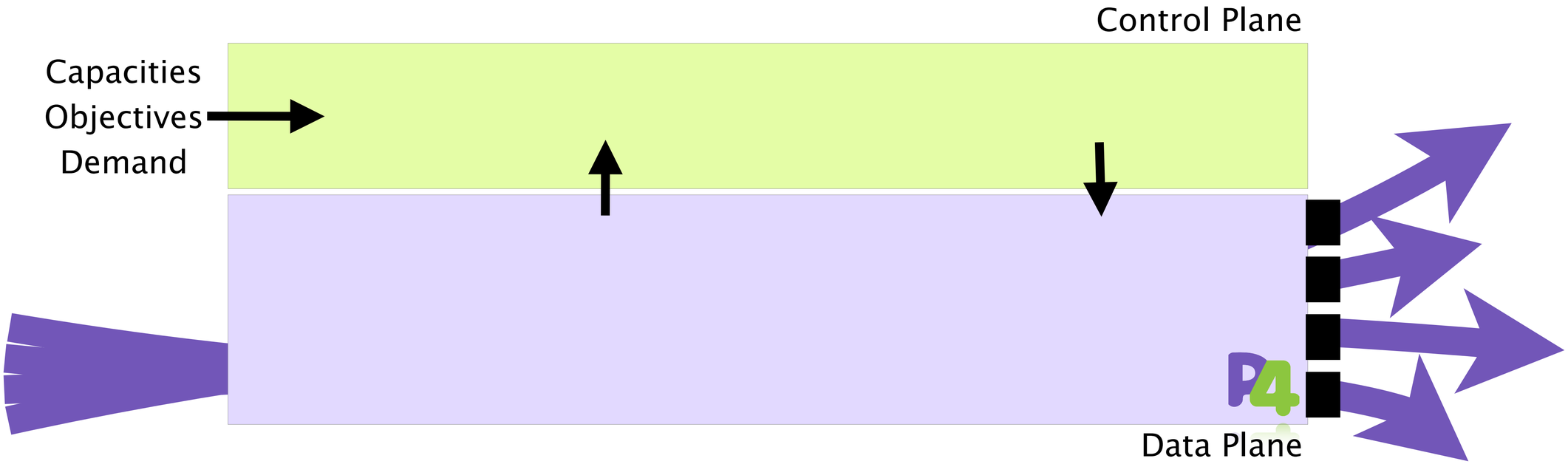

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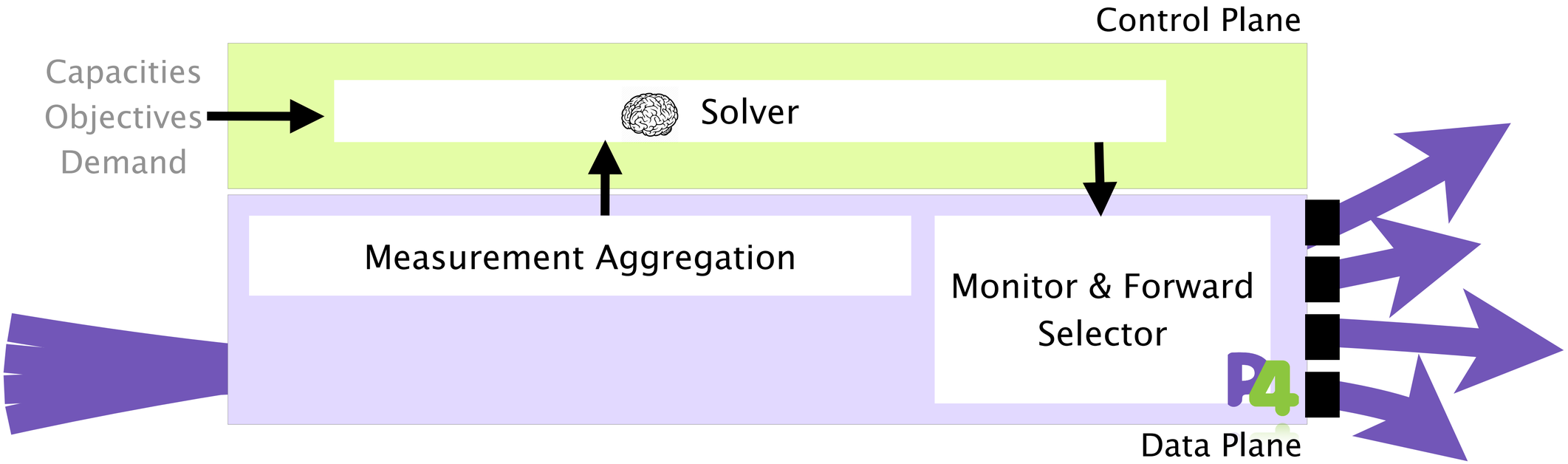

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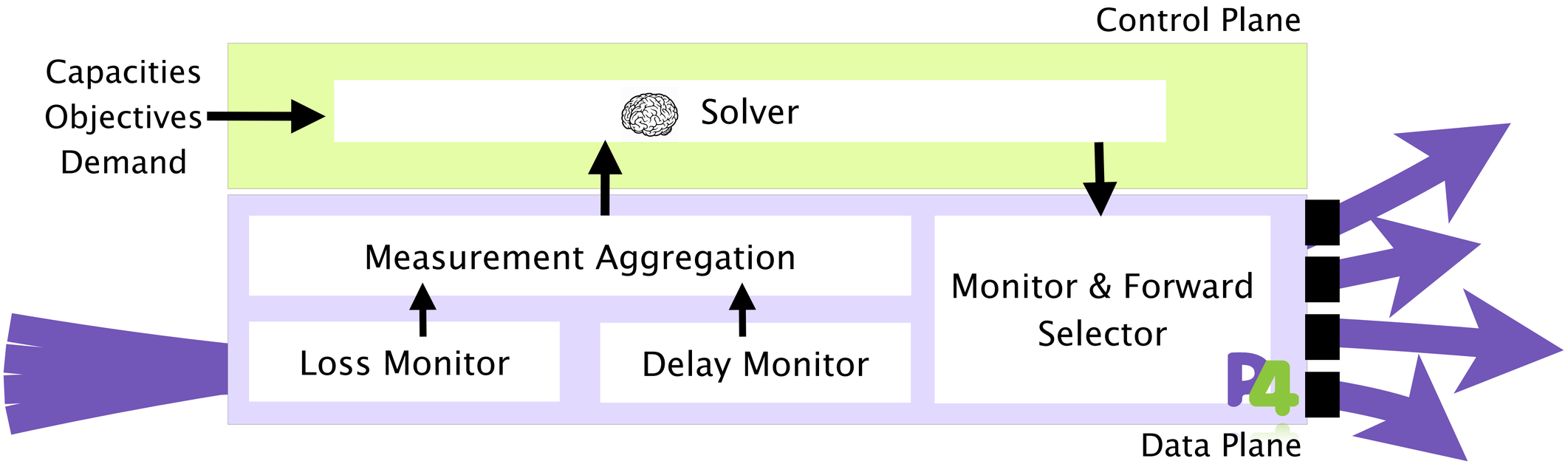

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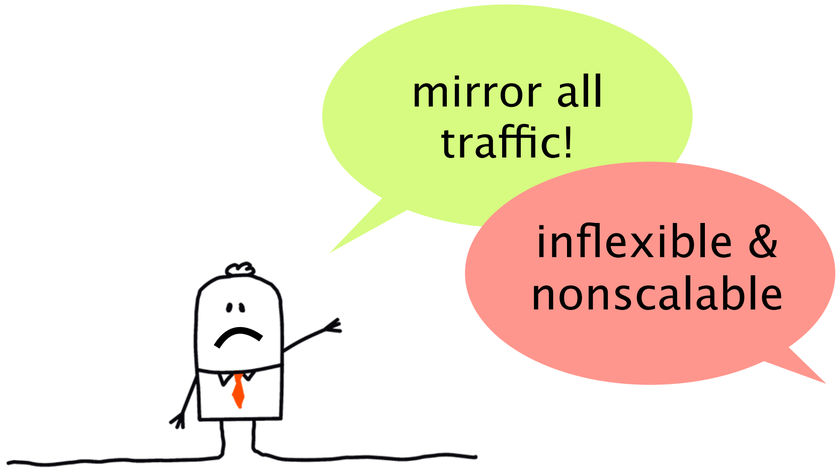

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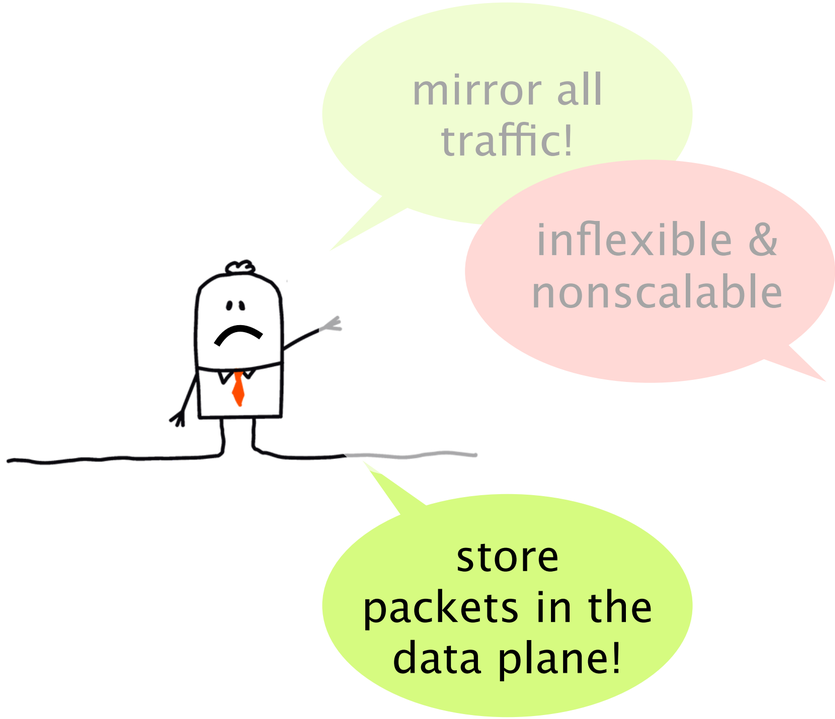

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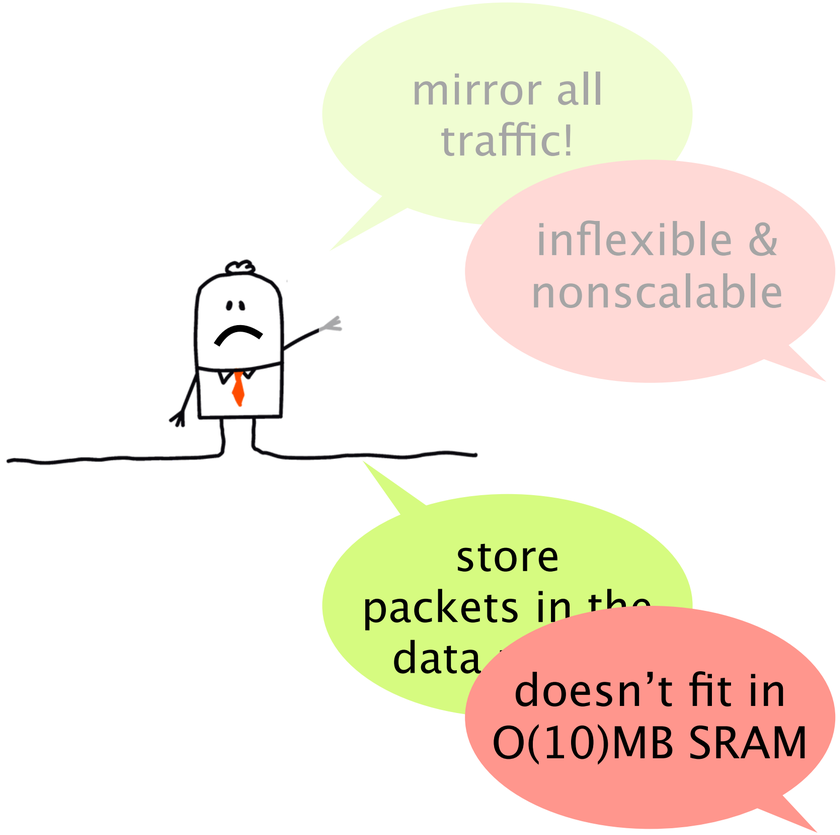

