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Towards Scalable and Expressive Stream Packet Processing

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OUTLINE

- Introduction and motivations
- Background on Data Stream Processing
- Proving the feasibility of using the DaSP approach in the networking scenario
  - Suitable extensions built for WindFlow
  - Experimental evaluation
- Final remarks and conclusions

Introduction and motivations

INTRODUCTION

- Modern networks
  - Accommodate a variety of services on the same infrastructure
  - Adapt to requests for service (de-)activation
  - Always guarantee Quality of Service (QoS) requirements

- Network operators need
  - Rapid and easy network (re-)configuration
  - Continuous real-time network monitoring for detecting
    - Security issues
    - Performance degradation

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A NEW ERA OF PROGRAMMABLE NETWORKS

- In-network data plane processing
  - Programmable software switches
  - Programmable abstractions (e.g., P4)
- Commodity hardware for data plane operations (general-purpose servers)
  - Cheaper alternatives to specialized hardware
  - High flexibility
  - Good maturity level
    - Multi-core architectures to enable parallel computations
    - Multi-queue NICs for parallel tapping of packets from the wire
    - Software accelerated packet capture frameworks

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THE NEED TO PROCESS LIVE PACKET STREAMS ON NETWORK END HOSTS

- Perform accurate packet analytic tasks in end-host servers depends on
  - Ability to capture all the packets arriving to the NIC at speeds of 10+ Gbps
  - Design processing applications to handle incoming data fast enough not to lose packets

STRENGTHS:

- Great flexibility, fully programmable platforms
- Multi-gigabit packet handling with huge volumes of traffic can be achieved
  - Use accelerated packet capture frameworks

PROBLEM:

- How to design network applications to scale with the speed of received data and not get overwhelmed?

THE NEED FOR PARALLELISM

- Design network applications which take advantage of multiple cores

COMPLEX TASK:

- Network programmers must build their applications from scratch by
  - Implementing the interfaces towards the lower hardware level
  - Implementing the proper mechanisms for parallel programming

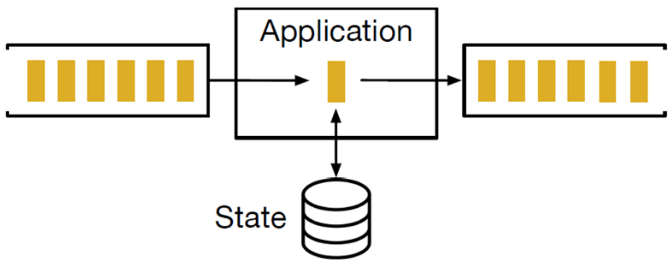
SOLUTION:

- Leverage the power of Data Stream Processing (DaSP) frameworks
  - Manage parallelism in an effective way
  - Offer high-level programming abstractions
- Let network programmers only focus on the application logic

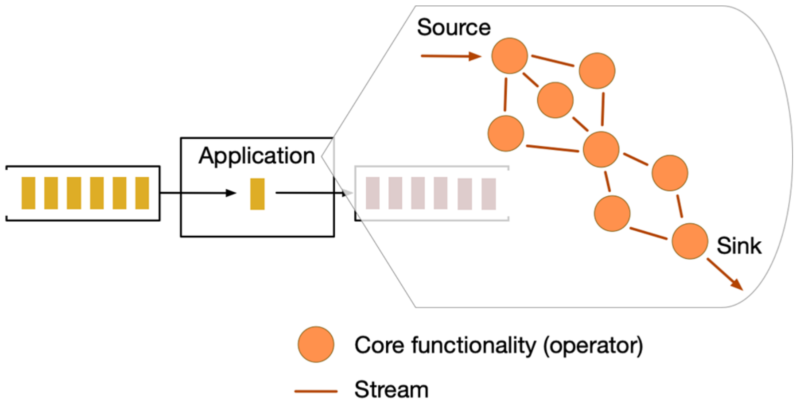
Background on Data Stream Processing

BACKGROUND: DATA STREAM PROCESSING (DASP)

