Accelerate Networking with Shared Memory Communications for Linux on IBM Z

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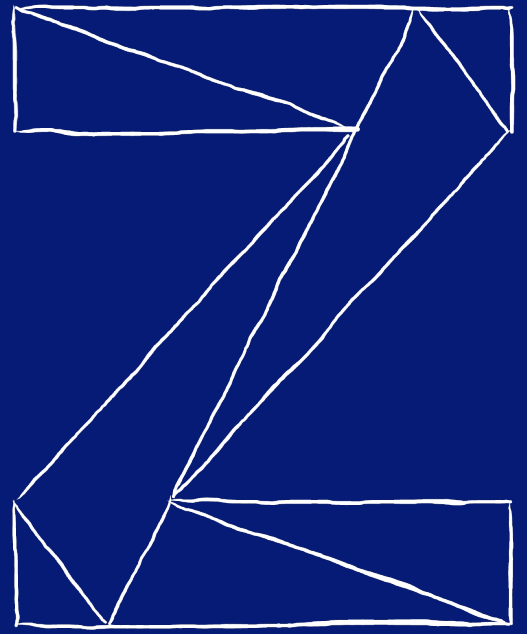
Stefan Raspl

Linux on IBM Z Development



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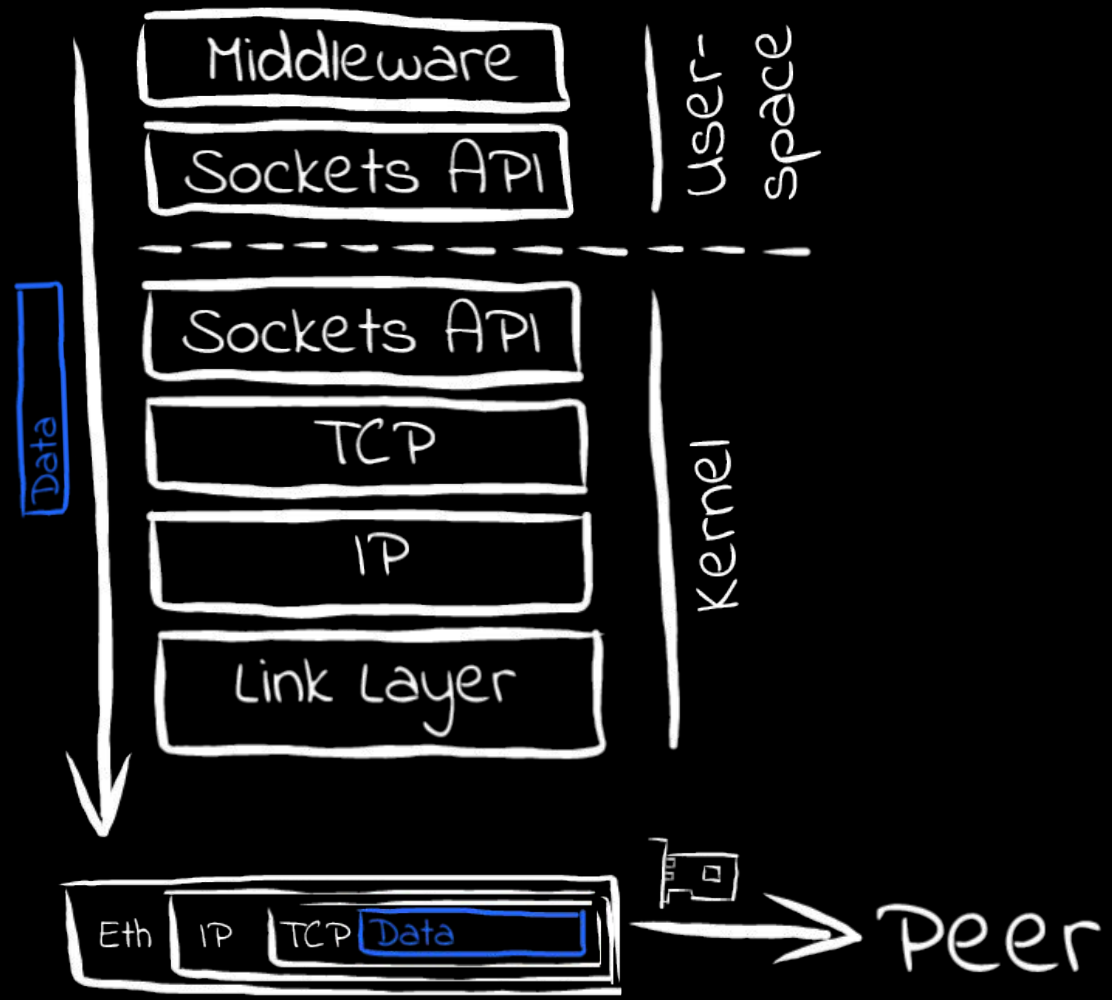
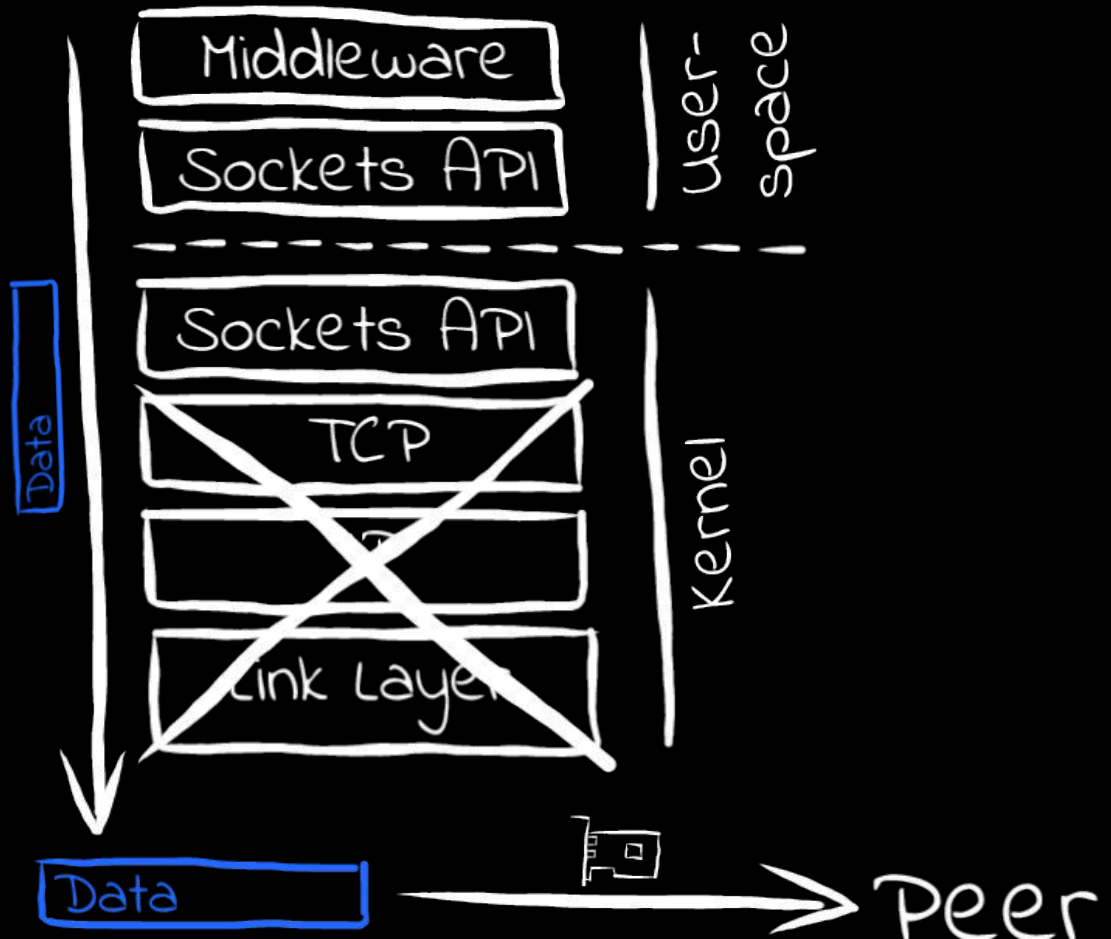
Agenda

- **SMC Basics**
  - Motivation
  - The SMC Protocol
  - Benefits
- **SMC for Linux on Z**
  - SMC-D and SMC-R
  - *smc-tools*
- **SMC in Action**
  - Usage Examples
  - Deploying SMC
  - Tips & Tricks
- **Outlook**
- **Miscellaneous**