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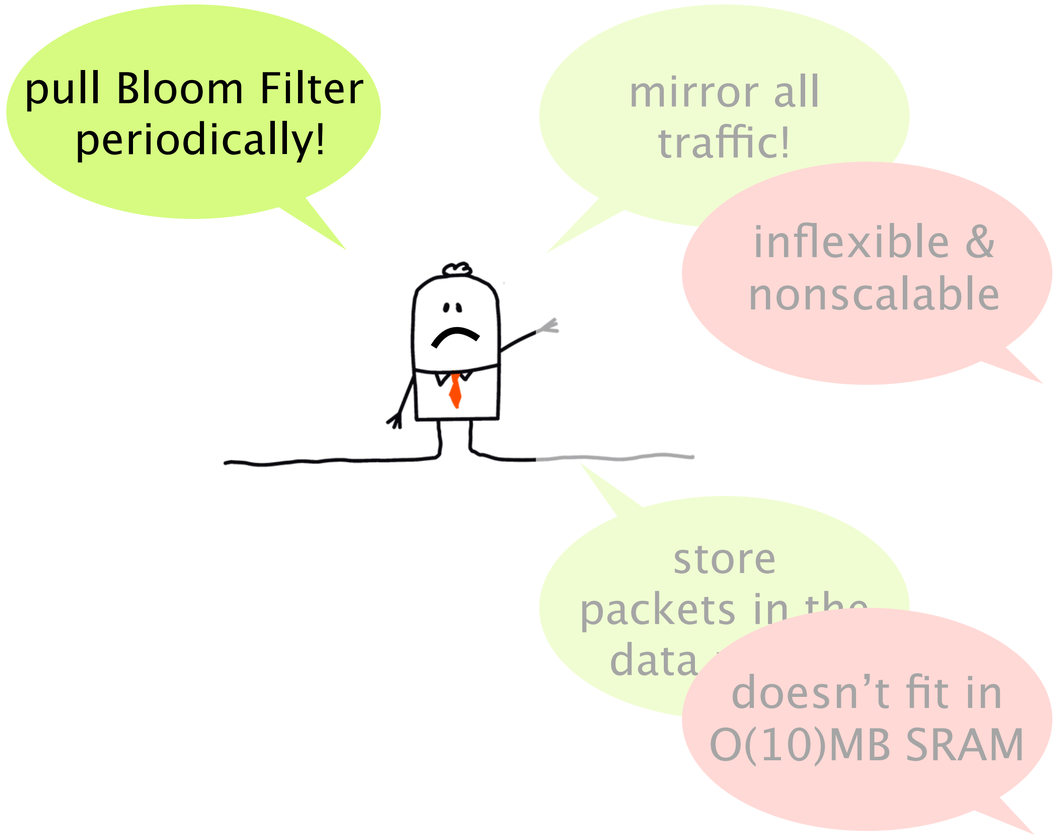

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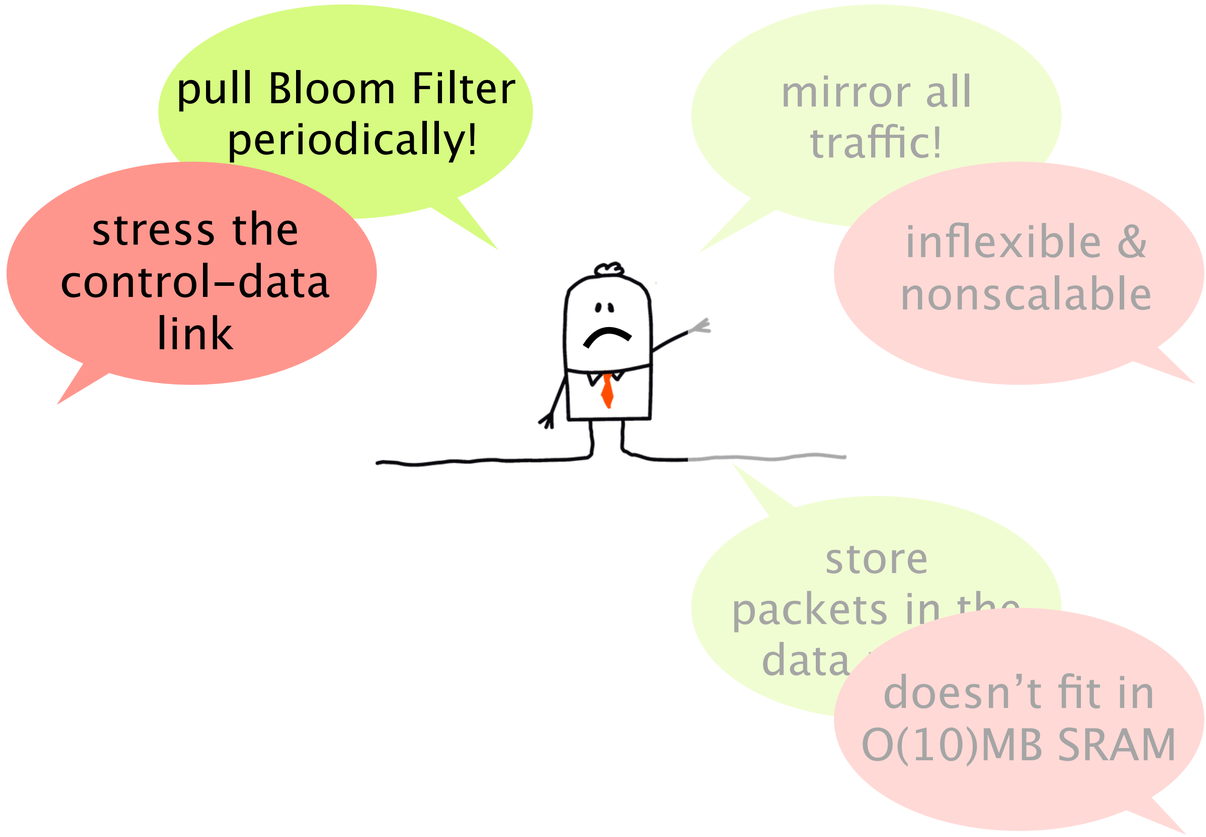

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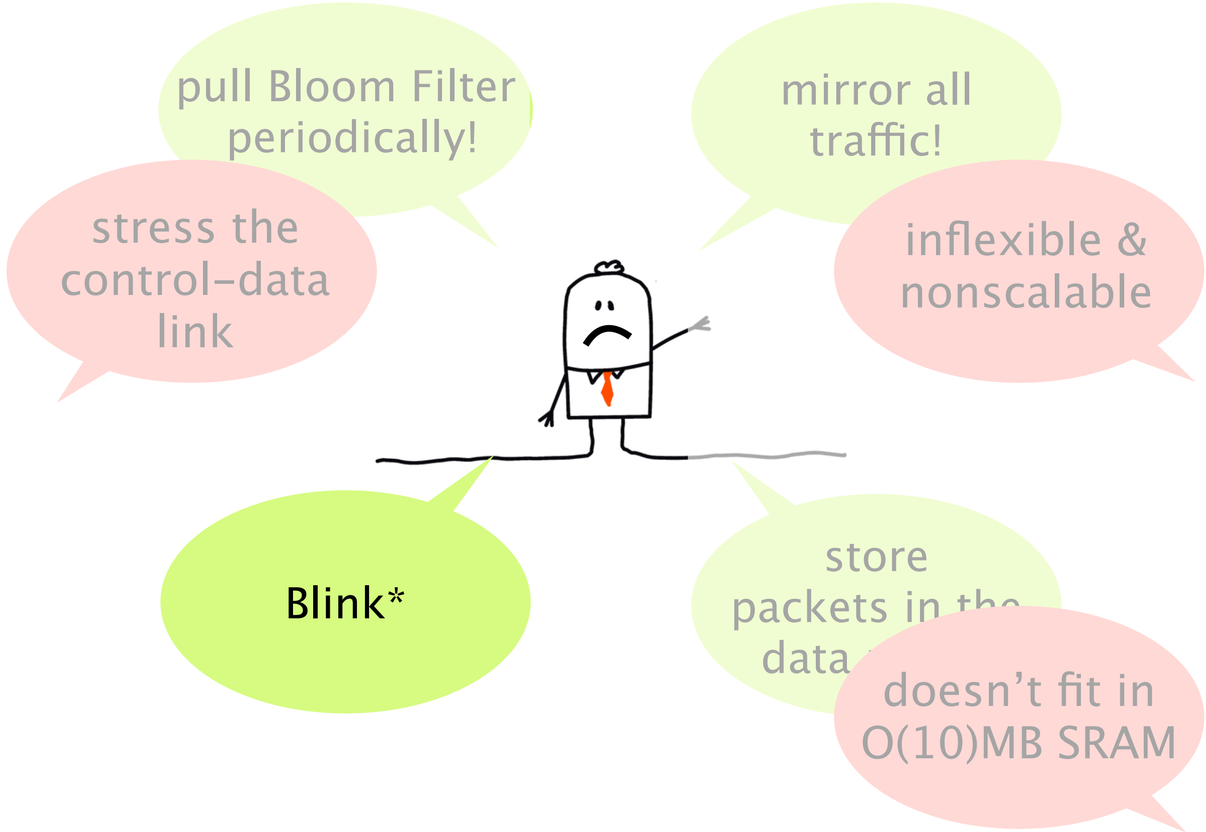

*Holterbach et. al, NSDI '19

Blink: Fast Connectivity Recovery Entirely in the Data Plane

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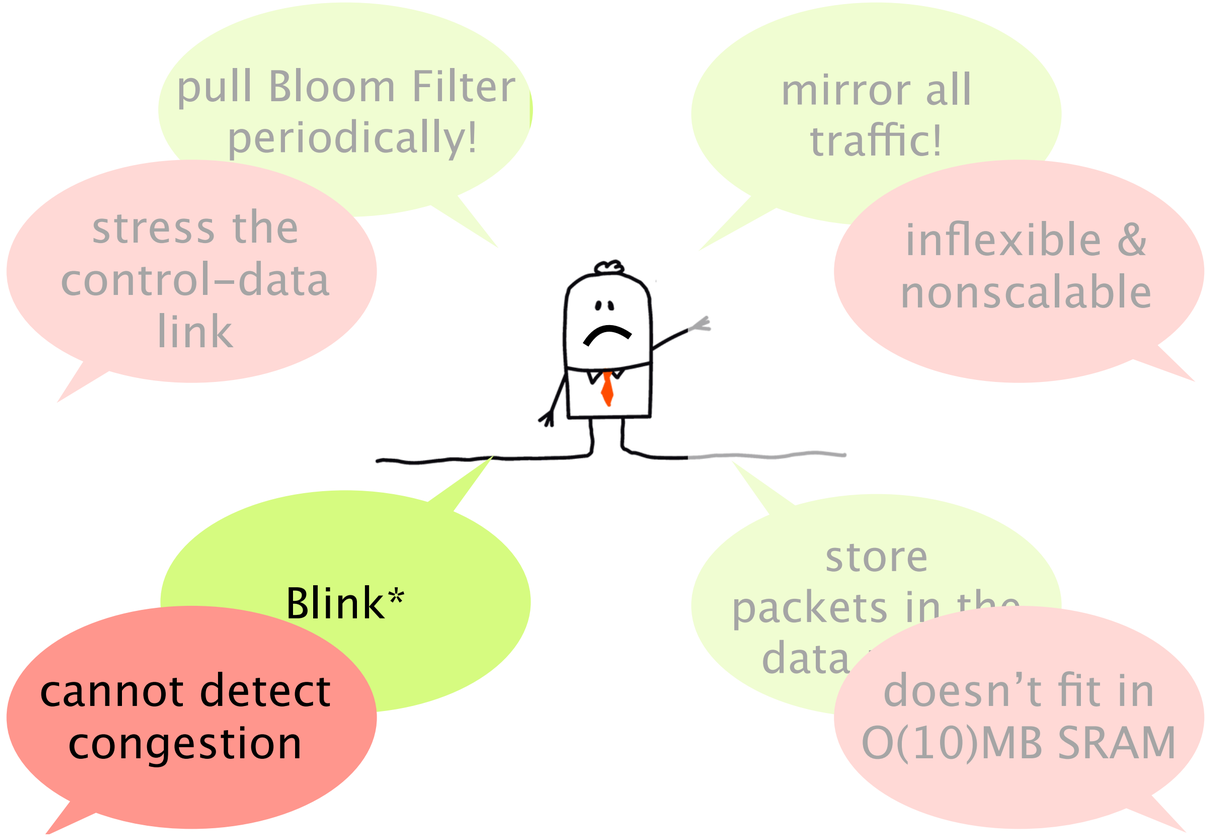

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The Loss Monitor…

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To measure loss uses a Count Min Sketch and an Aggregator

Count Min Sketch	
1	
2	
3	
4	
5	
6	
7	
8	

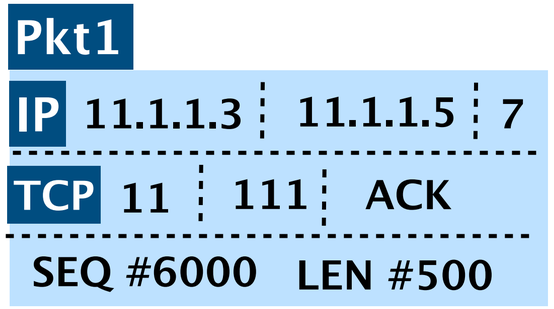
Loss Aggregator		
Prefix, NextHop	Expected	Lost
C,A		
C, B		

The Loss monitor uses a Count Min Sketch to detect retransmissions

	Count Min Sketch
1	0
2	0
3	1
4	2
5	0
6	0
7	0
8	0

Each non-empty packet, say Pkt1,

triggers the insertion of the next expected one to the CMS



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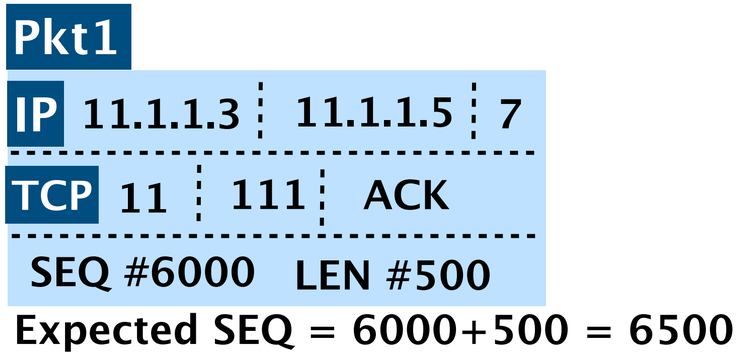