- Useful everywhere there is the need for continuous and real-time analysis of streaming data
  - Networking, smart cities, smart mobility, smart logistics, …



- DaSP frameworks
  - Simplify the implementation of efficient streaming computations
  - Designed to implement general-purpose applications
  - Offer programming abstractions of multi-stage pipelines
    - Every stage (operator) can be seamlessly parallelized
    - Lower-level details hidden to the programmer



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BACKGROUND: DATA STREAM PROCESSING FRAMEWORKS

- Mainstream DaSP frameworks
  - Based on the Java Virtual Machine
  - Support implementation of streaming applications on distributed environments
  - Many overheads impact performance
    - Not possible to keep up with common traffic rates in networking scenario

- A recent proposal: WindFlow
  - Targets single multi-core machines with GPU support
  - C++17-based
  - High performance + high expressiveness

Proving the feasibility of using the DaSP approach in the networking scenario

Suitable optimizations built for WindFlow

THE NEED FOR SUITABLE EXTENSIONS

- The WindFlow DaSP framework
  - Offers a modern design and high performance
  - However, it is conceived to implement general streaming computations
    - It lacks mechanisms for binding source operators to multiple sources of data (NIC hardware queues)
    - Source operators must be tuned for packet capturing and parsing

- We implemented proper optimizations for the networking domain
  - Full support for parallel source entities
    - Each one attached to a different NIC hardware queue
  - Acceleration of source operators
    - Fully generic memory pool of tuples

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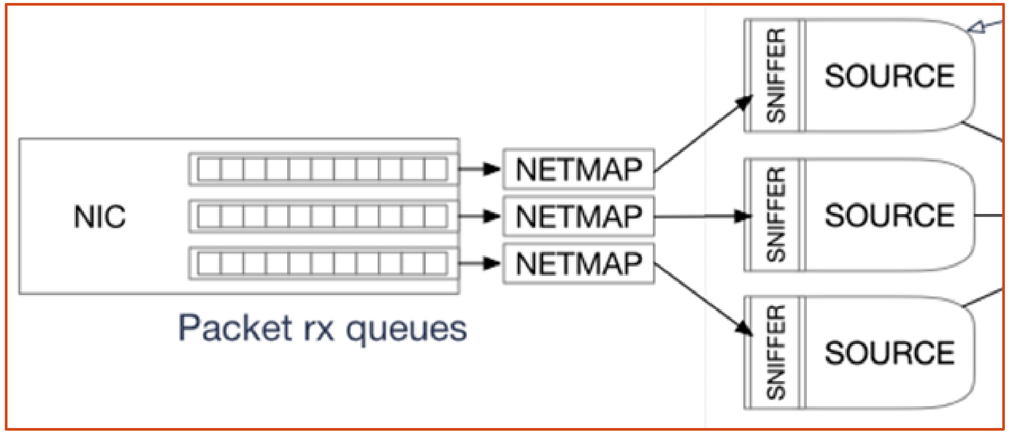
SUPPORT FOR MULTI-SOURCE

- The SOURCE oversees the following tasks
  - Receives captured packets from the NIC
    - Using fast packet capturing tools (e.g., Netmap, AF_XDP, libpcap, AF_PACKET)
    - Module called SNIFFER
  - Parses packet headers and creates accordingly all the tuples that will be processed in the graph