What sending data through BSD sockets looks like

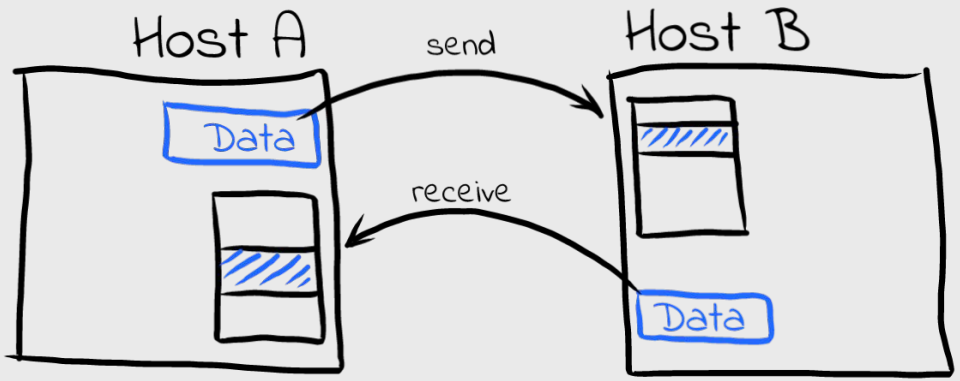


What if we had a simple buffer to write data to and let hardware do the rest...?



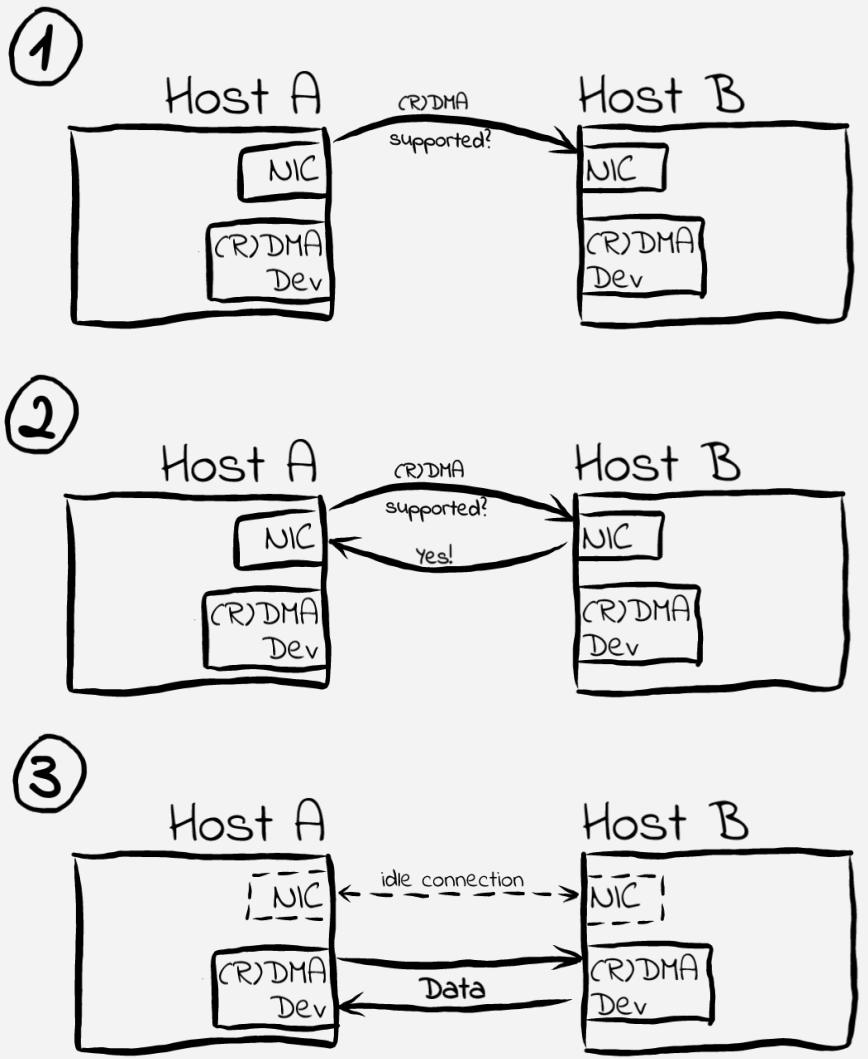
The RDMA Approach

- RDMA (***R**emote **D**irect **M**emory **A**ccess*) based technology originating from Infiniband (IB)
- Enables a host to read or write directly from/to a remote host's memory with drastically reduced use of remote host's CPU (interrupts required for notification only)
- Native / direct application exploitation requires rewrite of network-related program logic, deep level of expertise in RDMA and a new programming model
- Therefore, provide a transparent approach:
  - **SMC-R**: Use *RDMA* over Converged Ethernet (RoCE) technology
    - Unlike IB, RoCE does not require unique network components (host adapters, switches, security controls, etc.)
    - Utilize existing Ethernet fabric with RDMA-capable NICs and switches
  - **SMC-D**: Use *DMA* when both hosts are within a Z system via virtual PCI device



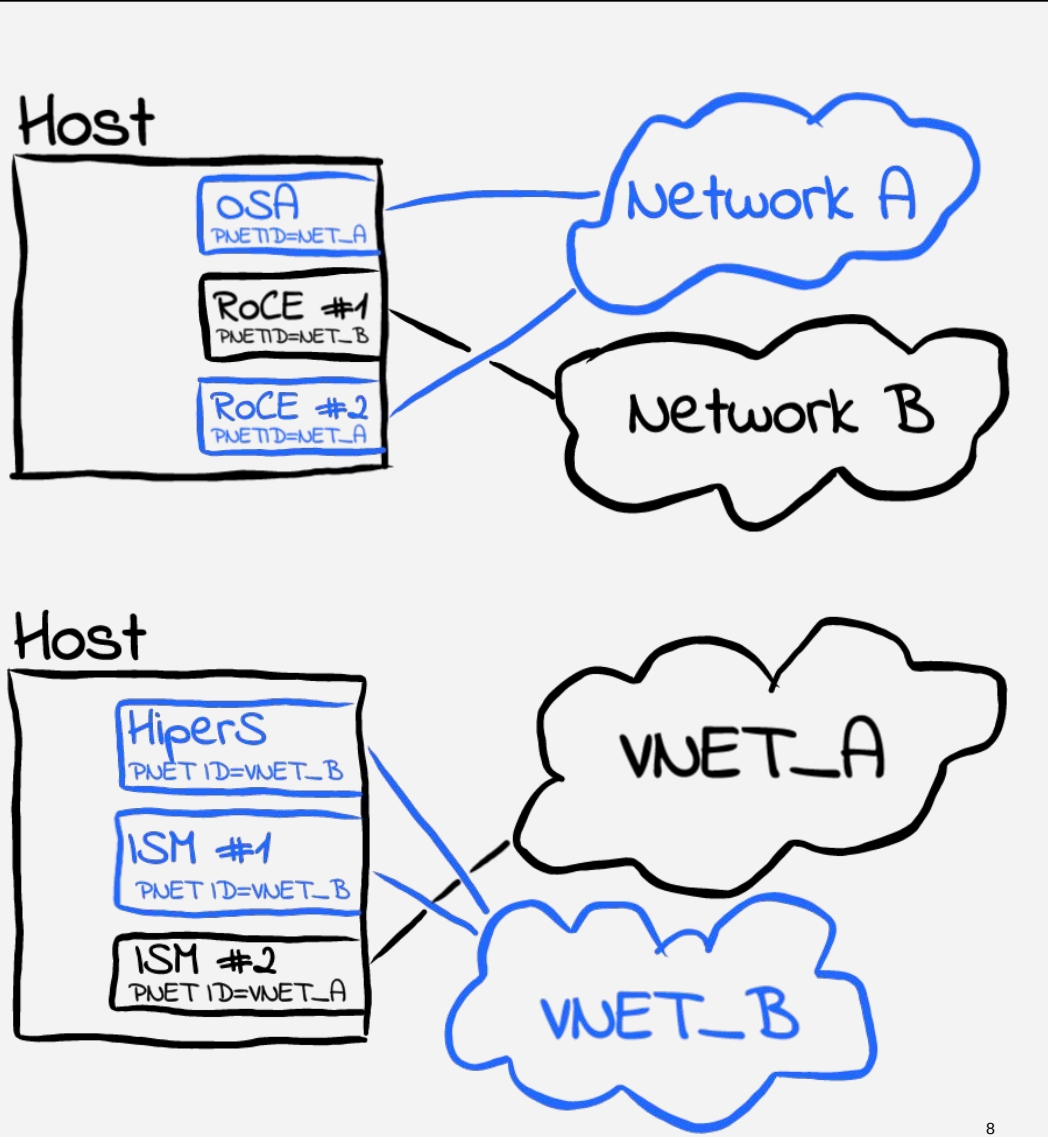
Overview

- For each new TCP connection:
  - Start out with a regular TCP/IP connection, advertising (R)DMA capabilities
  - If peer confirms, negotiate details about the (R)DMA capabilities & connectivity
  - Switch over to an (R)DMA device for actual traffic depending on the peers' capabilities
  - Regular TCP connection through NICs remains active but idle