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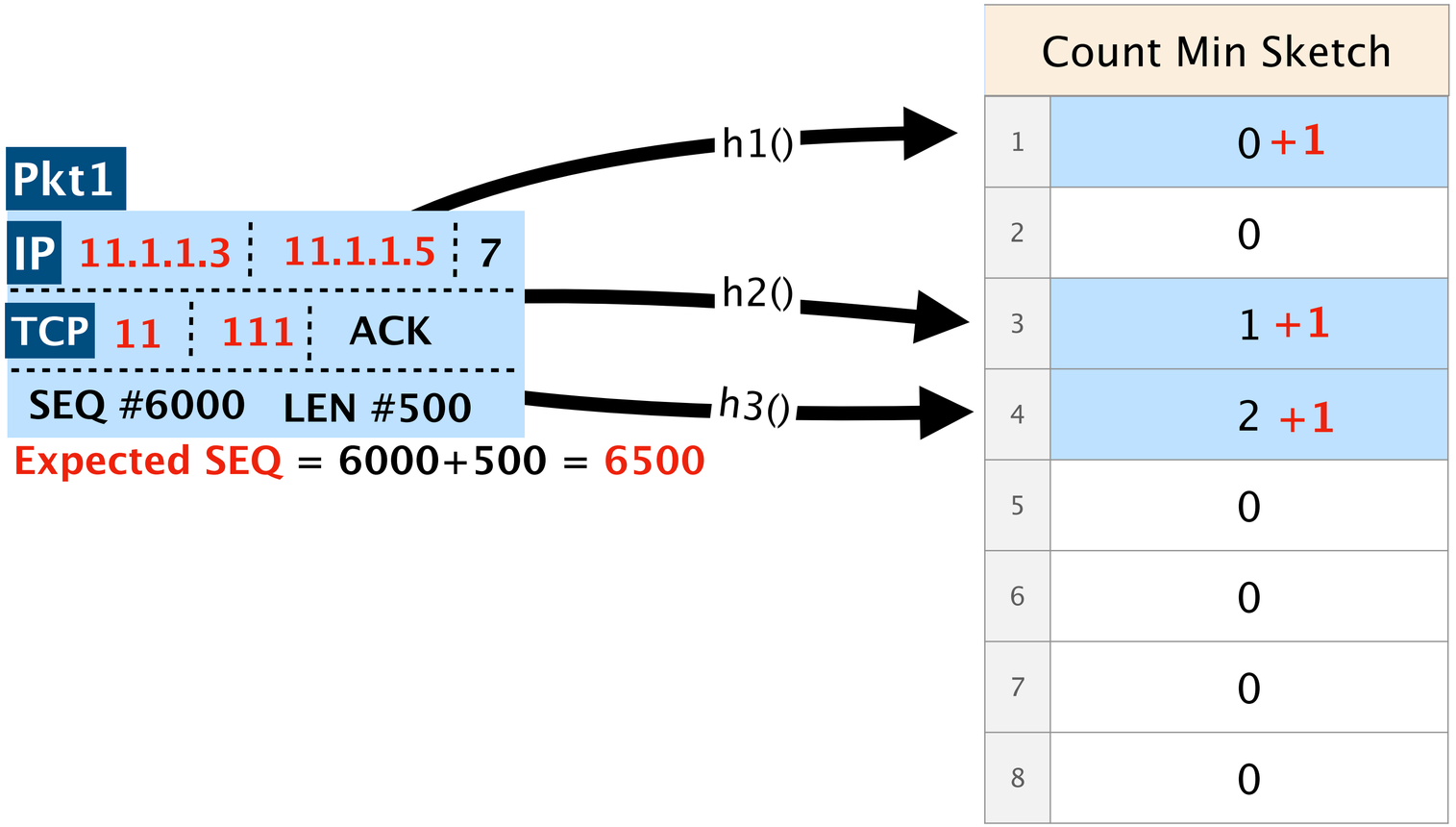
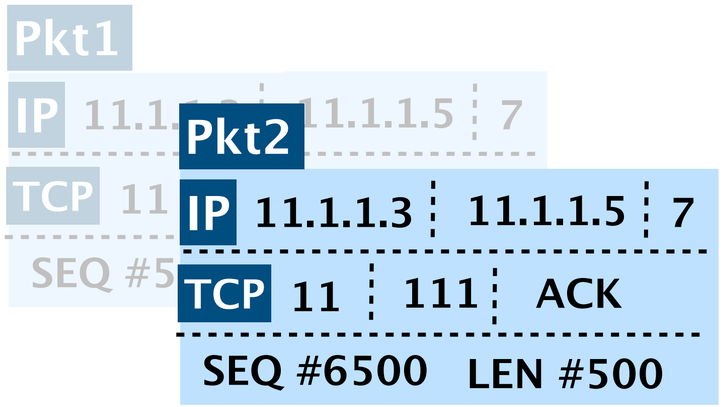


Step 1: Pkt2 arrives, it verifies that it is expected



Count Min Sketch	
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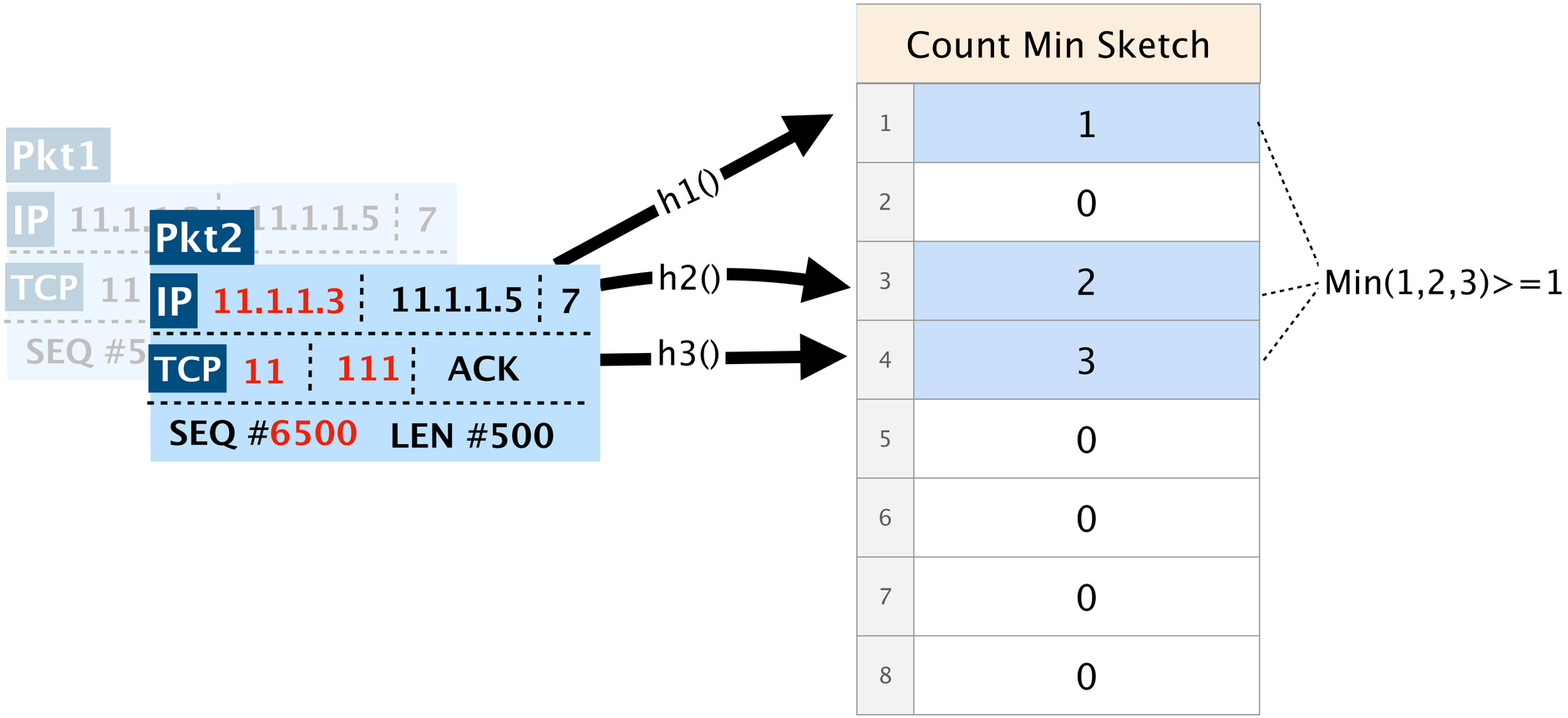
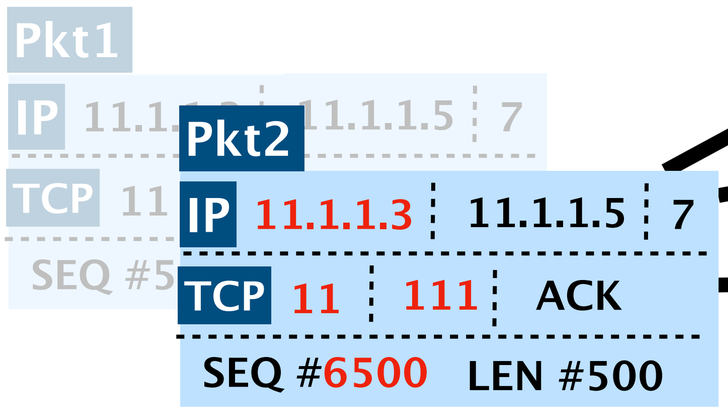
6	0
7	0
8	0

Step 1: Pkt2 arrives, it verifies that it is expected



Step 2: Pkt2 triggers an update in the Loss Aggregator



h1()

h2()

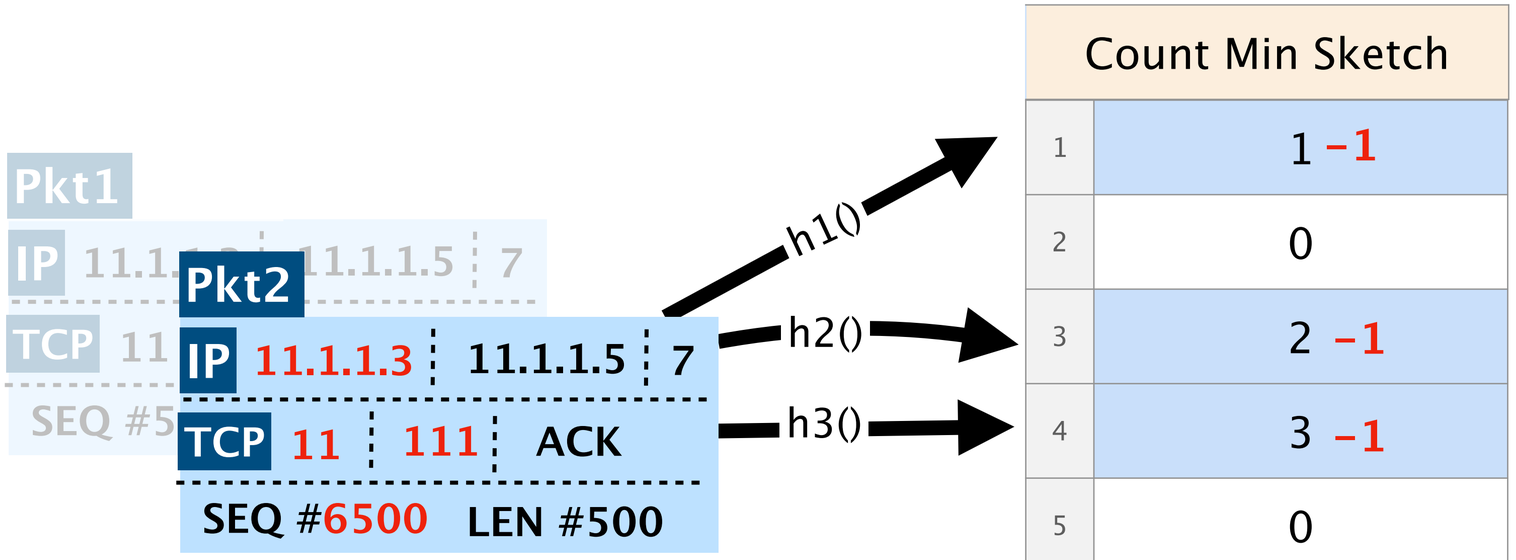
h3()