- The SOURCE is the bottleneck in the graph
  - Given its considerable workload

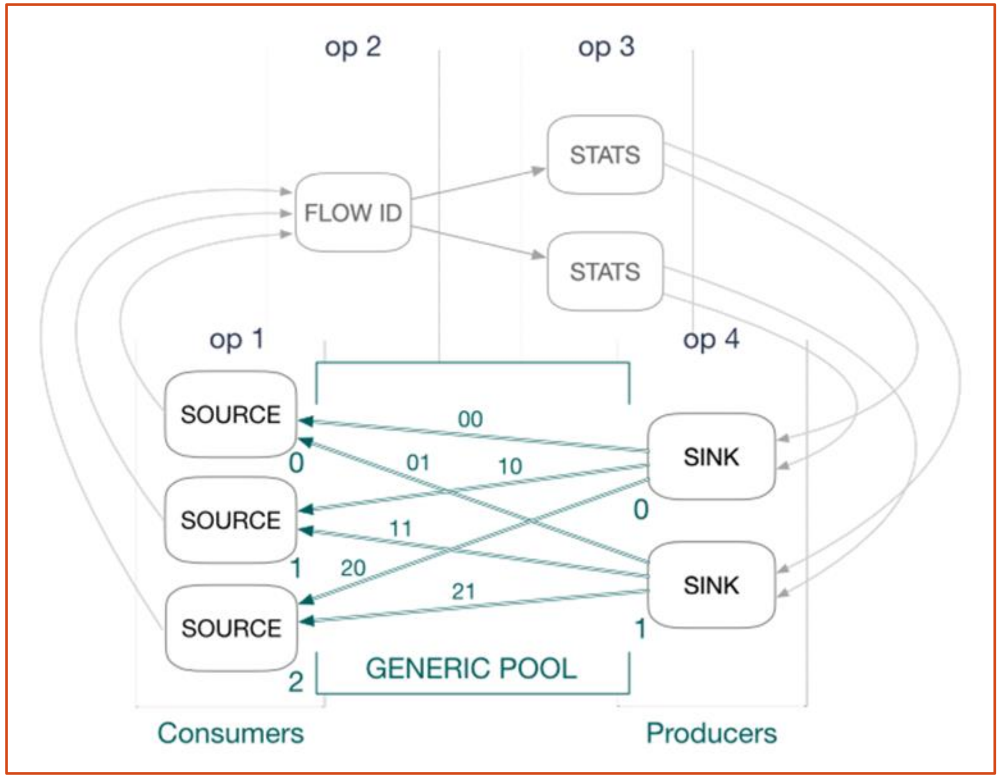
- We removed the performance bottleneck by parallelizing the SOURCE operator



GENERIC MEMORY POOL

* SPSC = Single Producer Single Consumer

- Tuples are the stream elements flowing in the application graph
  - SOURCE nodes initialize tuples from packet contents
  - SINK nodes collect tuples at the end of the processing
- Memory pool and tuple recycling in the application graph to avoid expensive memory allocations
  - Pre-allocated pool of empty tuples
  - Matrix of communication channels
    - Implemented as SPSC* queues
  - Support for generic number of consumer and producers
    - SOURCE consumes tuples from the pool
    - SINK produces tuples into the pool

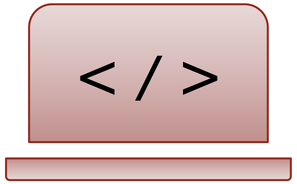


Experimental Evaluation

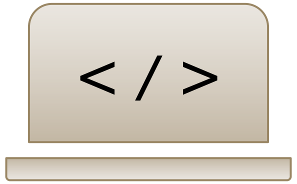
EXPERIMENTAL EVALUATION: TEST ENVIRONMENT

- Two machines equipped with Intel NICs and connected with a 40 Gb/s ethernet link

  - Server 1
    - Used as a traffic generator
    - Equipped with CPU Intel Core i7-3770K
    - Uses the Netmap framework to accelerate traffic generation

