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Efficient P4-Based BIER Implementation on Tofino

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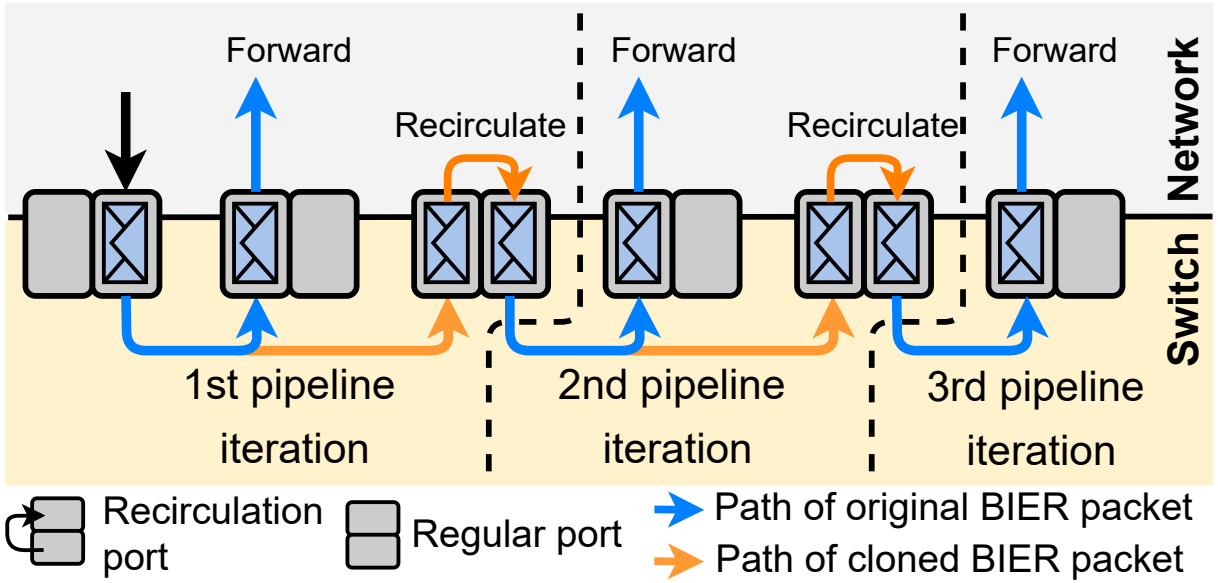
Outline

- Previous Work
- Problem Statement
- Implementation of Efficient BIER in P4
- Optimization

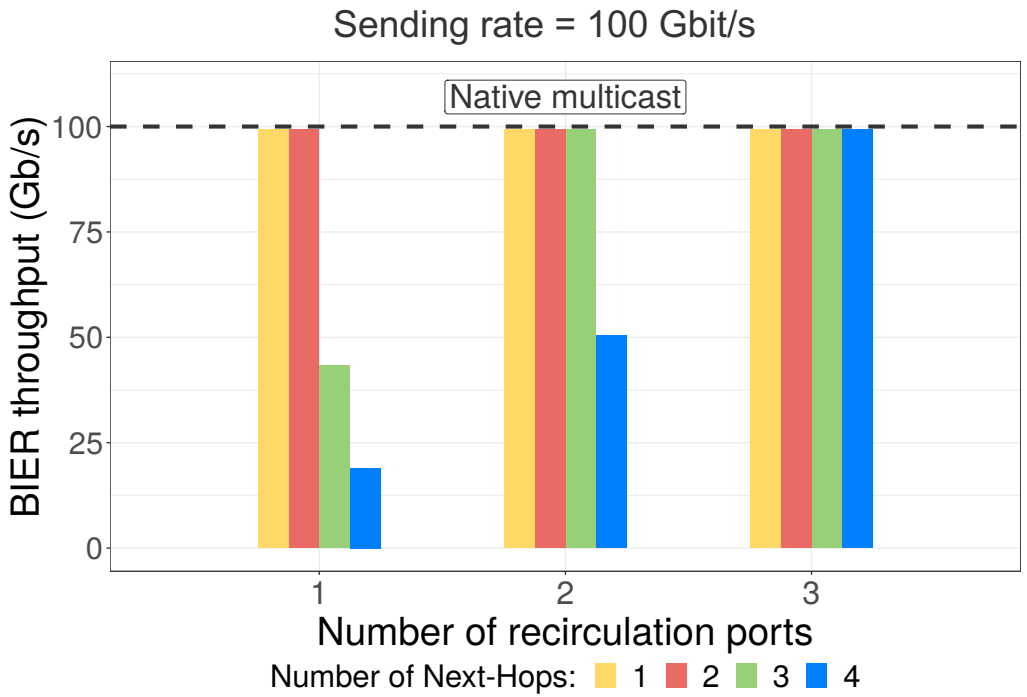
Previous Work (1)