Count Min Sketch	
1	1
2	0
3	2
4	3
5	0
6	0
7	0
8	0

Min(1,2,3)>=1

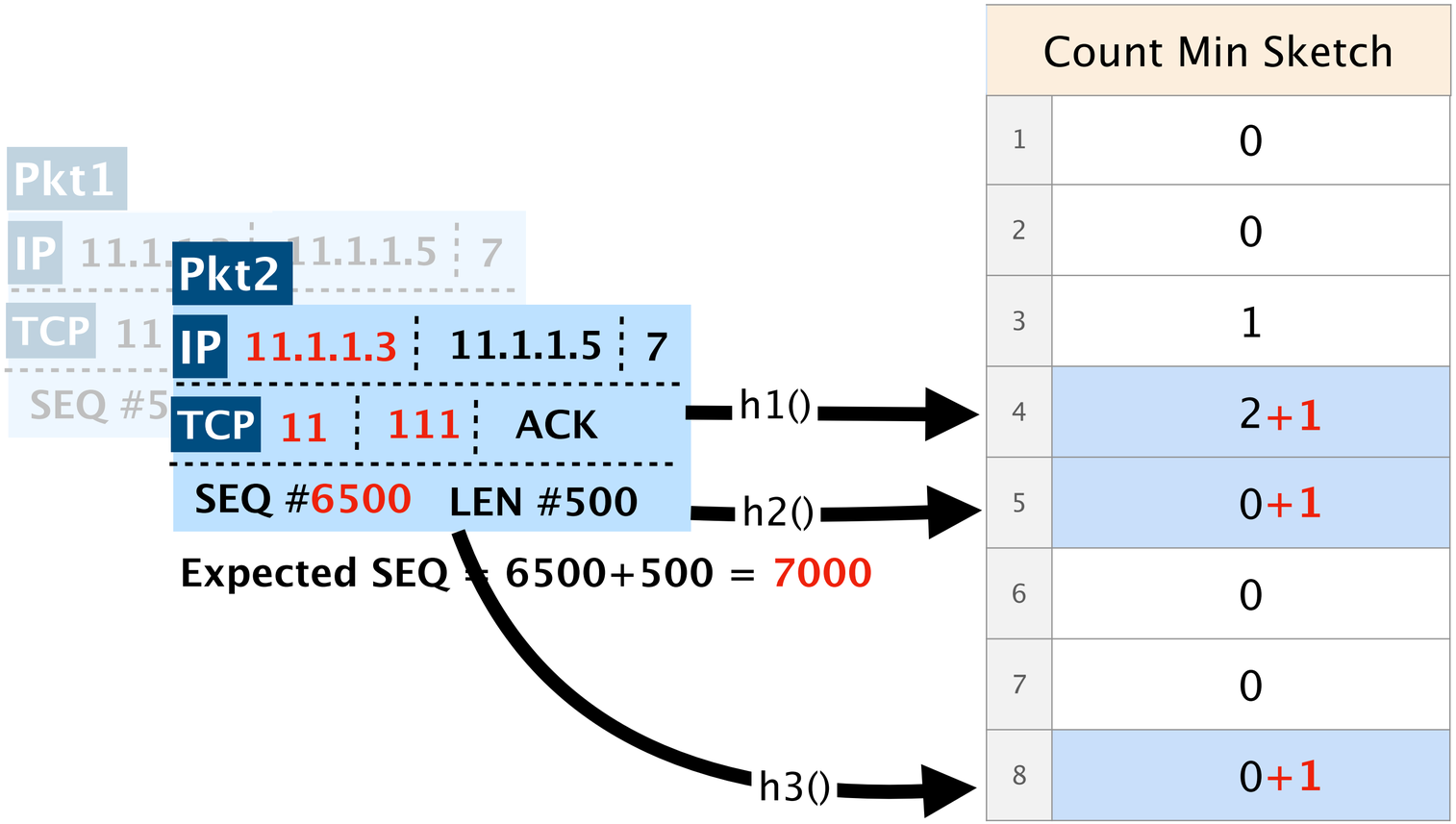
Loss Aggregator		
Prefix, NextHop	Expected	Lost
C,A	12+1	2
C, B	0	0

Step 3: Pkt2 cleans the filters



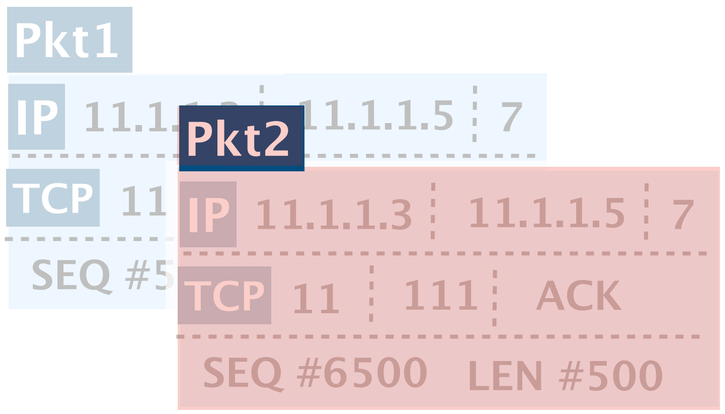
Count Min Sketch	
1	1 -1
2	0
3	2 -1
4	3 -1
5	0
6	0
7	0
8	0

Step 4: Pkt2 triggers the insertion the next expected packet, Pkt3



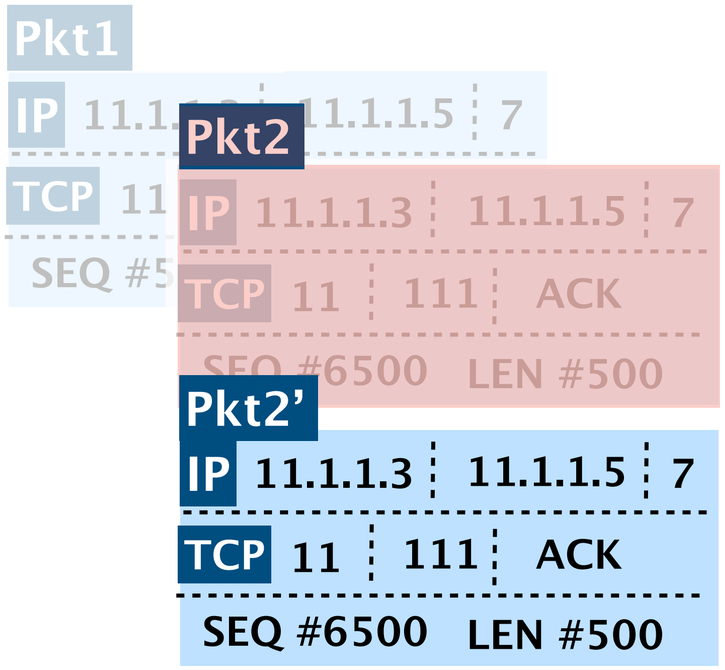
Count Min Sketch	
1	0
2	0
3	1
4	2+1
5	0+1
6	0
7	0
8	0+1

If Pkt2 is lost, it will be retransmitted



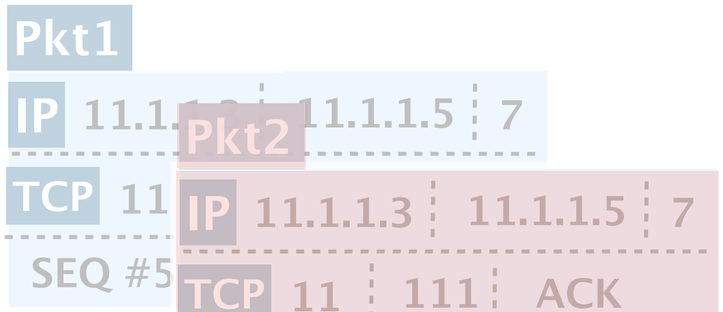
Count Min Sketch	
1	0
2	0
3	1
4	3
5	1
6	0
7	0
8	1

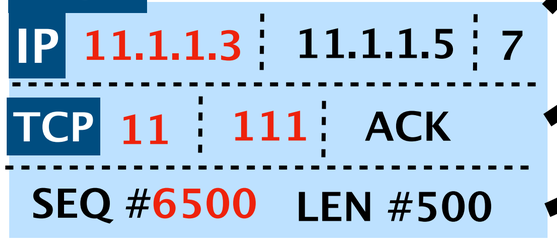
If Pkt2 is lost, it will be retransmitted

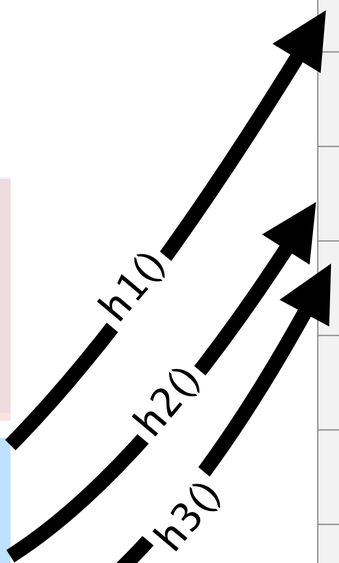


Count Min Sketch	
1	0
2	0
3	1
4	3
5	1
6	0
7	0
8	1

The retransmitted packet, Pkt2', will find that it is not expected





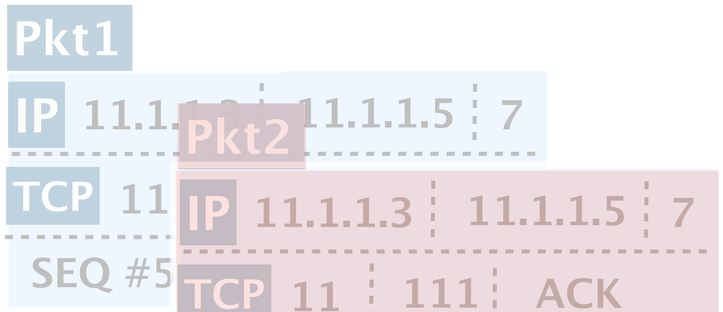


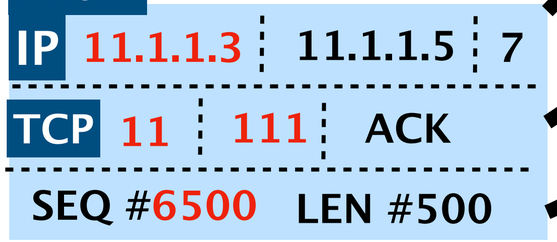
Count Min Sketch	
1	0
2	0
3	1
4	3
5	1
6	0
7	0
8	1

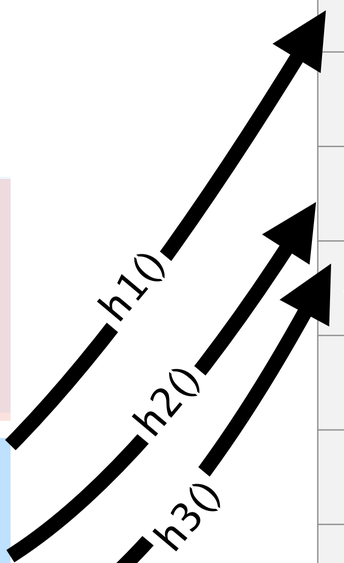
Min(3,1,1)>=1

Loss Aggregator		
Prefix, NextHop	Expected	Lost
C,A	13	2
C, B	0	0

The retransmitted packet, Pkt2', will find that it is not expected







Count Min Sketch	
1	0
2	0
3	1
4	3
5	1
6	0
7	0
8	1

Loss Aggregator		
Prefix, NextHop	Expected	Lost
C,A	13	2 +1
C, B	0	0

RouteScout: Performance-Driven Internet Path Selection

RouteScout Operations

RouteScout Architecture

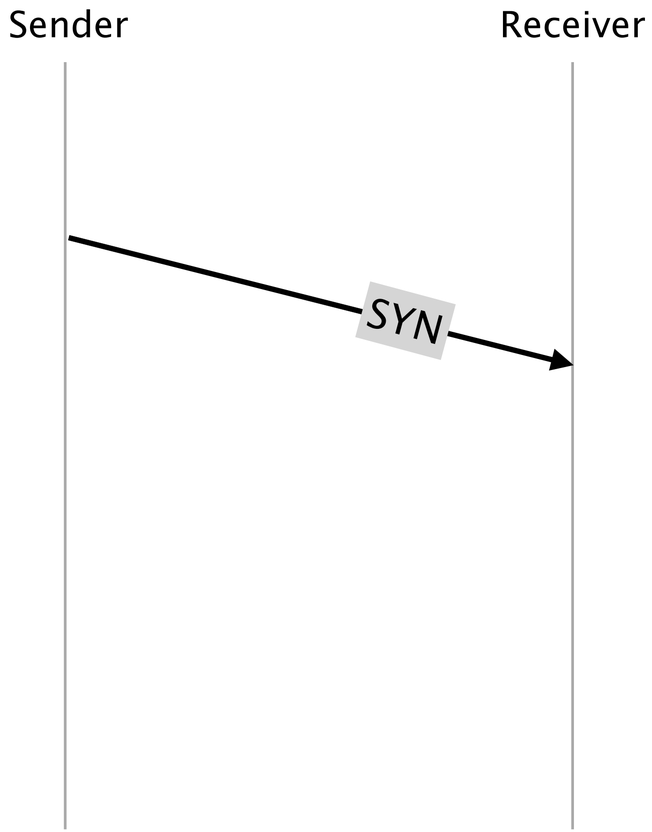
Data-Plane Design

- Loss Monitor
- Delay Monitor

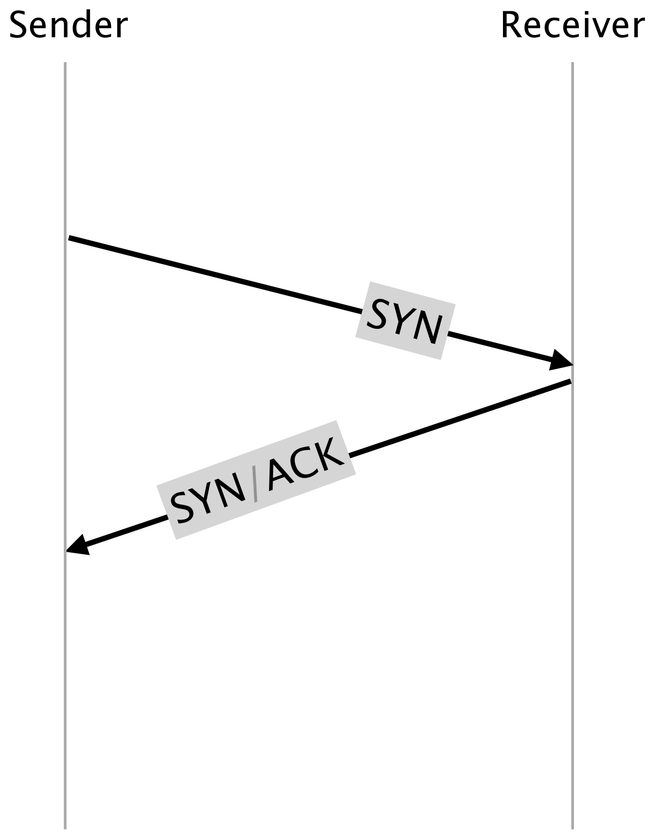
Evaluation

RouteScout measures delay by measuring the difference between SYN-ACK

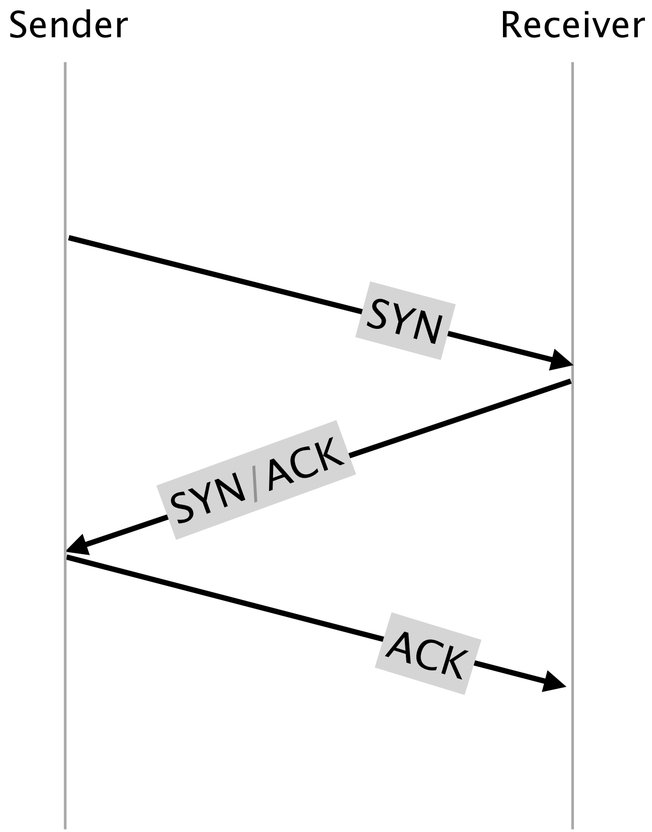
RouteScout measures delay by measuring the difference between SYN-ACK