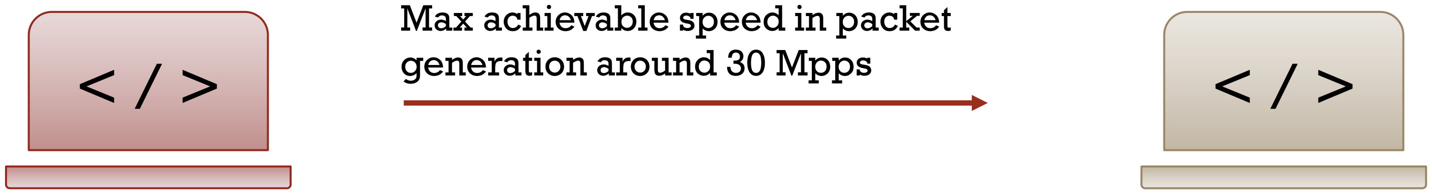


  - Server 2
    - Used to run a packet-analysis application
    - Equipped with CPU Intel Xeon E5-1660 v3 with 8 cores/16 threads
    - Uses the Netmap framework to accelerate traffic capturing
    - Uses the FastFlow and WindFlow libraries to run the application



EXPERIMENTAL EVALUATION: TEST ENVIRONMENT, RAW SPEED TEST

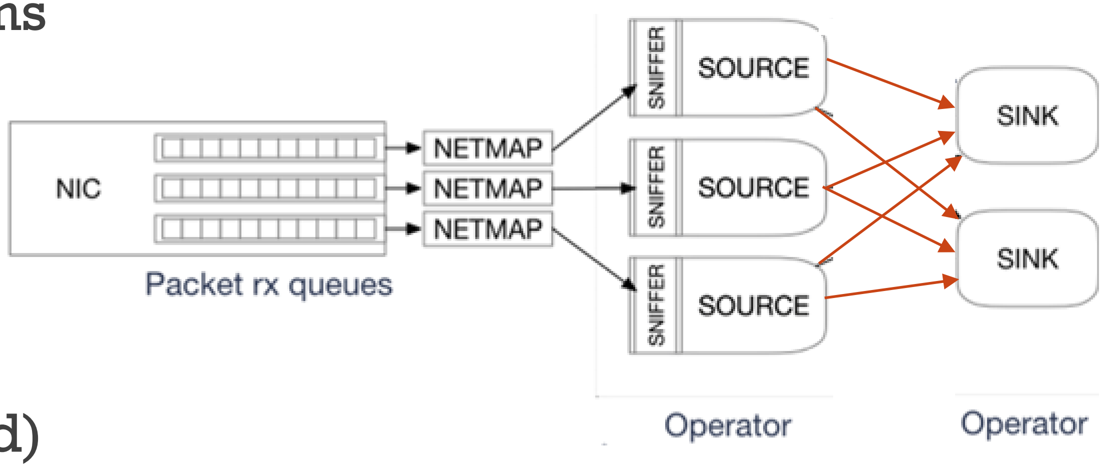
- Server 1 - generator
  - Sends minimally-sized packets to stress the system with a very high packet rate
  - Runs Netmap tool pkt-gen to generate 64 bytes UDP packets
    - Different destination IP addresses are assigned to packets so that Server 2 NIC can spread incoming packets equally among its available hw queues
- Server 2 - receiver
  - Runs the "packet counter" application (SOURCE-SINK)
  - Measures throughput with an increasing number of source nodes