- IETF 108
  - First implementation of BIER & BIER-FRR in P4 @ Intel™ Tofino
  - Iterative processing
    - In each iteration, one next-hop is served



Previous Work (2)

- Caveat
  - Recirculation requires capacity
  - 100 Gbit/s multicast traffic with 5 next-hops results in **400 Gbit/s recirculation traffic**
  - **Solution:** Add dedicated recirculation ports to increase recirculation capacity



Problem Statement

- Goal: Reduce recirculations to improve efficiency

- Idea
  - Determine all next-hops in (possibly) one shot
  - Use a (static) internal multicast group to replicate packets to next-hops

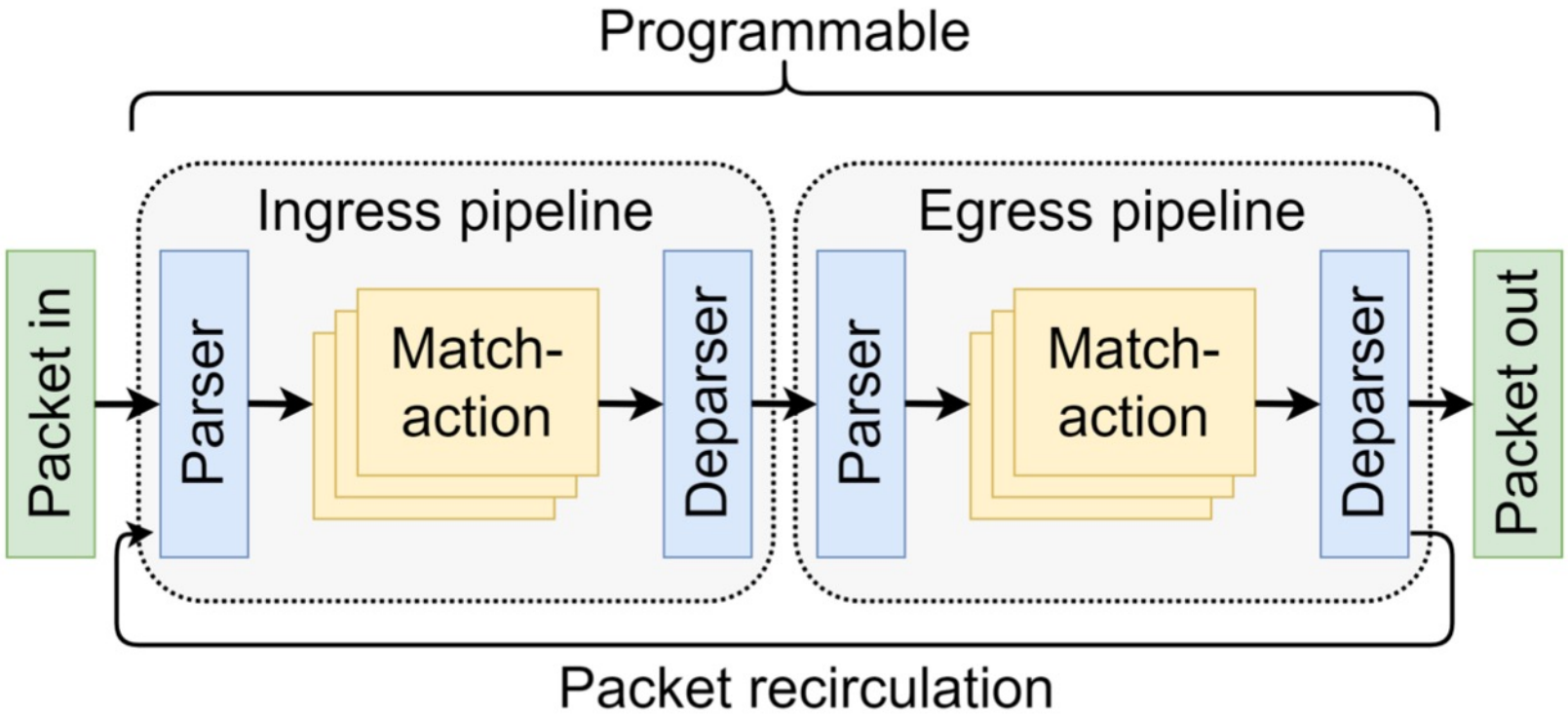
- Challenges
  - BIER bitstrings with 256+ bits difficult to map to the set of packet's next-hops in a single table lookup (without specialized hardware)
  - Limited number of configurable static multicast groups