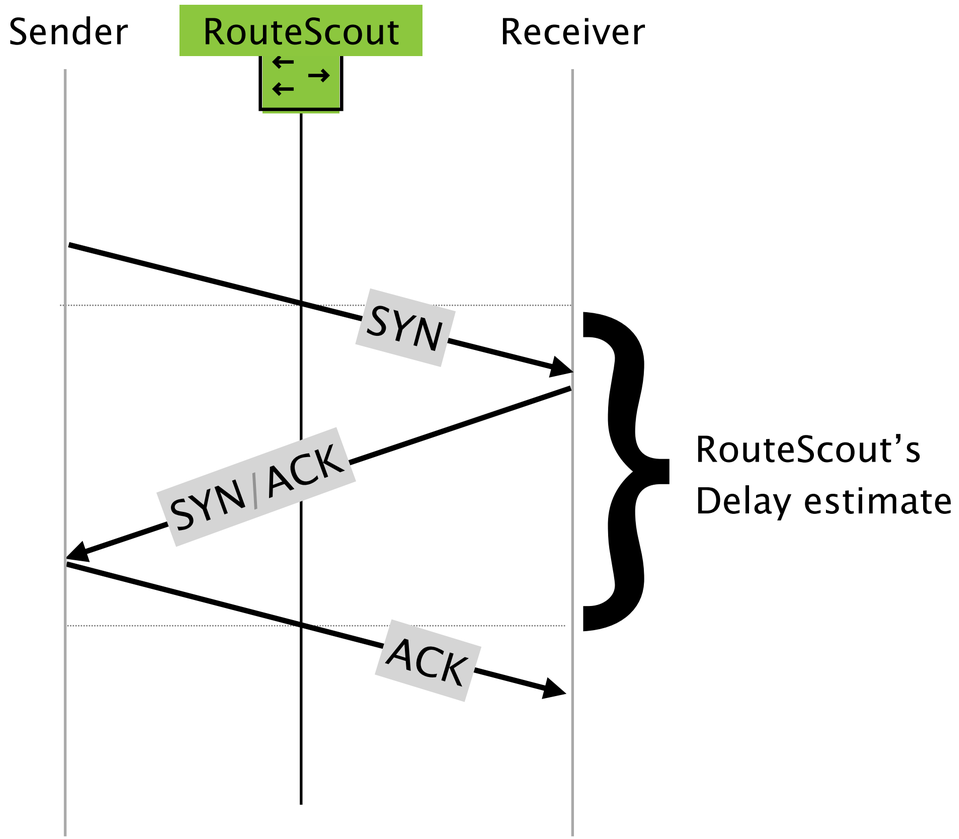
RouteScout measures delay by measuring the difference between SYN-ACK



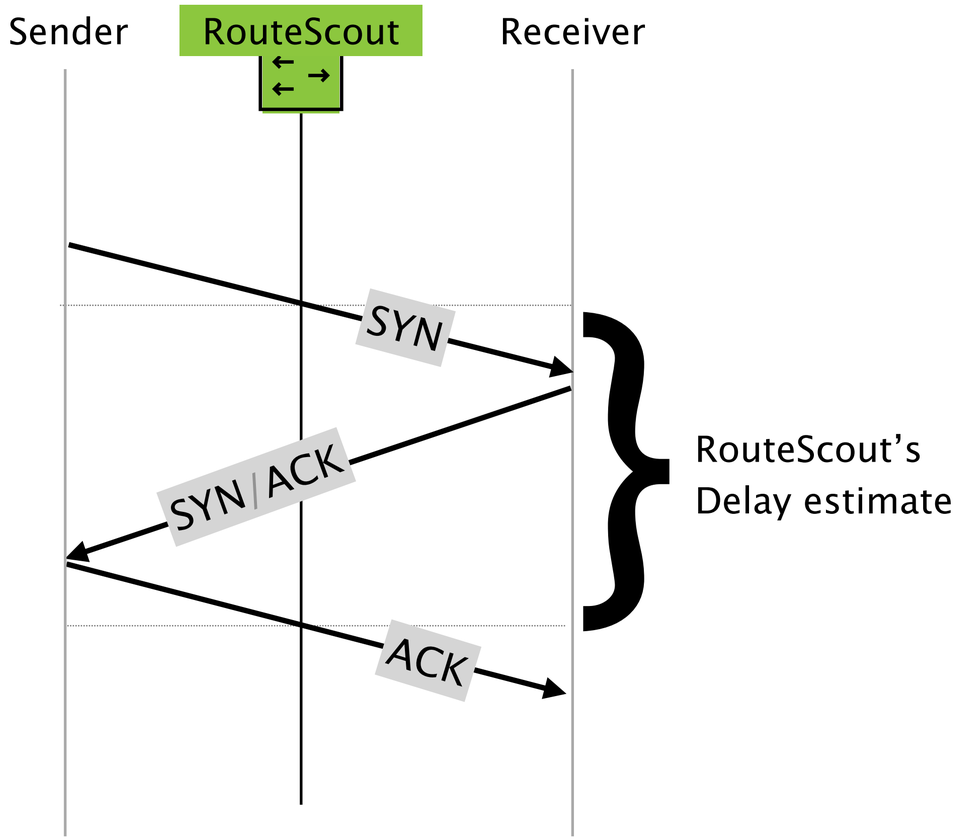
RouteScout measures delay by measuring the difference between SYN-ACK



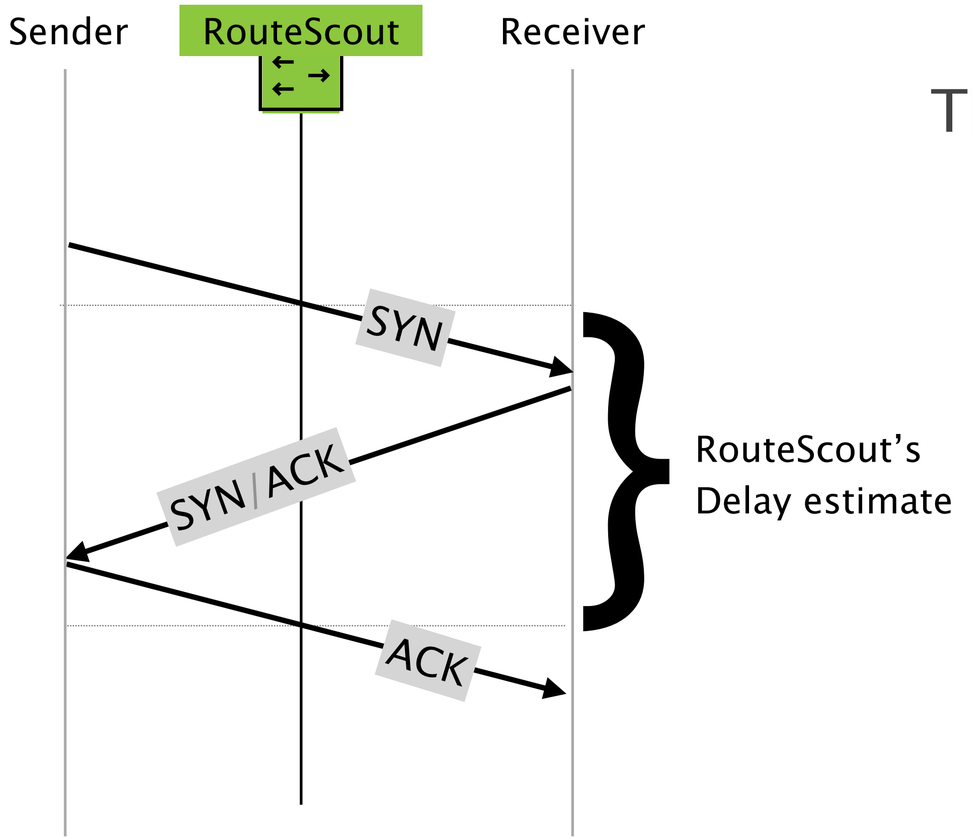
RouteScout measures delay by measuring the difference between SYN-ACK



RouteScout measures delay by measuring the difference between SYN-ACK



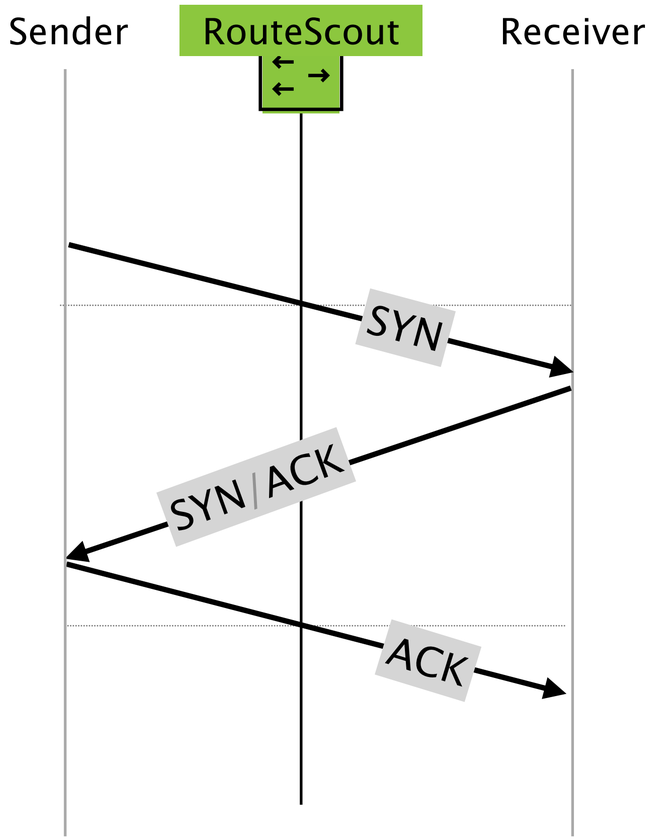
RouteScout measures delay by measuring the difference between SYN-ACK



The Delay Monitor…

does not require bidirectional traffic

RouteScout measures delay by measuring the difference between SYN-ACK



The Delay Monitor…

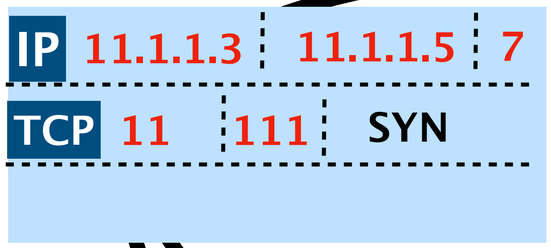
- does not require bidirectional traffic
- performs monitoring in the data plane
- performs aggregation in the data plane

To measure delay uses an Invertible Bloom Filter and an Aggregator

	Accumulator	CNT
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0

Delay Aggregator		
Prefix, NextHop	Sum Delays	# Delays

Upon arrival of a SYN packet its timestamp (T1) is XORed to multiple indexes



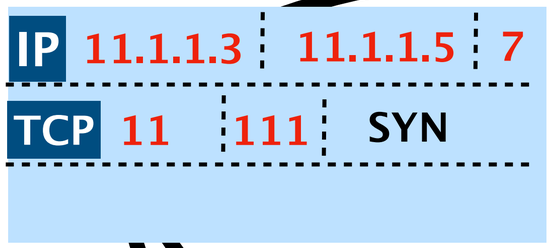
h1(5-tuple)

h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	$0 \oplus T1$	0
2	0	0
3	0	0
4	0	0
5	$0 \oplus T1$	0
6	$0 \oplus T1$	0
7	0	0
8	0	0

