Networking Virtualization Using FPGAs

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Outline

- Network virtualization
- Advantage of FPGA for virtualization
- Architecture of FPGA-based virtualization system
- Partially-reconfigurable implementation
- Results
Virtual Networking

- Internet growing to include new applications and services
  - Cloud computing, Data center networking

- Challenges
  - Lack of innovation at network core – Fixed internet routers
  - Coupled infrastructure-service provider model

- Solution
  - Network virtualization
  - Router hardware shared across multiple networks
Network Virtualization

- Many logical networks over a physical infrastructure
  - Virtual nodes
  - Shared network resources among multiple virtual networks
  - Reduces costs
  - Independent routing policies
Virtual Router

- Independent routing policies for each virtual router

- Key challenges
  - Isolation
  - Performance
  - Flexibility
  - Scalability
Traditional Network Virtualization Techniques

- **Software**
  - Full virtualization
  - Container virtualization
  - **Limitations**
    - Limited performance (~100Mbps)
    - Limited isolation

- **ASIC**
  - Supercharging PlanetLab Platform\(^1\)
  - Juniper E series
  - **Possible Limitations**
    - Flexibility
    - Scalability

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\(^1\) “Supercharging PlanetLab – A High Performance, Multi-Application, Overlay Network Platform”, J. Turner et al., SIGCOMM 2007
Virtualization using FPGAs

- A novel network virtualization substrate which
  - Uses FPGA to implement high performance virtual routers
  - Introduces scalability through virtual routers in host software
  - Exploits reconfiguration to customize hardware virtual routers
Architecture

CPU RX Q

PHY MAC

AC RX Q
Scalable Network Virtualization

- Approaches for implementing scalable virtual routers
  - Single receiver approach
    - All packets routed through NetFPGA hardware
  - Multi-receiver approach
    - Use a switch to separate packets to NetFPGA and software
Virtual Router Customization

- Multiple virtual routers share the substrate
- Individual virtual routers may need customization

Challenge

  - Minimize the impact on traffic in shared hardware virtual routers during modification
Multi Receiver Approach
Dynamic Reconfiguration

Reconfigure FPGA

New HW Virtual Router

Sw Virtual Router

Address Remap
Single receiver approach
Partial Reconfiguration

- Use partial reconfiguration to independently configure virtual routers
Partial Reconfiguration

- Up to 2 partially reconfigurable virtual routers in Virtex 2
- Up to 20 partially reconfigurable virtual routers in Virtex 5
Experimental Approach

- **Metrics**
  - Throughput
  - Latency

- **Packet generation**
  - NetFPGA packet generator
  - iPerf

- *Ping* utility used for latency measurements

- Software virtual routers run on 3Ghz AMD X2 6000+ processor, 2GB RAM, Intel E1000 GbE in PCIe slot
Dynamic Reconfiguration Overhead

- **Full FPGA reconfiguration**
  - Source pings destination through a single h/w virtual router
  - Migrate traffic to software
  - Reconfigure FPGA
  - Migrate traffic to hardware
  - 12 seconds reconfiguration overhead

- **Partial FPGA reconfiguration**
  - 0.6 seconds reconfiguration
  - Remaining virtual routers in FPGA remain active
Throughput of Single Hardware Virtual Router

- Hardware virtual router 1 to 2 order better than the software virtual router
- Consistent forwarding rates vs packet size

![Graph showing throughput vs packet size for hardware and software virtual routers.](image)
Full FPGA Reconfiguration

- Two virtual routers (A, B) initially in FPGA
- During reconfiguration router A migrated to software, the other eliminated
- After reconfiguration two virtual routers (A, B’) again in FPGA
Partial FPGA Reconfiguration

- A remains in hardware and operates at full speed
- 20X speedup in reconfiguration down time due to partial reconfiguration

Sustained Throughput
Scalability - Average Throughput of Virtual Routers

- Aggregate throughput of 1Gbps up to 4 h/w virtual routers
- Adding software virtual routers causes drop in aggregate throughput
Scalability – Average Latency of Virtual Routers

- Latency of h/w virtual router substantially better than software virtual router

![Graph showing latency comparison between software only and average hardware and software. The graph indicates that the hardware virtual router latency is consistently lower than the software virtual router latency across different numbers of virtual routers.]
Throughput Effect of Reconfiguration Frequency

- Partial reconfiguration beneficial during frequent updates
Average throughput for combined hardware/software

- Rigid placement constraints limit #hardware virtual routers
- Larger FPGAs sustain high throughputs for more virtual routers
Consistent packet forwarding rates of 1Gbps for all packet sizes (64-1024) bytes.
Packet throughput matches NetFPGA reference router in all cases.
Packet buffering in on-chip SRAM (300Kbit).
Resource Utilization

- Logic Utilization
  - 14% LUTs
  - 19% Logic registers
  - 9% Memory bits
  - 13% IOs

<table>
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<th>Altera DE4</th>
<th>NetFPGA</th>
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Reconfiguration Time

- 20X Faster virtual router updates with partial reconfiguration

**Full Reconfiguration**

**Partial Reconfiguration**
Resource Usage and Power Consumption

- Virtex 2 can support
  - 5 h/w virtual routers (without support for software routers)
  - 4 h/w virtual routers (with support for software routers)
  - 2 partially reconfigurable hardware routers

- Virtex 5 can support up to 32 virtual routers

- A single h/w virtual router consumes
  - 156mW static power
  - 688mW dynamic power

- Clock gating saves 10% power
Dynamic Virtual Network Allocation

- Assign virtual networks to software/hardware virtual routers based on bandwidth-resource requirements
- 15-20% more successful network upgrades with dynamic allocation
Conclusion

- FPGAs are ideal for a variety of networking applications
  - Partial reconfiguration growing in importance

- Virtual networking is an emerging networking area
  - Combined FPGA and software system gives high performance and scalability
  - A novel heterogeneous network virtualization substrate using FPGAs

- NetFPGA platform used to implement up to five virtual routers
  - Two order of magnitude throughput increase versus software.

- Partial FPGA reconfiguration reduces the number of implemented routers but reduces reconfiguration time to 0.6s
  - Allocation algorithm migrates highest throughput routers to hardware