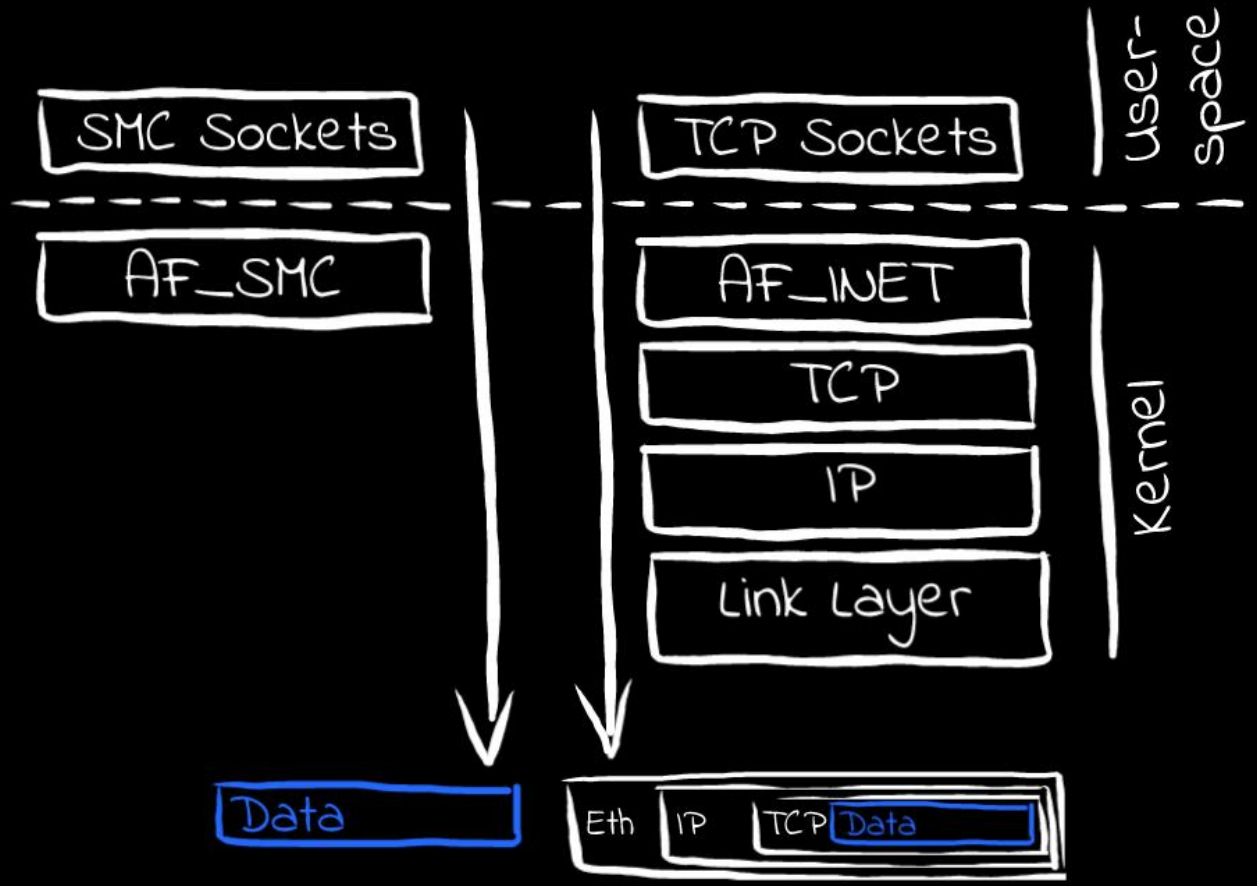


PNET IDs

- **PNET ID**: *Physical network identifier*
- Customer-defined value to logically group NICs and RDMA adapters connected to the same physical network within a host.
- Defined in
  - IOCDS for any of OSA, RoCE, HiperSockets or ISM, or
  - using `smc_pnet` tool (SMC-R only, all of the above and virtual networking facilities like z/VM vNICs et al)
- *Typically* associate
  - OSA and RoCE cards, or
  - HiperSockets and ISM devices
- **Note**: PNET IDs help to locate a suitable (R)DMA device for a given NIC ***within a host***. The peer can use totally different PNET IDs (as long as the right devices are grouped)



Less latency
Lower CPU usage



Run your applications unmodified

- SMC is transparent to existing applications – no changes required
- Use `smc_run`, also provided by *smc-tools*:

```
smc_run <my_application>
```

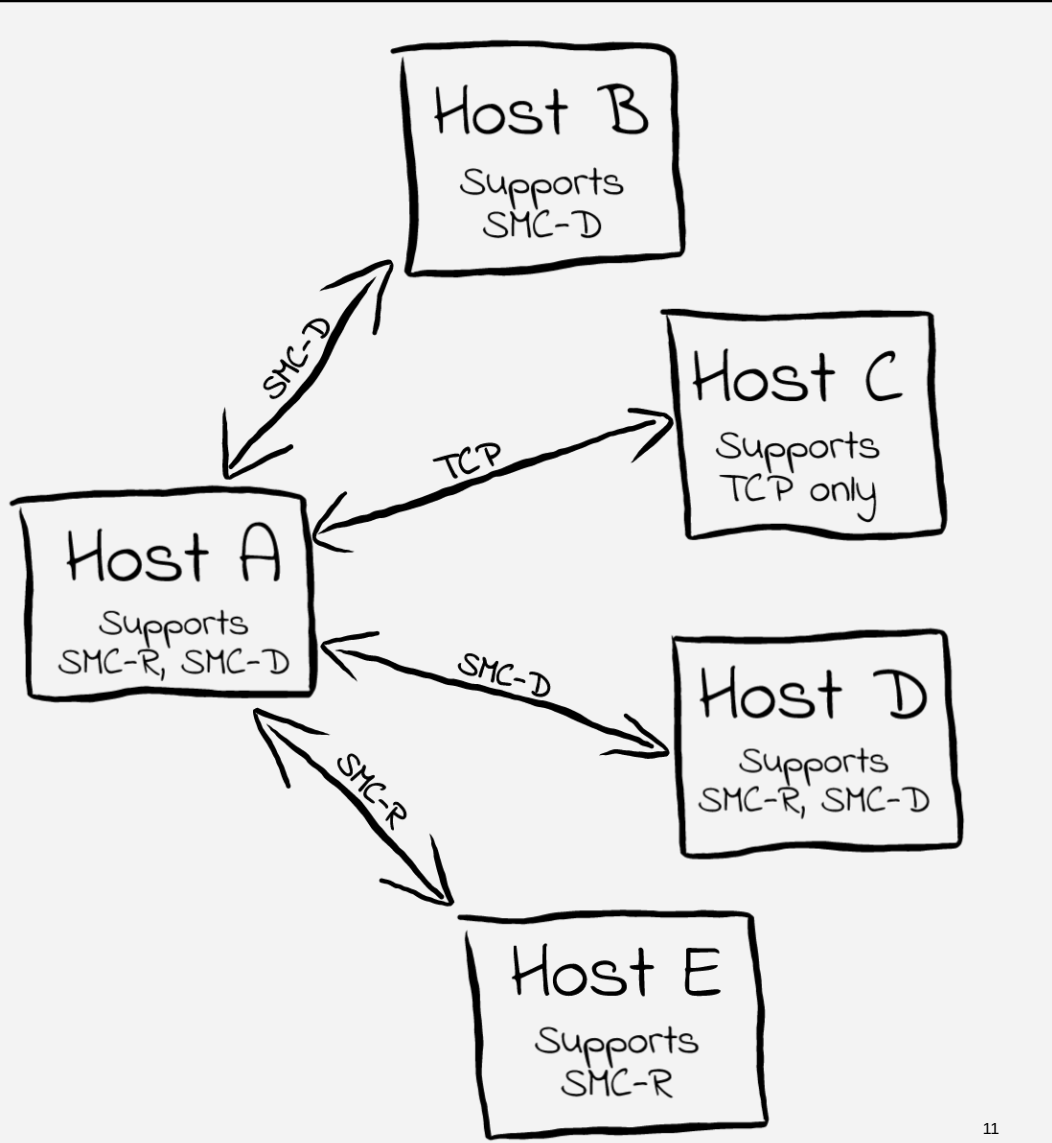
- Or use preload library directly, provided by *smc-tools*, to enable existing applications:

```
export LD_PRELOAD=libsmc_preload.so
```

Note: Will not work with statically linked applications.