Upon arrival of a SYN packet the corresponding counters increase by one



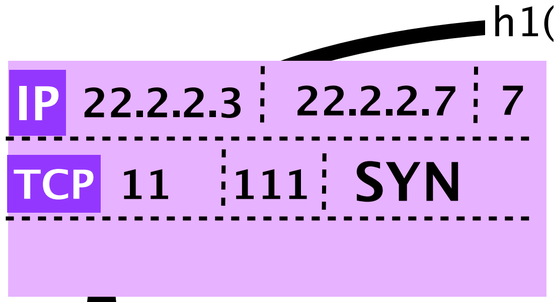
h1(5-tuple)

h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	T_1	0+1
2	0	0
3	0	0
4	0	0
5	T_1	0+1
6	T_1	0+1
7	0	0
8	0	0

Similar updates happen for each SYN packets



h1(5-tuple)

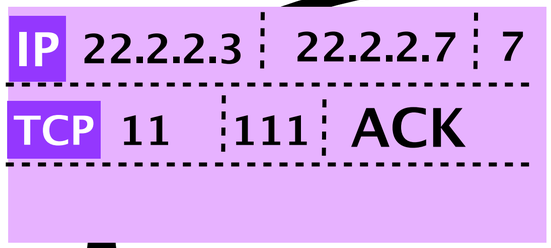
h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	$T1 \oplus T2$	2
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T_1 \oplus T_2$	2
7	0	0
8	$0 \oplus T2$	1

Upon arrival of an ACK Packet one of the indexes

Contains an unpolluted timestamp of the corresponding SYN



h1(5-tuple)

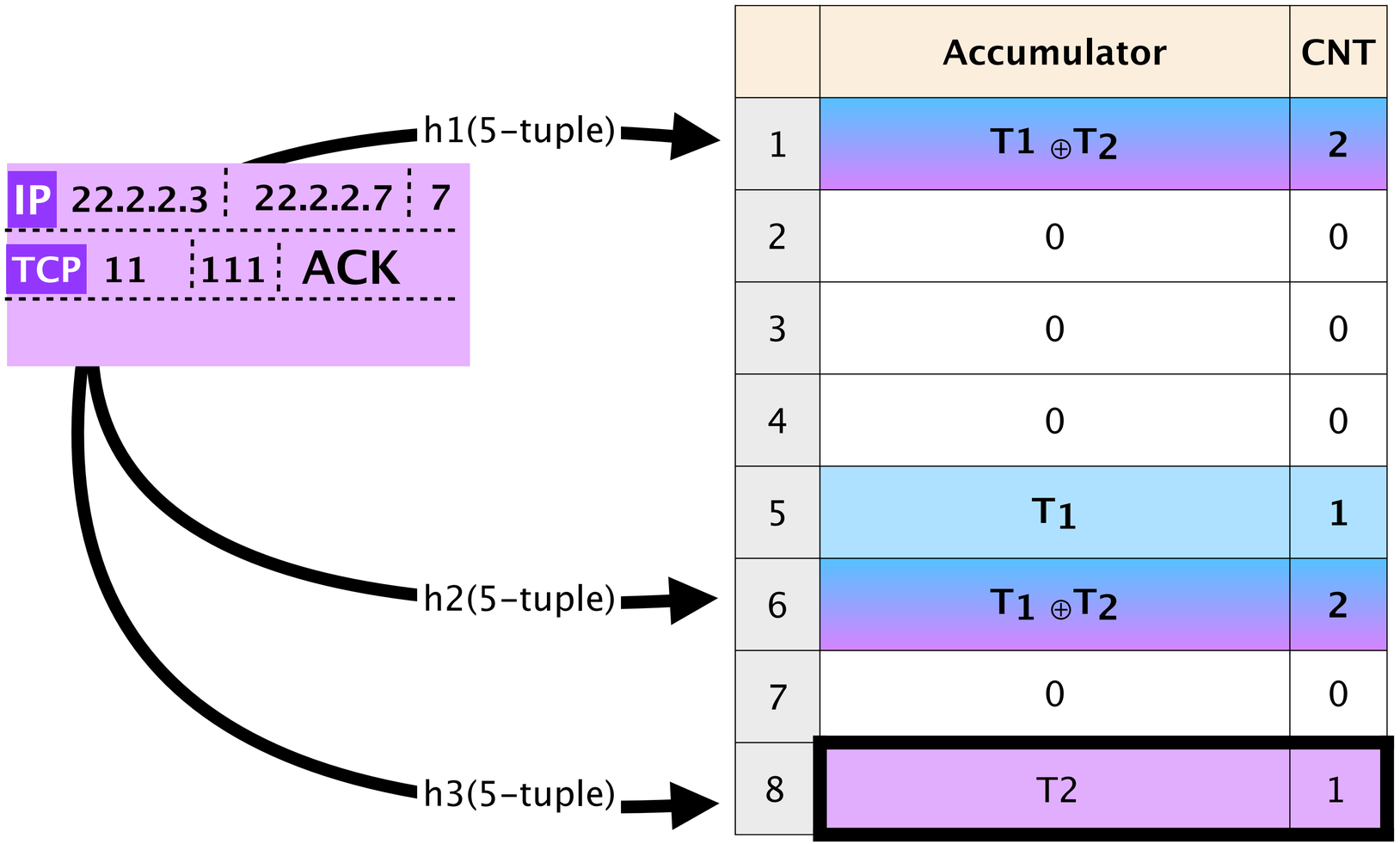
h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	$T1 \oplus T2$	2
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T_1 \oplus T_2$	2
7	0	0
8	T2	1

Upon arrival of an ACK Packet one of the indexes

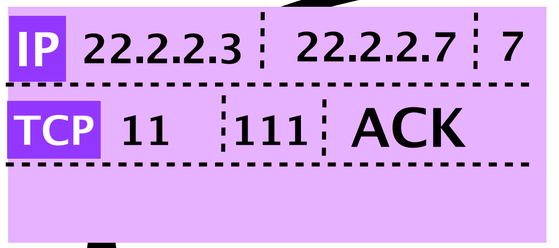
Contains an unpolluted timestamp of the corresponding SYN



	Accumulator	CNT
1	$T1 \oplus T2$	2
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T_1 \oplus T_2$	2
7	0	0
8	T2	1

Upon arrival of an ACK Packet one of the indexes

Contains an unpolluted timestamp of the corresponding SYN



h1(5-tuple)

h2(5-tuple)

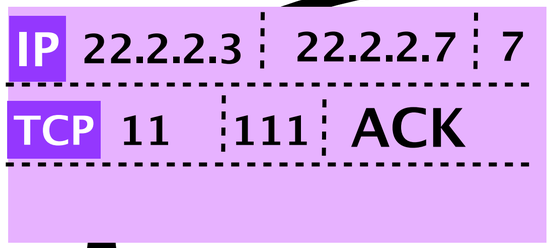
h3(5-tuple)

	Accumulator	CNT
1	$T1 \oplus T2$	2
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T_1 \oplus T_2$	2
7	0	0
8	T2	1

delay=Tack-Tsyn= T2-T3

Upon arrival of an ACK Packet one of the indexes

Contains an unpolluted timestamp of the corresponding SYN



h1(5-tuple)

h2(5-tuple)

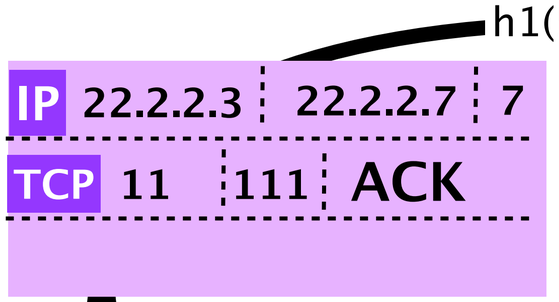
h3(5-tuple)

	Accumulator	CNT
1	$T1 \oplus T2$	2
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T1 \oplus T2$	2
7	0	0
8	T2	1

Delay Aggregator		
Prefix, NextHop	Sum Delays	# Delays
A	+=(T3-T2)	+=1
B		

delay=Tack-Tsyn= T3-T2

By XORing the timestamp to all indexes and the counters by one the IBF is cleared

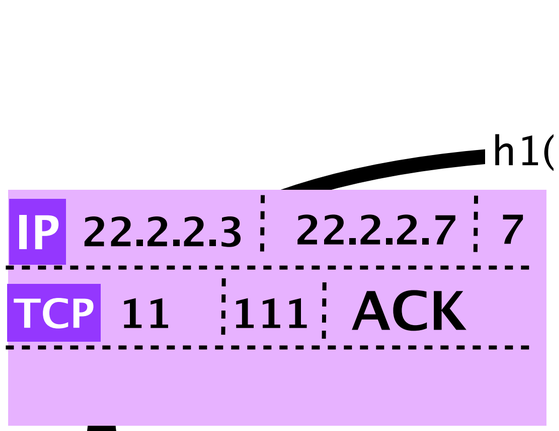


h1(5-tuple)

h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	$T1 \oplus T2 \oplus T2 = T1$	2-1
2	0	0
3	0	0
4	0	0
5	T_1	1
6	$T_1 \oplus T_2 \oplus T_2 = T_1$	2-1
7	0	0
8	$T2 \oplus T2 = 0$	1-1



h1(5-tuple)

h2(5-tuple)

h3(5-tuple)