How can we do this more efficiently?

Efficient Implementation of BIER in P4

P4

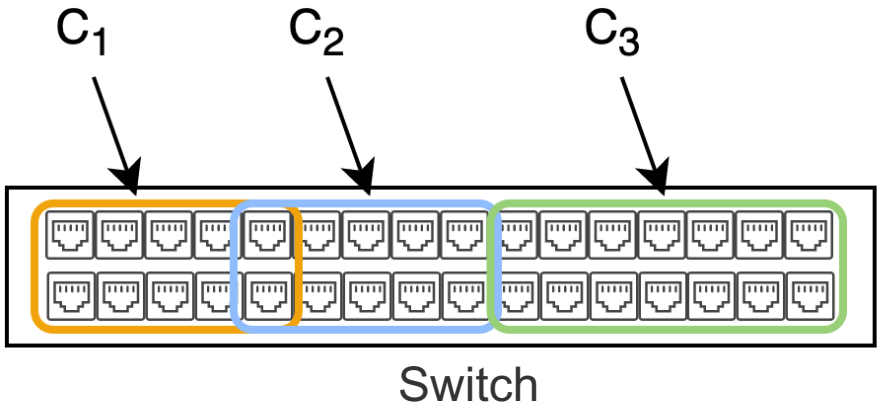
- High-level programming language to describe data plane
  - Compiler maps P4 program onto programmable pipeline of target



Efficient Implementation of BIER in P4 (1)

- Approach
  1. Divide all ports of a switch in *k* so-called *configured port clusters* C_i
  2. Determine which configured port cluster C_i requires a packet copy
     - Possibly iteratively with only a few iterations (like 1-4, not 1-32)
  3. For each chosen configured port cluster C_i, use a suitable (static) multicast group to replicate packet to required next-hops

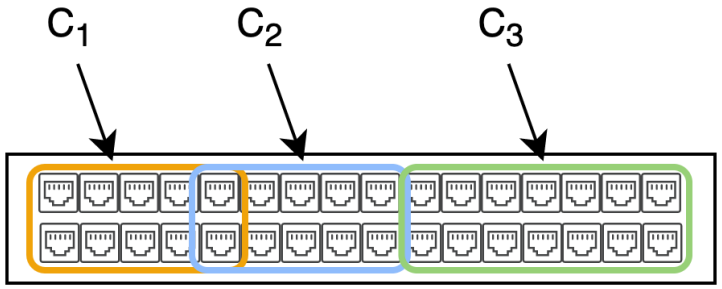
→ Maximal number of recirculations: *k-1*



- Example 32-port switch
  - Three configured port clusters with size 11, 11, 10
  - At most 2 recirculations; independent of number of next-hops

Efficient Implementation of BIER in P4 (2)

- How to determine which C_i requires a packet copy?
  - Look at all combinations of configured port clusters S_i
  - C-FBM(S_i) is combined FBM; indicates all BFERs reachable through S_i
  - Ternary match on BIER bitstring and complement of C-FBM → Match when result is 0
  - Ordered by $|S_i|$ → Select first configured port cluster C_j in S_i for further processing



Switch

BIER bitstring →

Ternary match		Action data
Mask	Value	
¬C-FBM($\mathcal{S}_1$)	0	Select cluster
¬C-FBM($\mathcal{S}_2$)	0	Select cluster
...	...	...