Mixing SMC Usage

- Both variants of SMC can be used concurrently to provide an optimized solution
- Enable SMC independent of peers' capabilities; i.e. no commonality in SMC support on all peers required
- Use
  - SMC-D for local connections
  - SMC-R for remote connections
  - fall-back to regular TCP where neither SMC variant is supported



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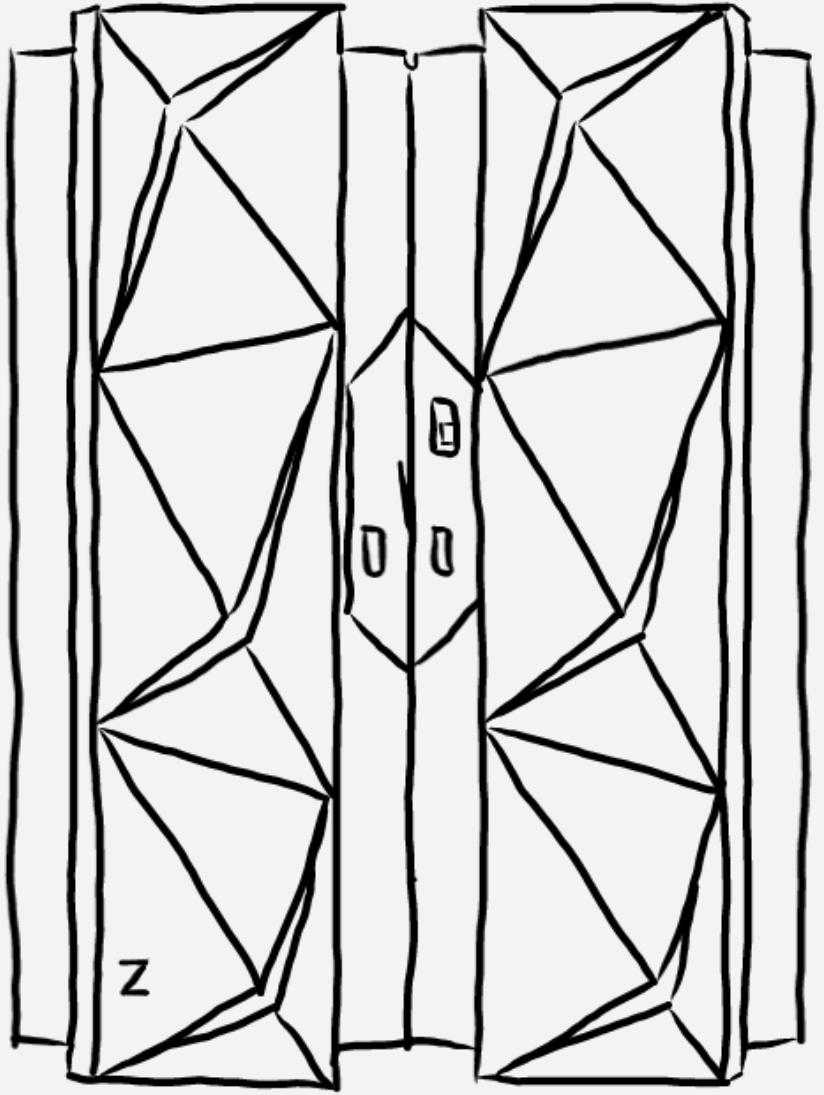
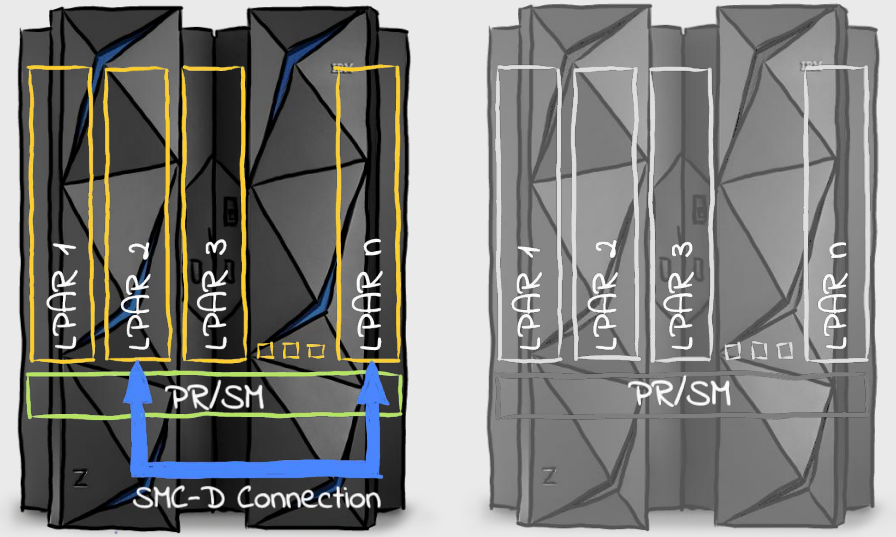


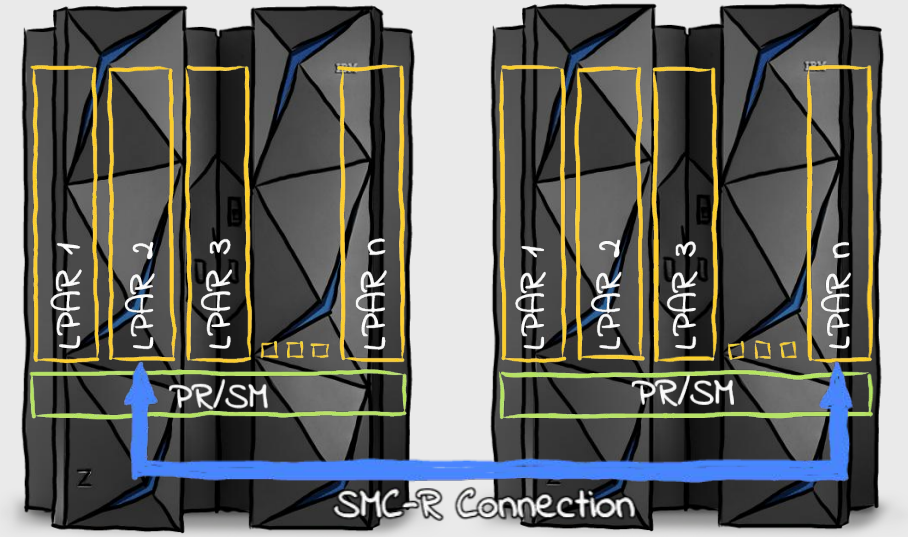
SMC-D Overview

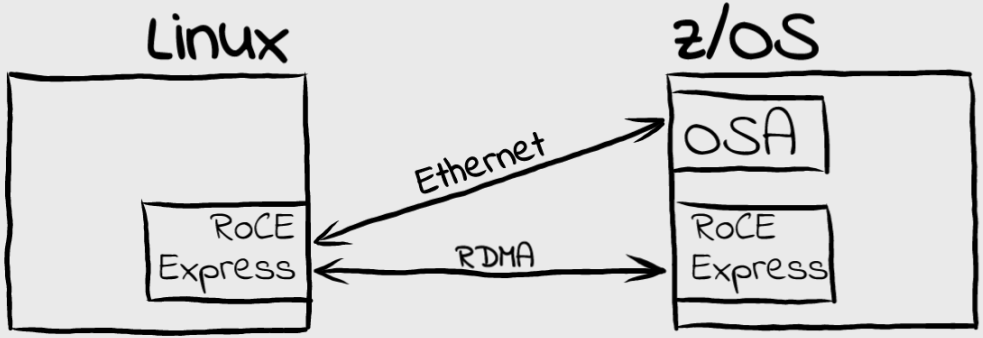
- Intra-CEC connectivity using ***Internal Shared Memory*** (ISM) devices
- IBM Z hardware requirements
  - IBM z13 (requires driver level 27 (GA2)) and z13s, or later
  - LinuxONE Emperor and LinuxONE Rockhopper, or later
  - Classic mode only (i.e. DPM not supported)
- ISM devices
  - *Virtual* PCI network adapter of new VCHID type ISM
    - No PCI bus usage
    - No extra hardware required
  - Provides access to memory shared between LPARs
  - 32 ISM VCHIDs per CPC, 255 VFs per VCHID (8K VFs per CPC total)
    I.e. the maximum no. of virtual servers that can communicate over the same ISM VCHID is 255
  - Each ISM VCHID represents a unique (isolated) internal network, each having a unique Physical Network ID
- PNET ID configuration
  - IOCDS only
  - Use HiperSockets, OSA or RoCE cards for regular connectivity