	Accumulator	CNT
1	T_1	1
2	0	0
3	0	0
4	0	0
5	T_1	1
6	T_1	1
7	0	0
8	0	0

RouteScout: Performance-Driven Internet Path Selection

RouteScout Operations

RouteScout Architecture

Data-Plane Design

Evaluation

RouteScout: Performance-Driven Internet Path Selection

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Evaluation

- Accuracy vs Memory Footprint
- Complexity vs Run Time
- Feasibility

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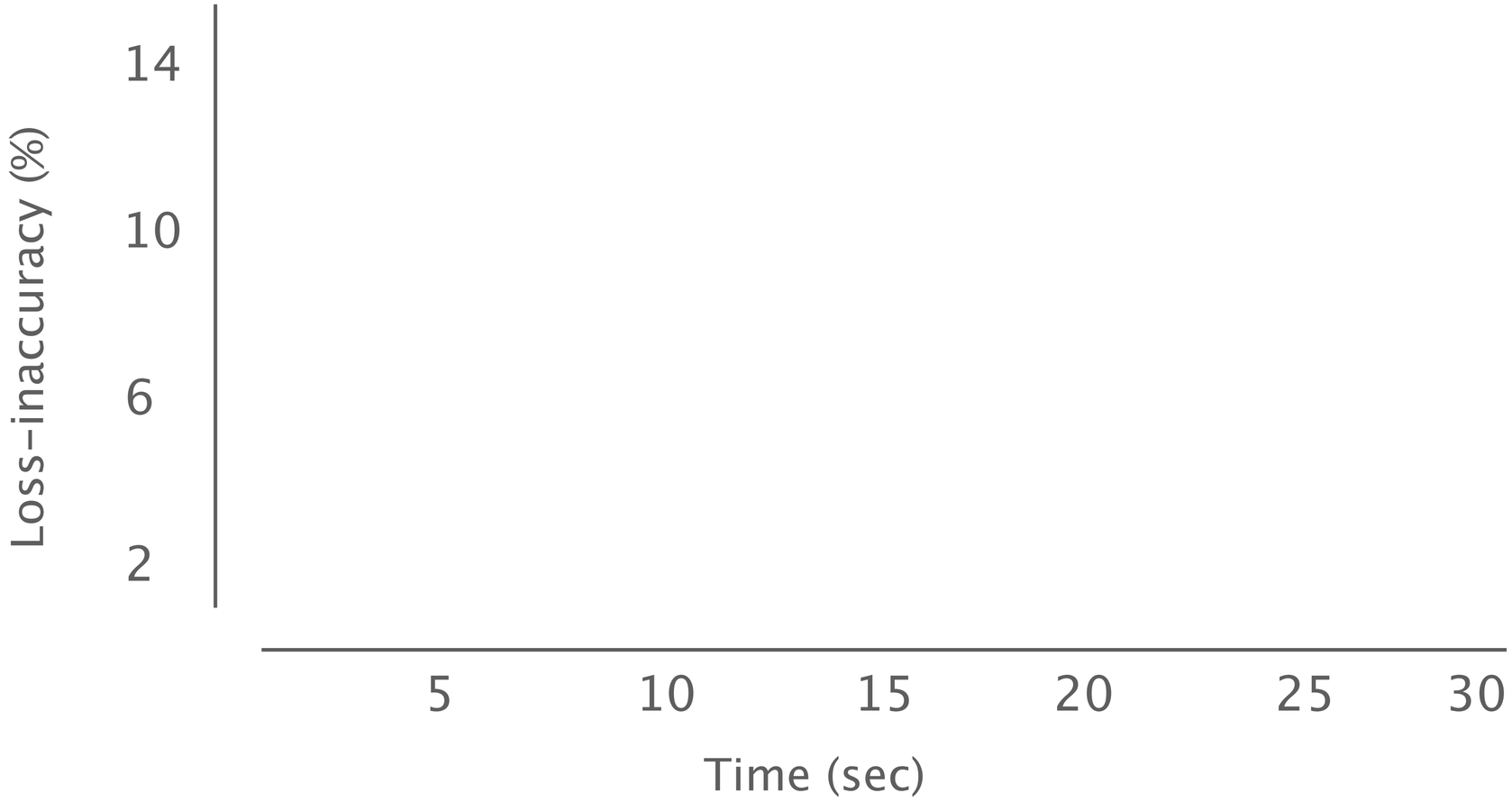
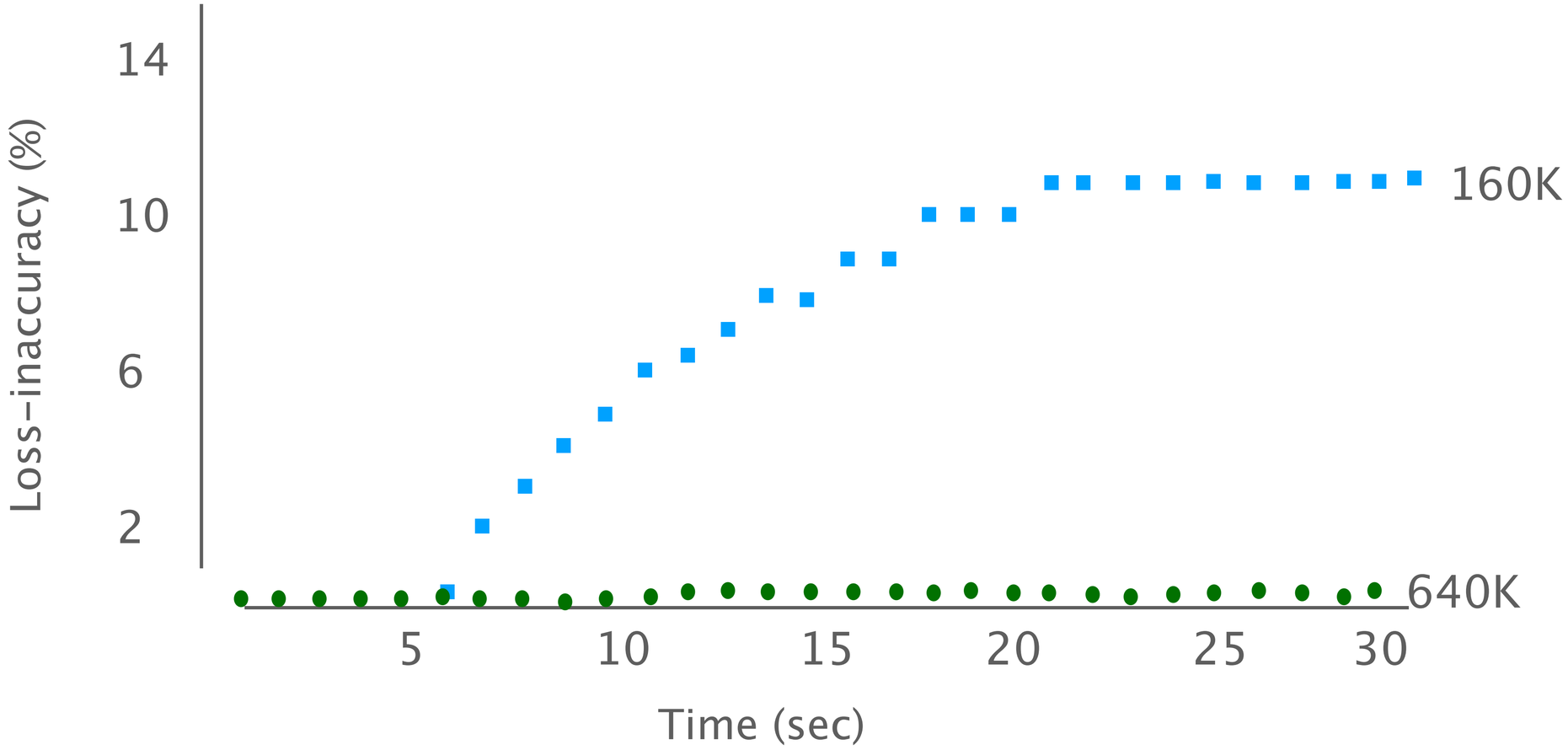
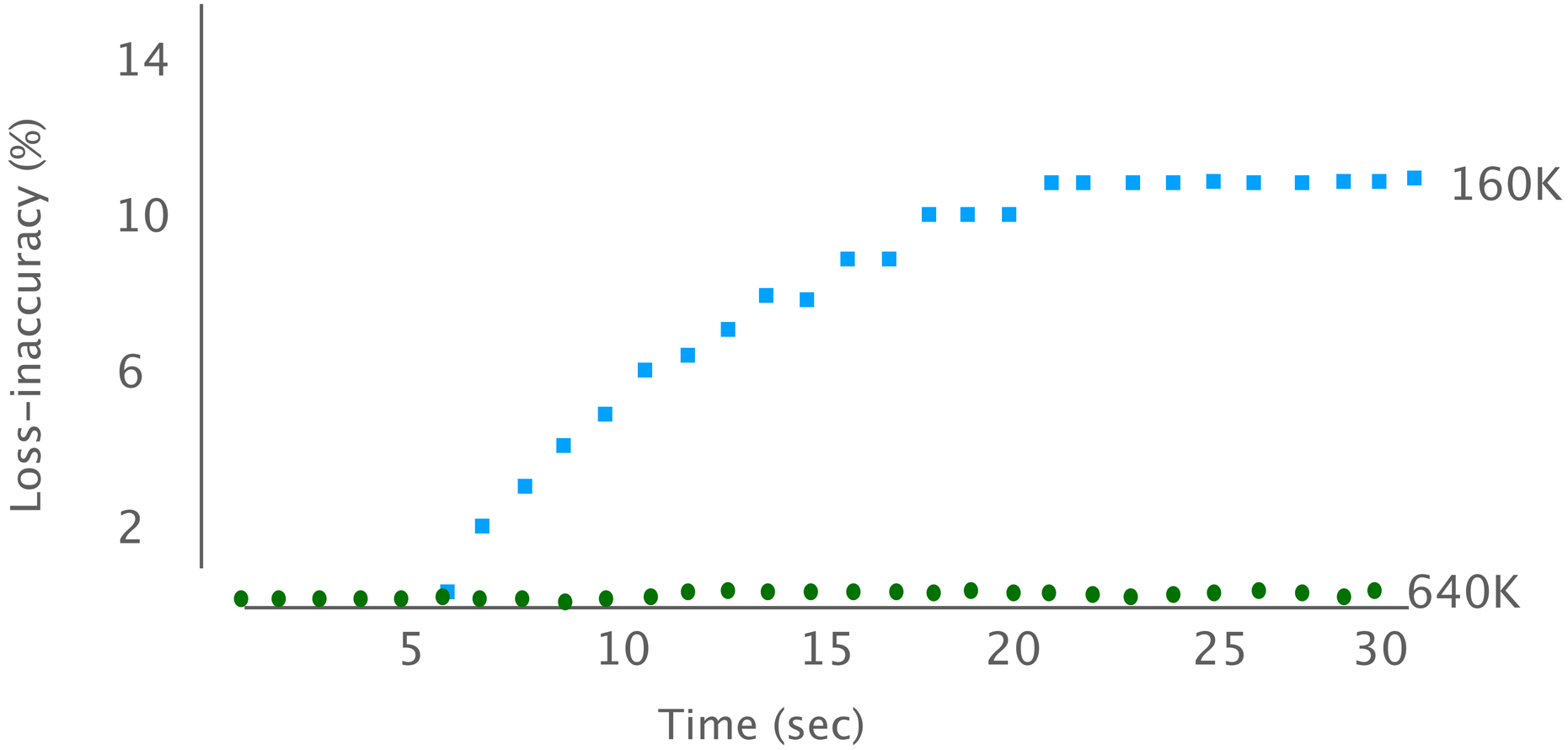
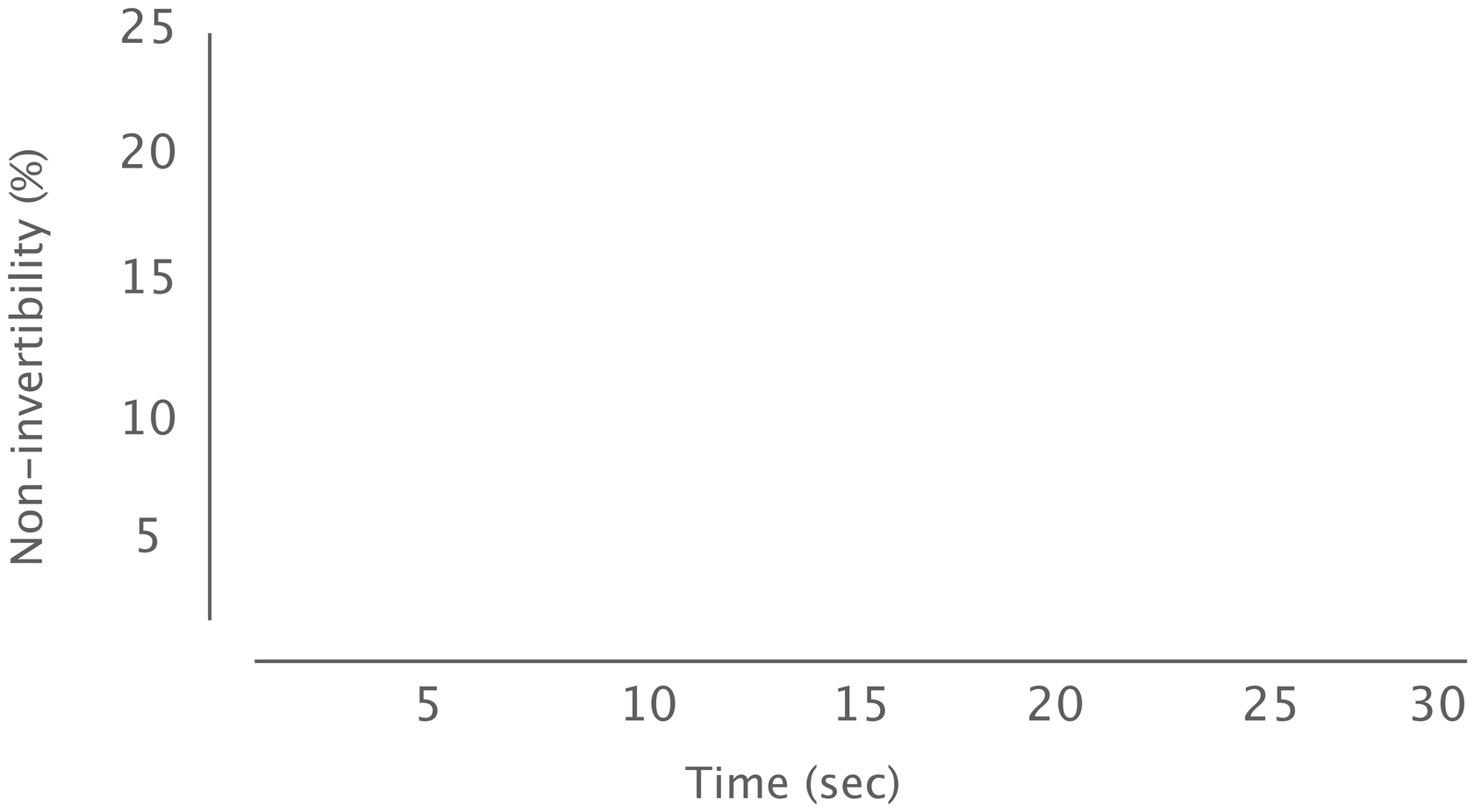

Loss-inaccuracy (%)
14
10
6
2
5
10
15
20
25
30
Time (sec)

Using 625KB (640K elements) and 2 hashes,
the Loss monitor calculates the loss rate with high accuracy

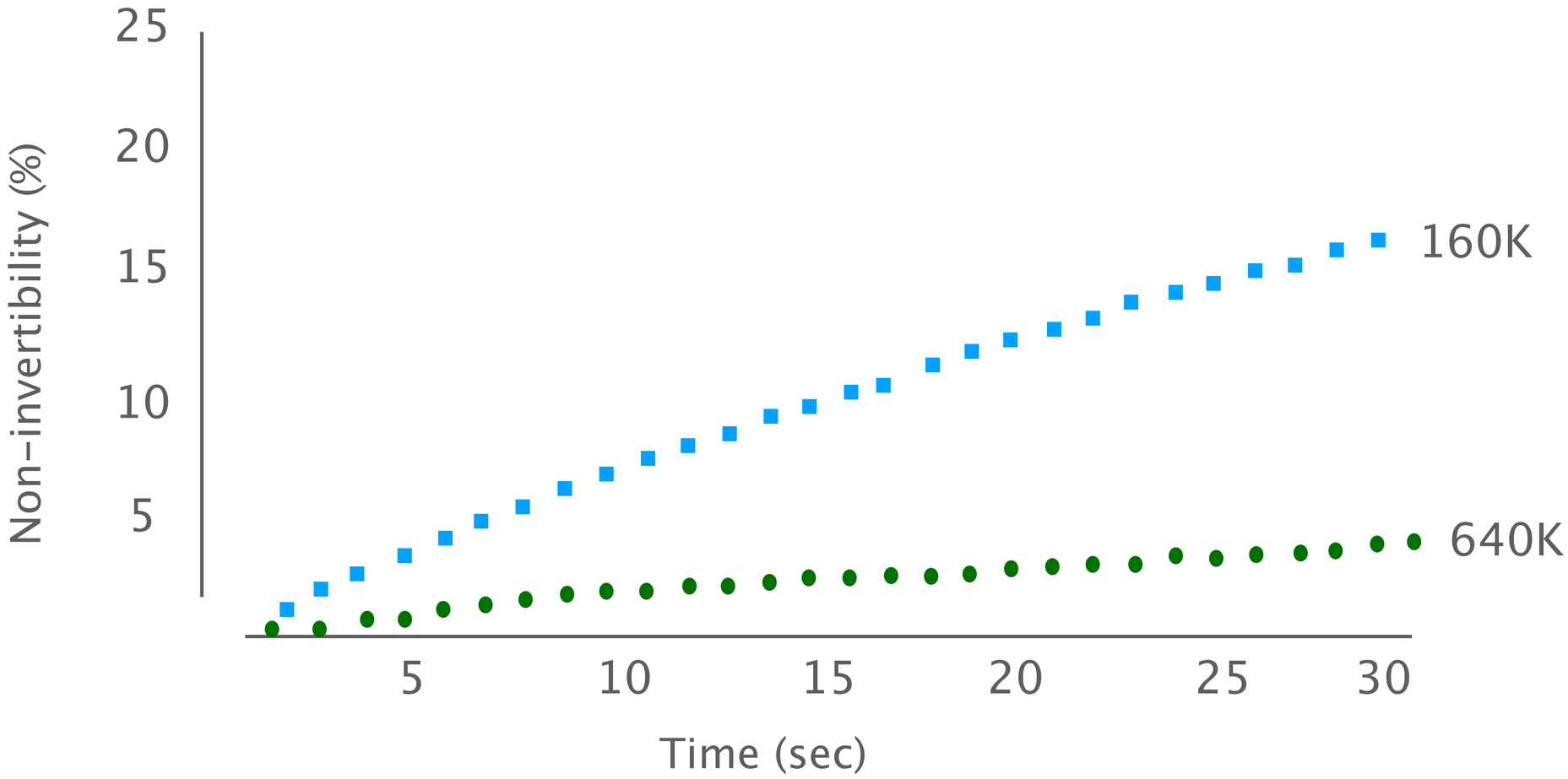


Using 625KB (640K elements) and 2 hashes,
the Loss monitor calculates the loss rate with high accuracy