Match-action-table (MAT)

Example BitString: 00001101

Subset	C-FBM		¬C-FBM
$\mathcal{S}_1 : \{C_1\}$	00000111	&	11111000
$\mathcal{S}_2 : \{C_2\}$	00111000		11000111
$\mathcal{S}_3 : \{C_3\}$	11100000		00011111
$\mathcal{S}_4 : \{C_1, C_2\}$	00111111		11000000
$\mathcal{S}_5 : \{C_1, C_3\}$	11100111		00011000
$\mathcal{S}_6 : \{C_2, C_3\}$	11111000		00000111
$\mathcal{S}_7 : \{C_1, C_2, C_3\}$	11111111		00000000

Efficient Implementation of BIER in P4 (3)

- How to determine appropriate multicast group within C_i?
  - Configure all combinations of ports within configured port cluster C_i as static multicast group H_i
    - Robustness against change in the multicast tree, e.g., some BFERs join / leave
  - C-FBM(H_i) is combined FBM; indicates all BFERs reachable through H_i
  - Ternary match on BIER bitstring and complement of C-FBM → Match when result is 0
  - Ordered by $|H_i|$

- Caveat
  - $|C_i| = n$ requires $\approx 2^n$ static multicast groups

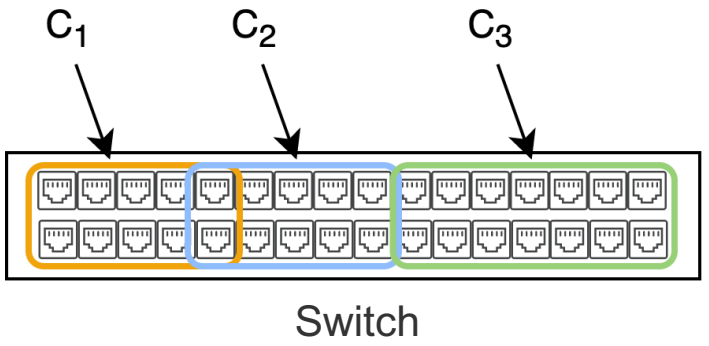
- Example 32-port switch
  - Three configured port clusters with size 11, 11, 10
  - $\leq 2^{11} + 2^{11} + 2^{10} = 5120$ static multicast groups

- Runs at 100 Gbit/s per port on Intel™ Tofino

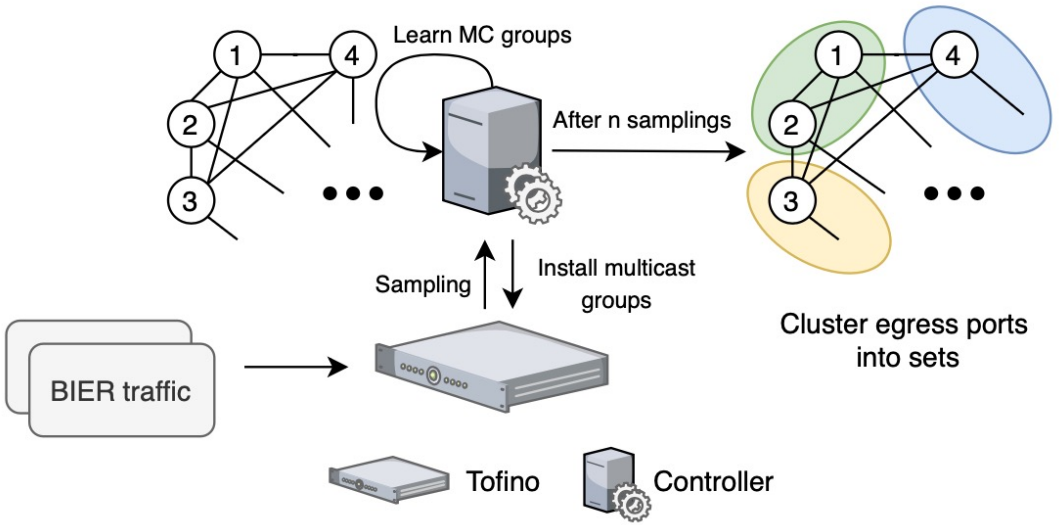
Optimization

Optimization (1)