SMC-R Overview

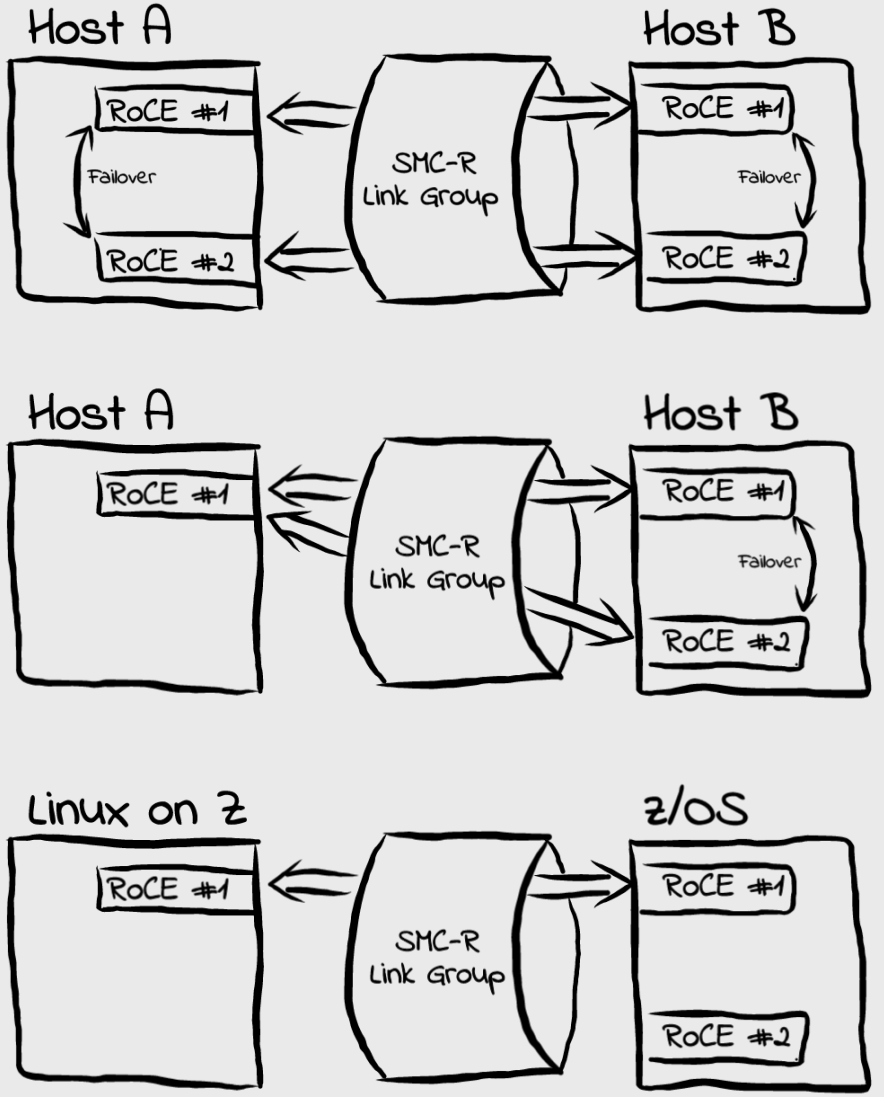
- Cross-CEC connectivity using ***RoCE Express*** cards
- IBM Z hardware requirements
  - IBM z12EC and z12BC or later
  - LinuxONE Emperor and Rockhopper or later
  - Classic and DPM mode supported
- RoCE Express cards
  - RoCE Express & RoCE Express2 cards supported
  - Switches need to support and enable *Global Pause* (standard Ethernet switch flow control feature as described in IEEE 802.3x)
- PNET ID configuration
  - IOCDS or `smc_pnet` (→ see *smc-tools* package)
  - Use OSA or RoCE card for regular connectivity
- **Note**:
  - Linux on Z can use a single RoCE card for regular and RDMA traffic!
  - No link failover!





SMC-R Link Groups

- SMC-R ***link groups*** provide for load balancing and recovery
  - New TCP connection is assigned to the SMC-R link with the fewest TCP connections
  - Load balancing only performed when multiple RoCE Express adapters are available at each peer
- **Full redundancy** requires:
  - Two or more RoCE Express adapters at each peer
  - Unique system internal paths for the RoCE Express adapters
  - Unique physical RoCE switches
- **Partial redundancy** still possible in the absence of one or more of these conditions
- Linux on Z:
  - No failover support (yet)



smc-tools Package Overview

- **Current version**: v1.2.1 (download from https://ibm.biz/Bdz4K3)
- *smc-tools* provides the following commands:
  - `smc_pnet`
    - Associate NICs via PNET ID in software
    - Does ***not*** modify/create IOCDS entries
    - Also works with bonding and VLAN devices
    - **Note**: PNET IDs defined in IOCDS always override
  - `smc_run`: Enable a binary application to use SMC.
  - `smcss`: Information about SMC-enabled sockets and link groups. Includes information on SMC mode used, as well as TCP fallbacks
  - `smc_rnics` (v1.2 or later)
    - List all available PCI (R)DMA devices, including PNET ID
    - Hotplug / hotunplug PCI (R)DMA devices
  - `smc_dbg` (v1.2 or later)
    - Collect debugging information
    - As a side effect, lists PNET IDs for CCW devices

```
# List all (R)NICs
$ smc_rnics
FID  Power  PCI ID        PCHID  Type           Port  PNET ID  Interface
--------------------------------------------------------------------------
  1  1      0000:00:00.0  0144   RoCE Express   0     76       ens1
  1  1      0000:00:00.0  0144   RoCE Express   1              ens1d1
 80  1      0001:00:00.0  07c0   ISM            n/a   NETSR
 81  0

# Hotplug FID 81
$ smc_rnics -e 81

# Note: FID 81 is now available
$ smc_rnics
FID  Power  PCI ID        PCHID  Type           Port  PNET ID  Interface
--------------------------------------------------------------------------
  1  1      0000:00:00.0  0144   RoCE Express   0     76       ens1
  1  1      0000:00:00.0  0144   RoCE Express   1              ens1d1
 80  1      0001:00:00.0  07c0   ISM            n/a   NETSR
 81  1      0001:00:00.0  07c0   ISM            n/a   NETSR
```