25
20
15
10
5
Non-invertibility (%)
5
10
15
20
25
30
Time (sec)

The probability of an ACK to decode its SYN's timestamp is >95% with a 1MB (640K elements) delay monitor of 2 hashes



RouteScout: Performance-Driven Internet Path Selection

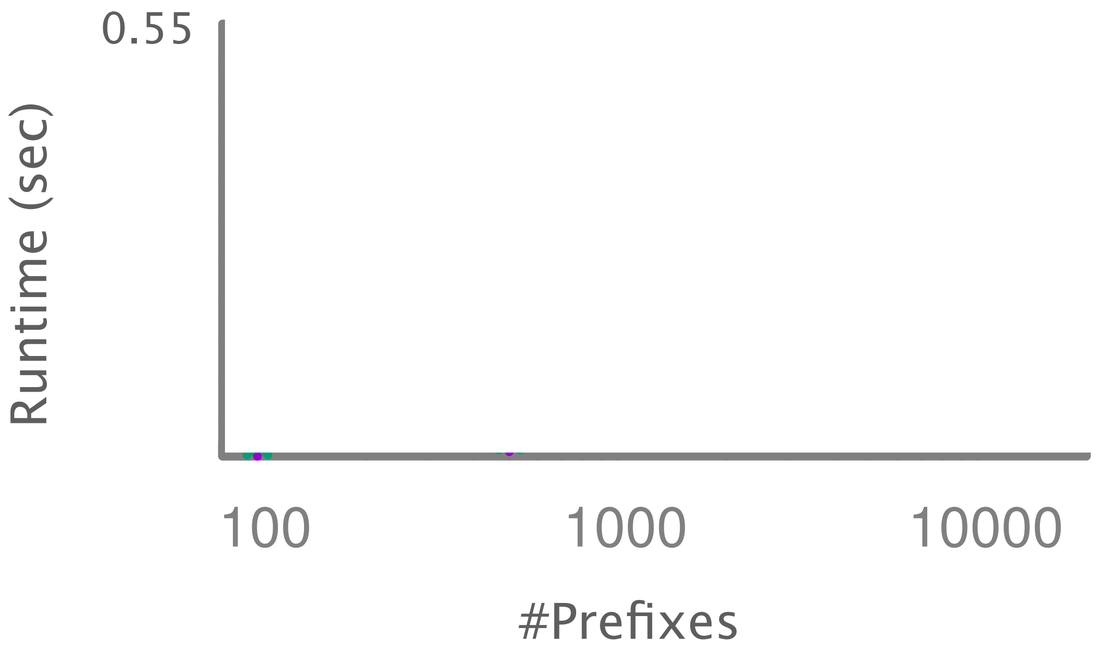
RouteScout Operations

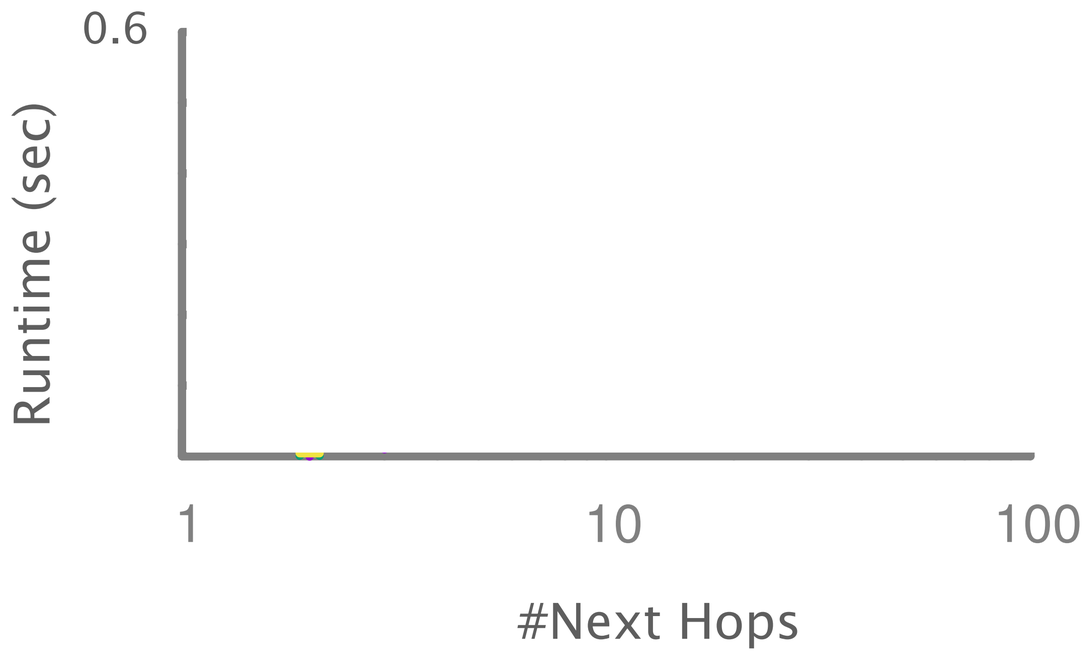
Routescout Architecture

Data-Plane Design

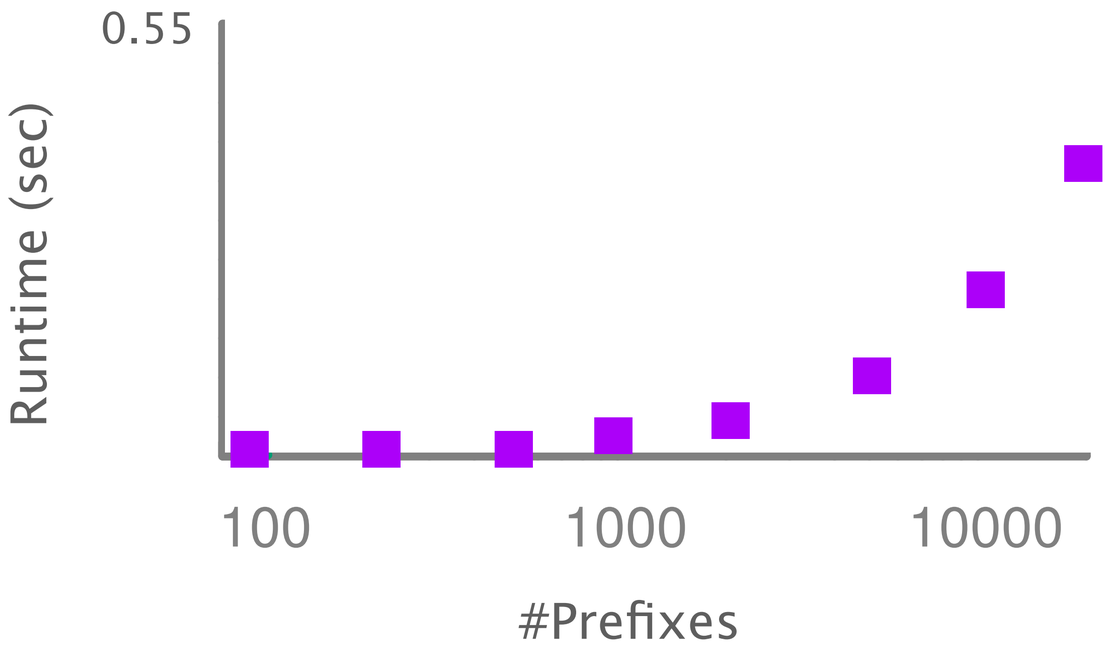
Evaluation

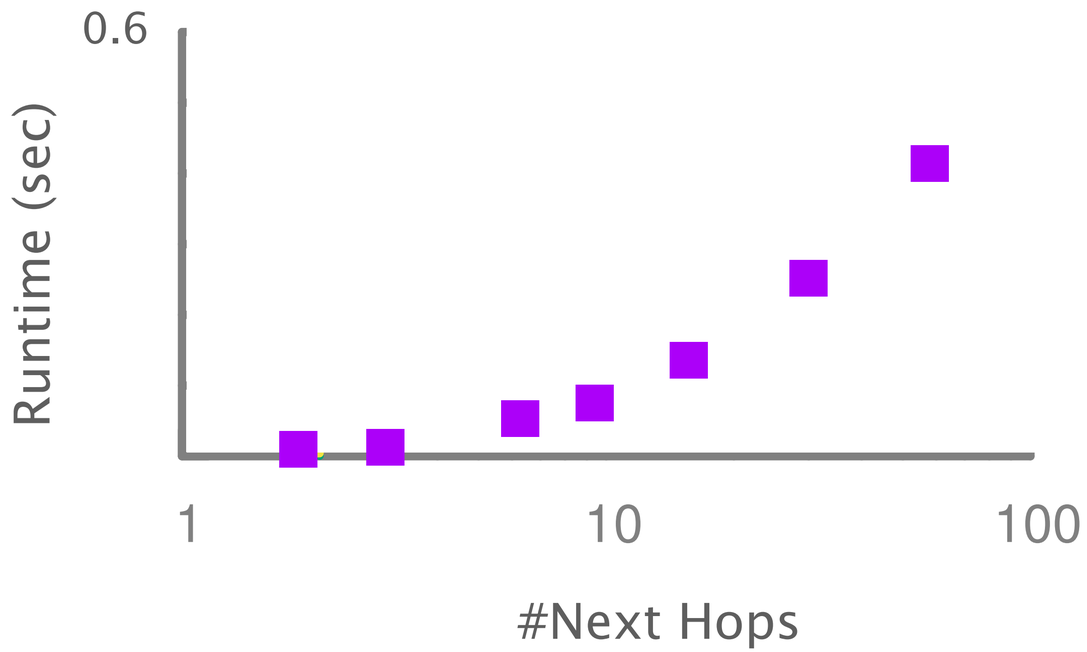
- Accuracy vs Memory footprint
- Complexity vs Run Time
- Feasibility


0.55
Runtime (sec)
100
1000
10000
#Prefixes


0.6
Runtime (sec)
1
10
100
#Next Hops

RouteScout is fast even when run with an increasing number of next hops and destinations





RouteScout: Performance-Driven Internet Path Selection

- RouteScout Operations
- RouteScout Architecture
- Data-Plane Design
- Evaluation
  - Accuracy vs Memory Footprint
  - Complexity vs Run Time
  - Feasibility

RouteScout: Performance-Driven Internet Path Selection

RouteScout Operations

RouteScout Architecture

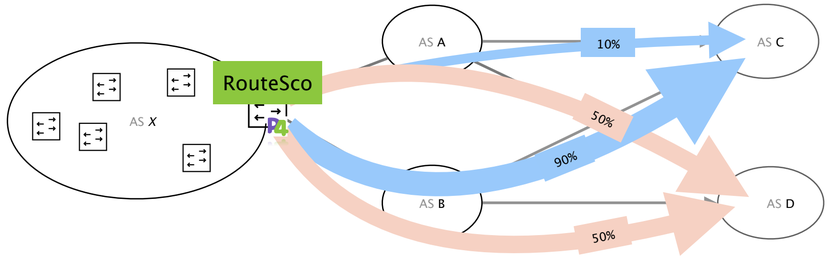
Data-Plane Design

Evaluation

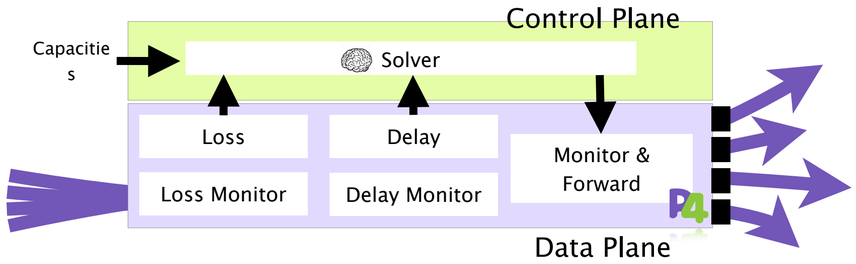
- Accuracy vs Memory Footprint
- Complexity vs Run Time
- Feasibility

RouteScout: Performance-Driven Internet Path Selection

RouteScout is a modern answer to the old problem of performance-aware Internet routing.



RouteScout is a closed-loop control system with hardware and software components that leverages programmable data planes.



RouteScout's data plane fits in today's devices while its control plane runs in sub-second operating times.

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