EXPERIMENTAL EVALUATION: RAW SPEED TEST

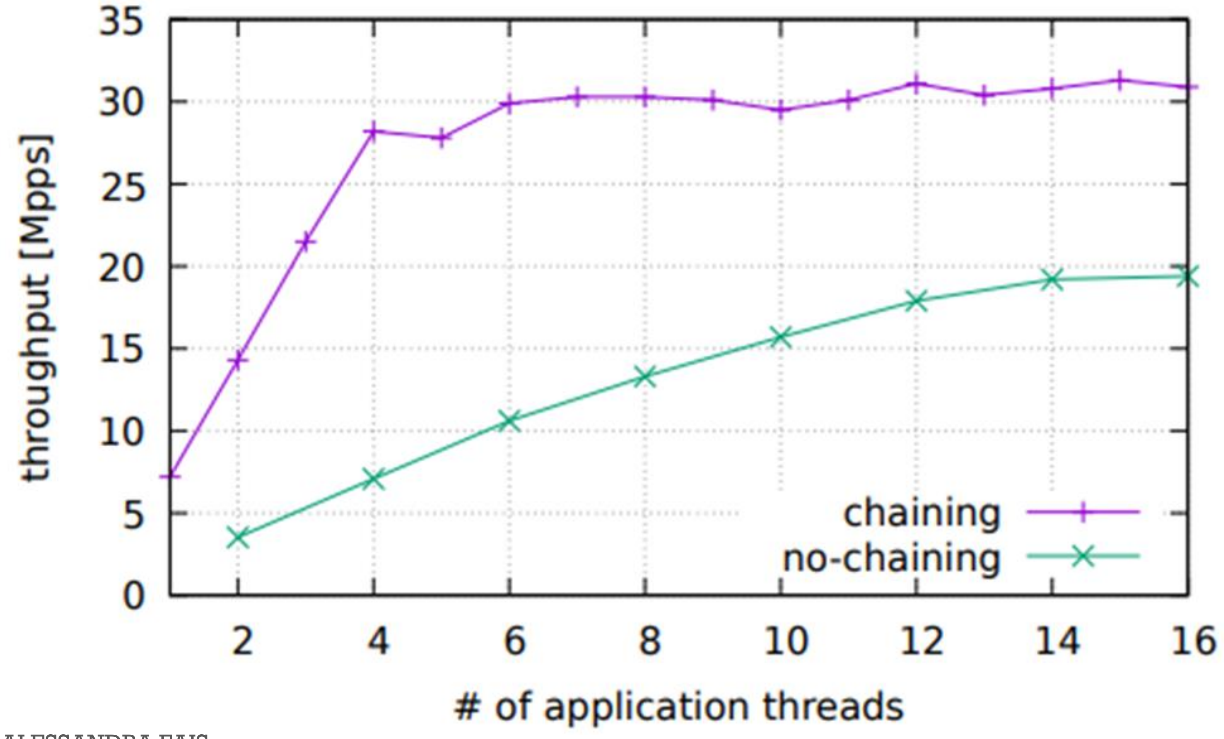
- Raw speed test
  - Assess the scalability of the basic framework
  - Modules in the system
    - Packet capturing sub-system
    - Inter-thread communication mechanisms
    - Tuple memory pool

- Minimal configuration of the application
  - SOURCE and SINK operators only
  - Tested configurations
    - Chained execution (on the same thread)
    - Non-chained execution (on separated threads)



EXPERIMENTAL EVALUATION: RAW SPEED TEST

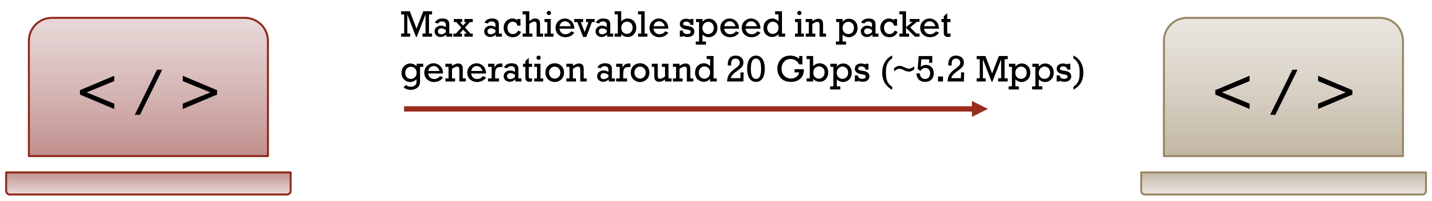
- Workload characteristics
  - Synthetic traffic
  - Minimally sized packets (64 bytes, UDP)
  - Traffic generator runs pkt-gen (Netmap suite)



- Packet rate (millions of packets per second) sustained by the minimal packet-counter application for increasing number of source nodes
- Given X application threads, the number of source nodes in the chaining case is X, while in the no-chaining case is X/2