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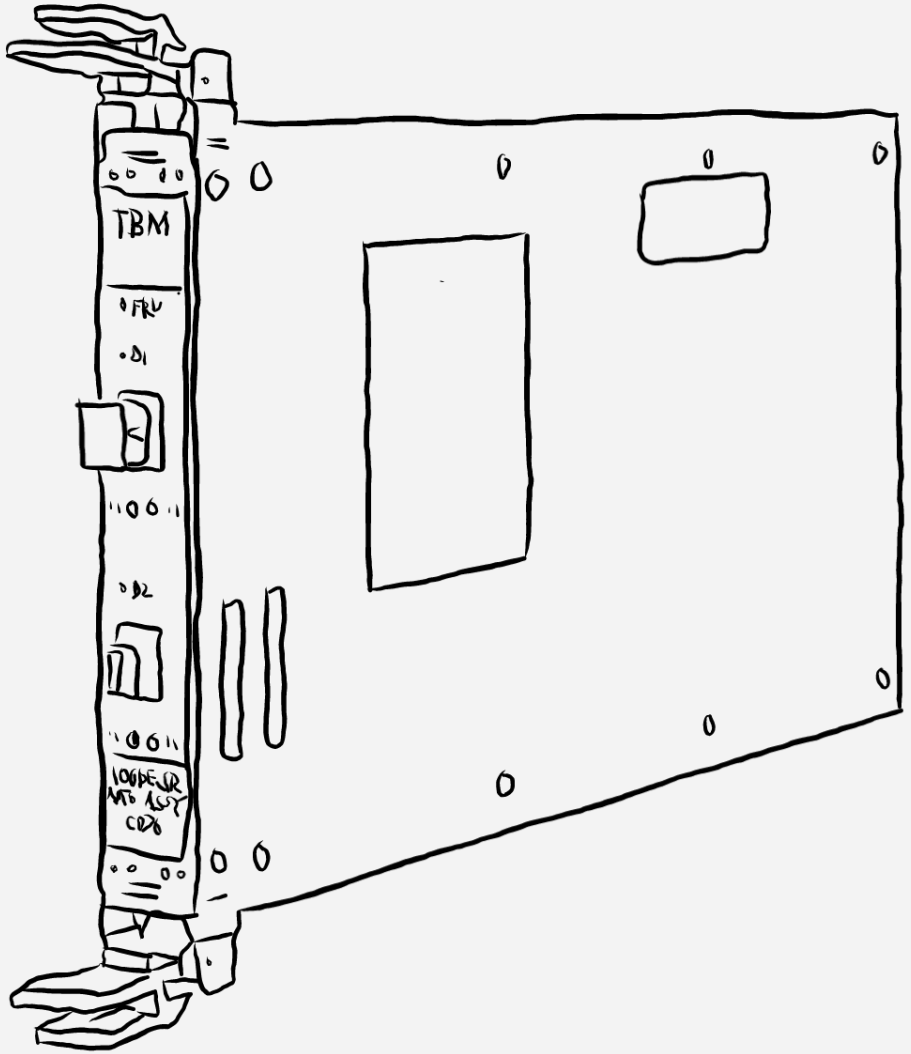


Supported Environments

- **Linux on Z Environments**
  - **LPAR** yes
  - **z/VM guests** yes (z/VM 6.3 or later)
  - **KVM guests** in progress
  - **Docker** tbd
- **Operating Systems**:
  - ***SMC-D***
    - **Linux on Z**
    - **z/OS**: IBM z/OS V2R2 (via APAR) or later
  - ***SMC-R***
    - **Linux on Z**
    - **z/OS**: IBM z/OS V2R1 (via APAR) or later
    - **AIX**: System P with AIX 7.2, see https://ibm.biz/BdZutT

Supported Linux Distributions

- **RHEL 8**
- **SLES 12 SP4**: Use Linux kernel level 4.12.14-95.13.1 or higher (available via maintweb update) for essential bug fixes
- **SLES 15 SP1**
- **Ubuntu 18.10** or later
- **Note**: All shipments include z/OS compatibility

Prerequisites

- ***Direct connectivity*** over same IP subnet.
  I.e. no routed traffic, no peers in different IP subnets
- (R)DMA device(s) attached and configured
- PNET IDs assigned
- Linux kernel supports SMC-R and/or SMC-D
- ***TCP only***, i.e. no UDP
- No IPsec (SSL/TLS works)
- No NAT (violates same subnet prerequisite)

Usage Example: SMC-D

Prerequisites: Applications in different LPARs on same CEC communicating through HiperSockets.
ISM (FID: 80) and HiperSockets devices have the same PNET ID configured in IOCDS in each LPAR.

One-time Setup

```
# Hotplug ISM device if not yet visible via lspci command (see next step)
# Alternative: Use echo 1 > /sys/bus/pci/slots/00000080/power if smc_rnics is not available
$ smc_rnics -e 80

# Verify presence of ISM device
# NOTE: No extra setup for VLAN usage required
$ lspci
0001:00:00.0 Non-VGA unclassified device: IBM Internal Shared Memory (ISM) virtual PCI device
```

```
# Run application using smc_run
$ smc_run foo_socks

# Verify that SMC is really used
$ smcss -a
State          UID   Inode  Local Address           Foreign Address         Intf Mode
ACTIVE         20000 115762 10.101.4.8:60594        10.101.4.49:3220        0000 SMCD
ACTIVE         20000 112844 10.101.4.8:60592        10.101.4.49:3220        0000 SMCD
ACTIVE         20000 112605 10.101.4.8:60590        10.101.4.49:3220        0000 SMCD
```

Usage Example: SMC-R

Prerequisites: Existing Applications in LPARs on separate CECs communicating through OSA card `enccw0.0.f500`.
RoCE Express adapter has network interface `ens2` and infiniband interface `mlx4_0` - we will use its 1st port. No PNET IDs configured.

One-time Setup

```
# Verify presence of RoCE card
$ lspci
0000:00:00.0 Ethernet controller: Mellanox Technologies MT27500/MT27520 Family [ConnectX-3/ConnectX-3 Pro Virtual Function]

# Set RoCE card interface UP, and verify
$ ip link set ens2 up
$ ip link show ens2
3: ens2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc mq state UP mode DEFAULT group default qlen 1000
    link/ether 82:03:14:32:f1:a0 brd ff:ff:ff:ff:ff:ff

# OPTIONAL (VLANs only): Define an interface, and assign an IP – interface does not need to be in state UP!
$ ip link add dev ens2.201 link ens2 type vlan id 201
$ ip addr add 192.168.23.42/24 dev ens2.201

# OPTIONAL (no PNET IDs in IOCDs): Configure PNET ID on OSA and RoCE device:
$ smc_pnet -a PNET1 -I enccw0.0.f500 -D mlx4_0 -P 1
$ smc_pnet -s
PNET1 enccw0.0.f500 mlx4_0 1

# Run application using smc_run
$ smc_run foo_socks

# Verify that SMC is really used
$ smcss -a
State          UID   Inode  Local Address           Foreign Address         Intf Mode
ACTIVE         20000 115762 10.101.4.8:60594        10.101.4.49:3220        0000 SMCR
```

Deployment Considerations

- Verify that your workload is applicable to SMC
  Specifically, TCP only – e.g. Oracle RAC is known to predominantly use UDP, hence benefit will be small
- Take into account that SMC-D/R might not apply to all traffic
  Again, UDP traffic would continue to flow through regular NICs
- SMC-R: No link failover (yet)
  With support pending, HA must either be achieved in layers above networking, or be dispensable

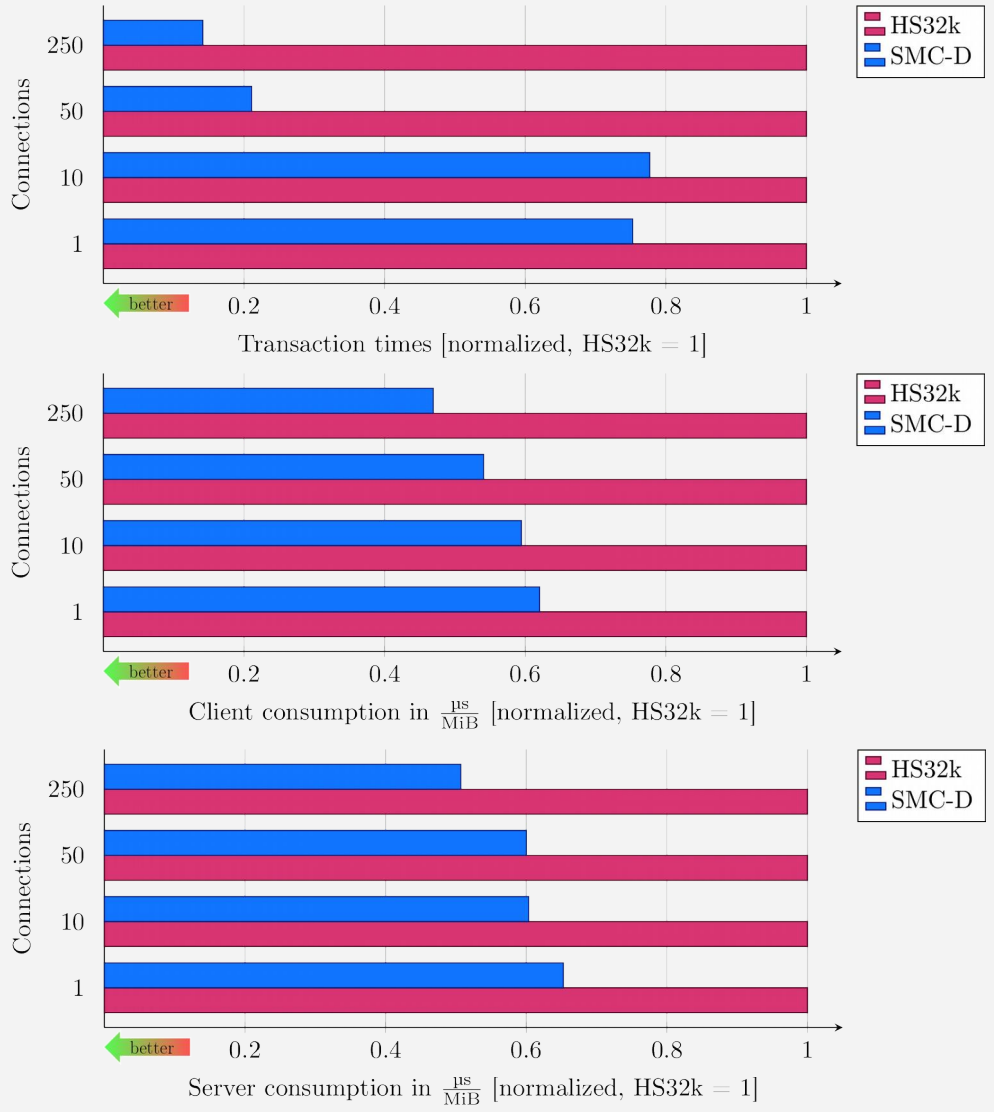
- z/VM
  - Utilize passthrough devices (OSA/HiperSockets/RoCE/ISM) for SMC-D/R usage without any restrictions
  - VSWITCH does not forward PNET ID from attached OSA to vNICs
    ⇒ Use *smc_pnet* to configure PNET IDs for SMC-R manually
- KVM
  - *virtio-net* devices do not forward PNET IDs
    ⇒ Use *smc_pnet* to configure PNET IDs for SMC-R manually