- Assumptions
  - Multicast traffic is not random
    - Some correlation on egress ports
  - Limited number of static multicast groups available

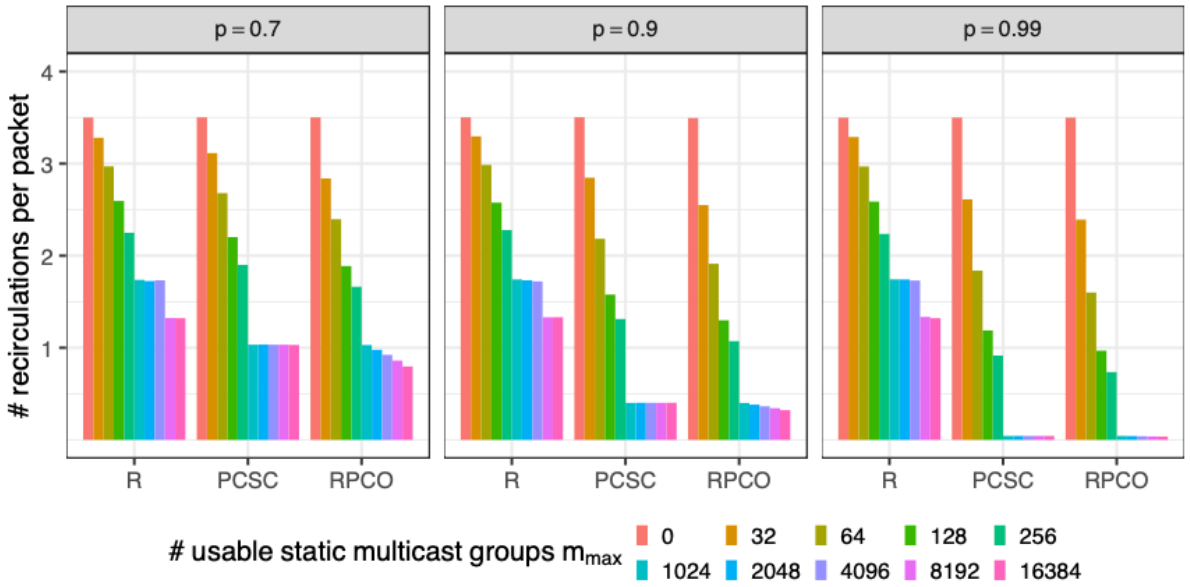


- Idea
  - Sample BIER traffic
  - Store information about used ports for each BIER packet in a graph structure
  - Apply clustering methods to choose configured port clusters C_i such that
    - all of them cover all ports
    - few of them are needed to cover most BIER packets



Optimization (2)

- Example
  - BIER traffic with 4.5 next-hops on average
  - Old version requires 3.5 recirculations on average (red bar)
  - Highly correlated multicast traffic
    - Almost 0 recirculations with > 1024 static multicast groups
  - Less correlated multicast traffic
    - < 1 recirculations with > 1024 static multicast groups



(a) Traffic sampled from four generating port clusters of size 8 with different port correlation p.

Conclusion

- Mechanism to forward BIER traffic with a few iterations instead #next-hops
  - Configuration: Choose configured port clusters C_i
  - Iterative processing
    1. Select configured port cluster C_i
    2. Send packet to all required ports within C_i
  - Step 2 may be achieved through pre-defined internal multicast groups
    - Does not require dynamic state
    - May bee done differently depending on technology
  - Max. number of iterations bounded by max. number of port clusters (~ 3 instead of 32)
  - Optimized port clusters further reduce required iterations
- Implemented in P4 at line rate @ Intel™ Tofino
- More details
  - Paper under submission: https://atlas.informatik.uni-tuebingen.de/~menth/papers/Menth22-Sub-2.pdf
  - We're happy to discuss

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