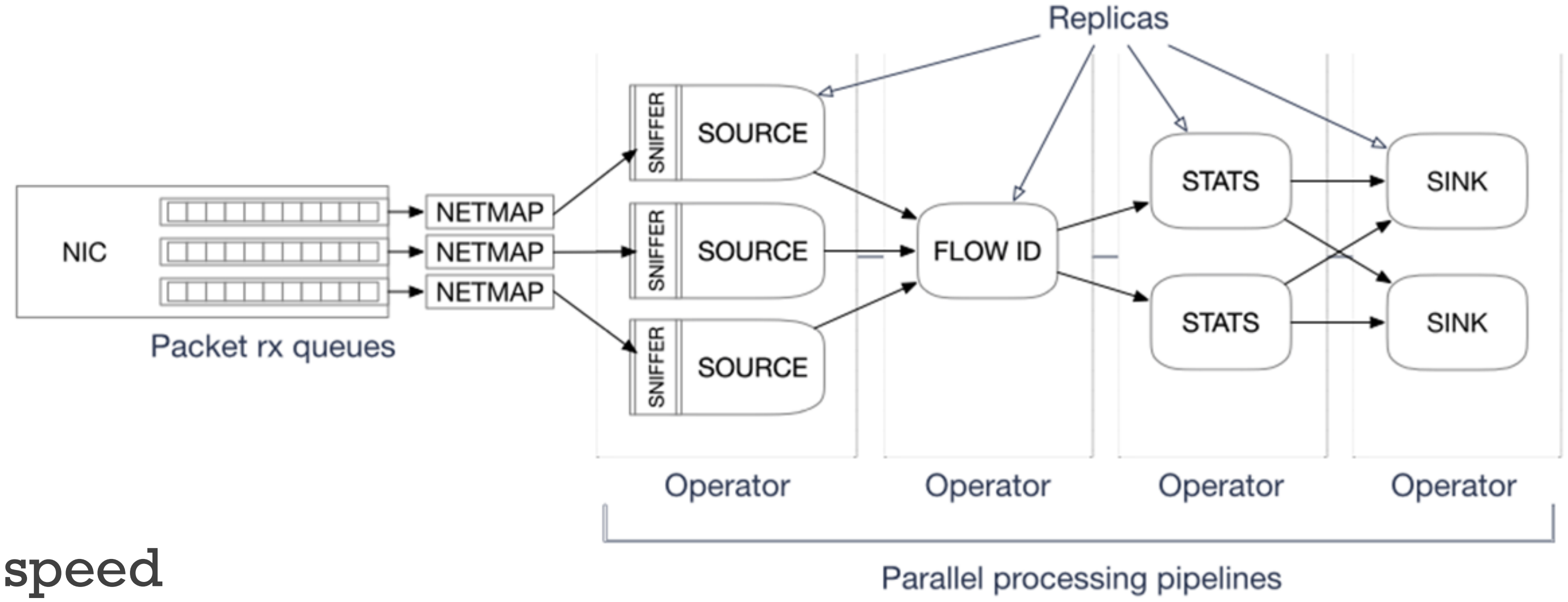
EXPERIMENTAL EVALUATION: TEST ENVIRONMENT, MONITORING APP TEST

- Server 1 - generator
  - Sends realistic traffic by replaying a pcap file at max speed
  - Runs Netmap application nmreplay to replay the pcap file
- Server 2 - receiver
  - Runs the complete “flow counter” application (SOURCE-FLOWID-STATS-SINK)
  - Measures throughput with an increasing number of source nodes resulting in different test configurations



EXPERIMENTAL EVALUATION: A SIMPLE MONITORING APPLICATION

- Flow counter application test
  - More complex application
  - Produce some packet and flow level analytics from the processing of packet headers
- Pipeline of 4 nodes
  - All can be replicated in parallel independently of the others
- Workload characteristics
  - Realistic traffic
  - pcap file replayed at max speed using nmreplay (Netmap suite)
  - packets of different lengths (generally larger than 64 bytes)