SMC-D Performance

- Machine: IBM z14
- Configuration:
  - 2 LPARs
  - Fedora28 with custom 4.16 kernel
  - Cores per LPAR: 10 IFLs
  - Memory per LPAR: 4GB
- SMC-D Setup (Client & Server)
  - Send buffer: 64KB
  - Receive buffer: 256KB
- Benchmark: *uperf* (https://github.com/uperf/uperf)
- Baseline: HiperSockets 32K
- **Note**: All results are preliminary and specific to this setup!

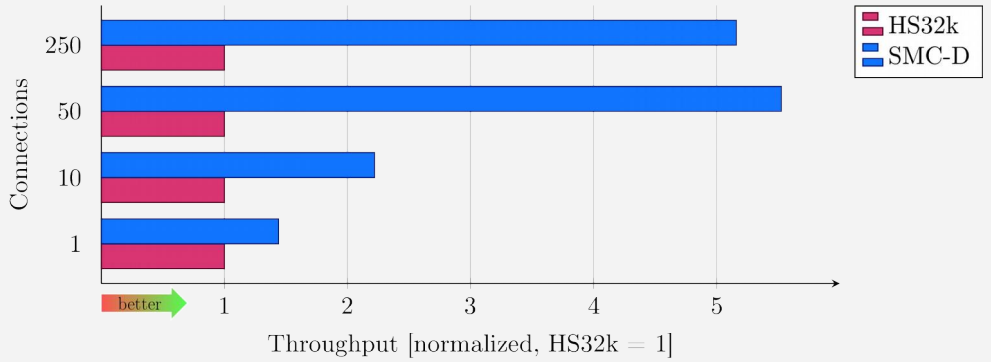
SMC-D Performance

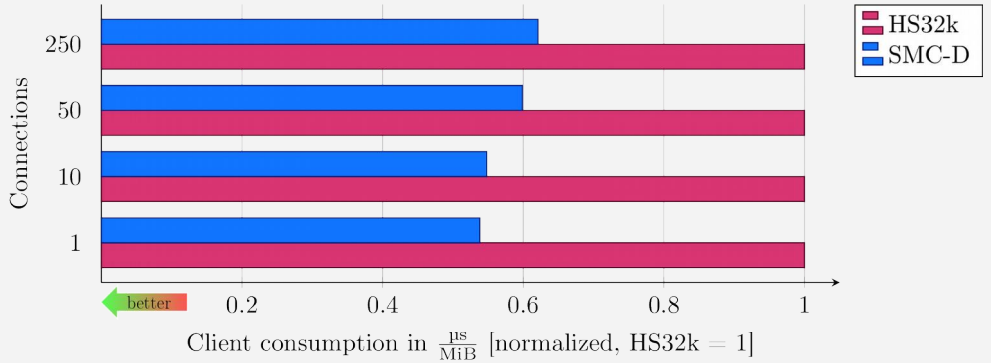
- Workload: **rr1c-200x1000**
- Results:
  - Transaction times reduced by 20% with SMC-D (up to 80% reduction for high numbers of parallel connections)
  - CPU consumption reduced by 30% to 50% for client and server with SMC-D

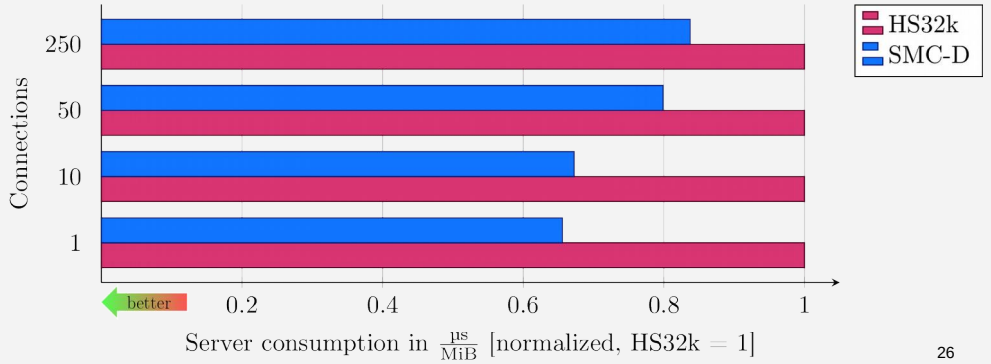


SMC-D Performance

- Workload: **rr1c-200x30K**
- Results:
  - Throughput increases by 1.4x (single connection) and up to 5x (high number of parallel connections) with SMC-D
  - CPU consumption reduced by 35% to 45% for the client with SMC-D
  - CPU consumption reduced by 15% to 35% for the server with SMC-D