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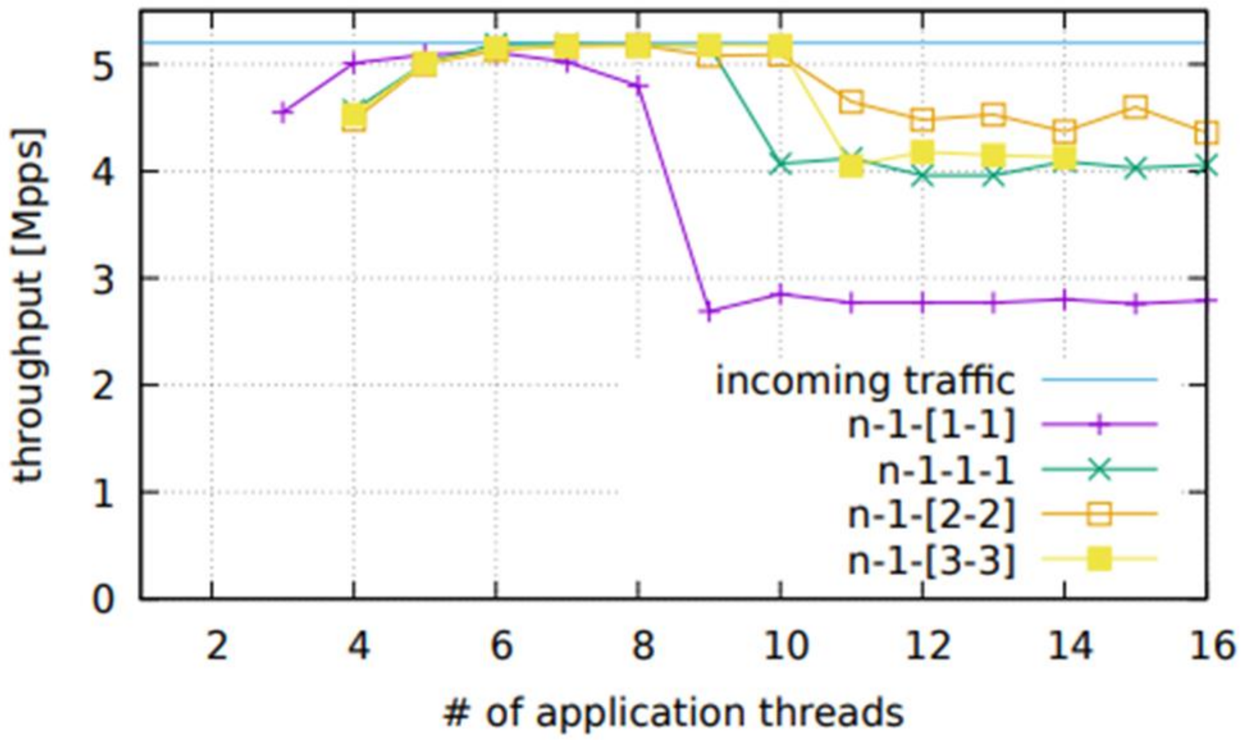
EXPERIMENTAL EVALUATION: A SIMPLE MONITORING APPLICATION



- Packet rate (millions of packets per second) sustained by the test monitoring application with three different combinations of replication and chaining

n-1-1-1	n SOURCE nodes, no other replicated nodes, no chaining
n-1-[1-1]	n SOURCE nodes, no other replicated nodes, STATS node is chained with SINK node
n-1-[2-2]	n SOURCE nodes, one FLOWID node, two nodes each of both STATS and SINK chained pairwise

Final remarks and conclusions

Conclusion

- The application throughput increases linearly with the number of sources
  - Full data elaboration sustained up to nearly 20 Gbps in different configurations
- Proved feasibility of using DaSP approach to compute packet and flow level analytics from live data
  - Common computational pattern for network applications
  - Network monitoring is one of the largest domains of interest
- WindFlow can be a convenient development platform in the networking domain
  - Future directions:
    integrate these results into the WindFlow framework to provide a new native networking module with *ad hoc* ready-to-use network-oriented operators