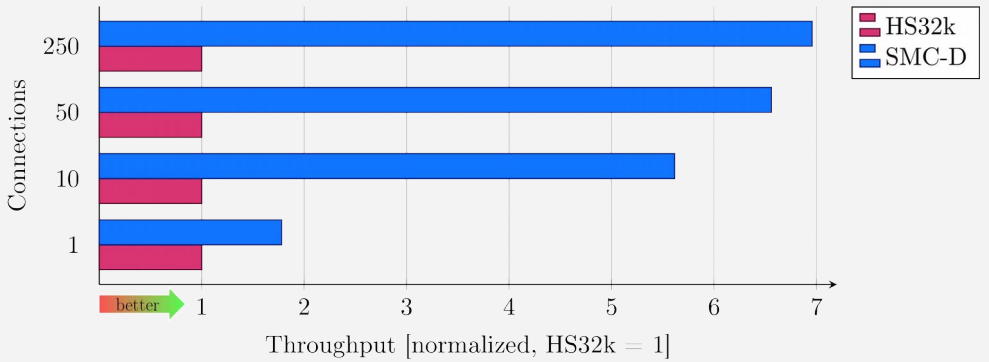


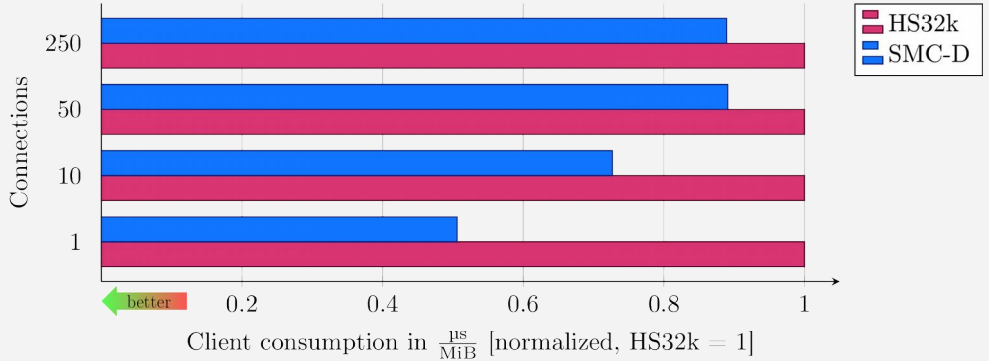


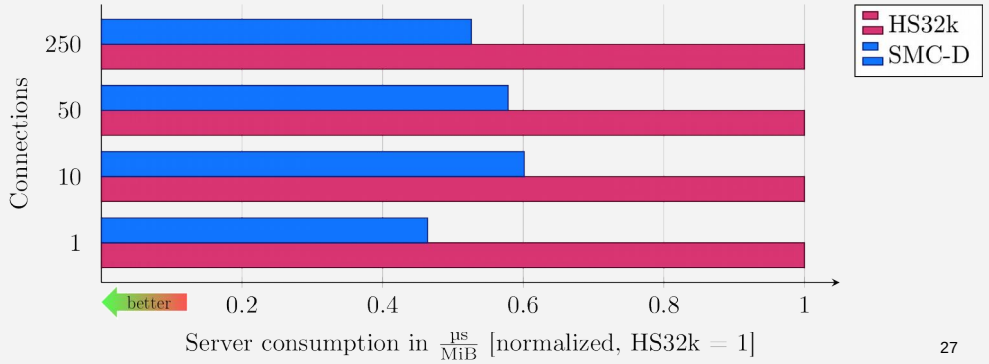


SMC-D Performance

- Workload: **str-writex30k**
- Results:
  - Throughput increases by 1.7x (single connection) and up to 6.9x (high number of parallel connections) with SMC-D
  - CPU consumption reduced by 10% to 50% for the client with SMC-D
  - CPU consumption reduced by 40% to 50% for the server with SMC-D



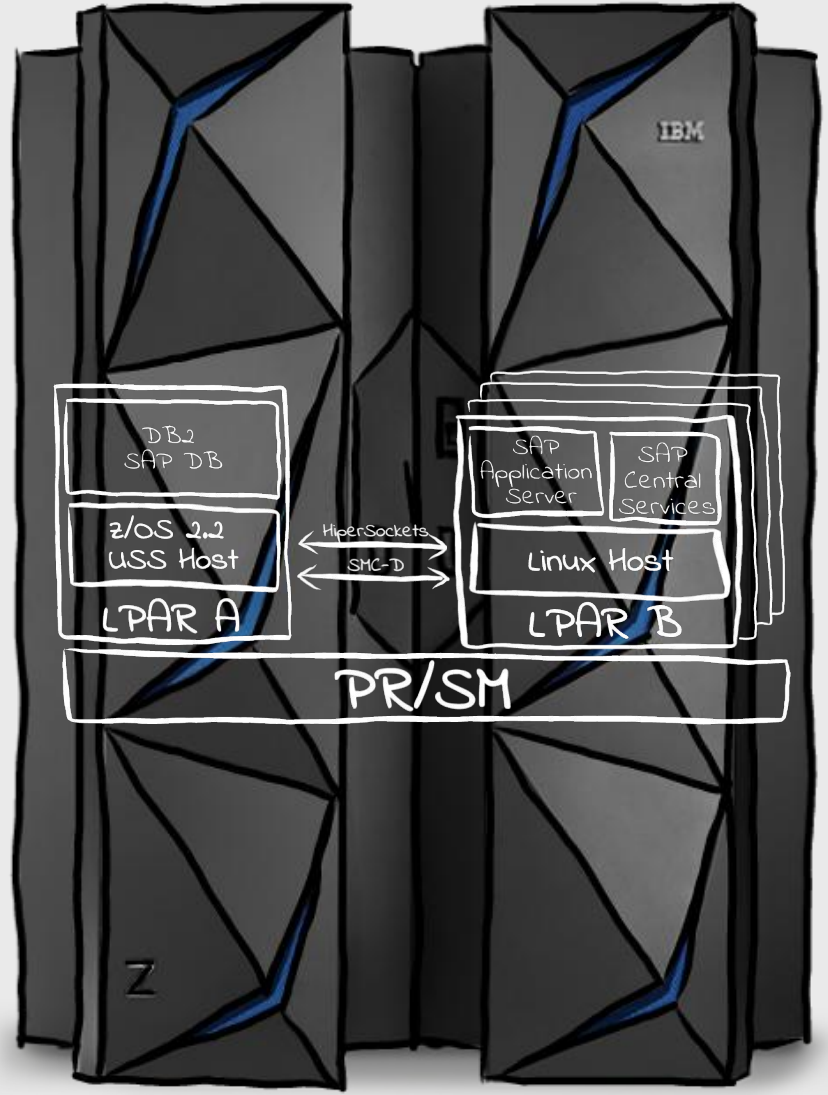




Usage Example: SAP on IBM Z

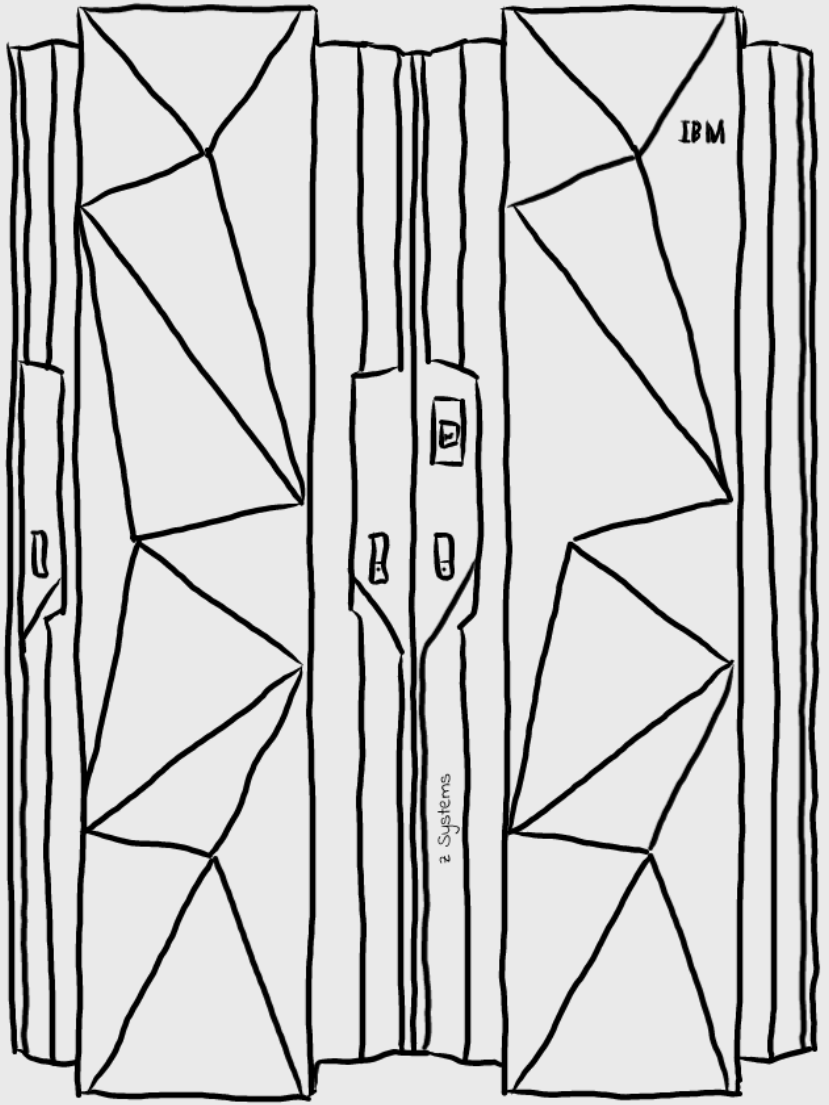
- Deploy
  - DB2 SAP Database on z/OS
  - SAP Central Services and SAP Application Server on Linux on Z
- Provides lower latency, less CPU used

→ Higher transaction rates



Agenda

- **SMC Basics**
  - Motivation
  - The SMC Protocol
  - Benefits
- **SMC for Linux on Z**
  - SMC-D and SMC-R
  - *smc-tools*
- **SMC in Action**
  - Usage Examples
  - Deploying SMC
  - Tips & Tricks
- **Outlook**
- **Miscellaneous**



More to come!

- Performance optimizations
- Failover support (SMC-R)
- Blacklisting peer IPs/ports
- Improved diagnostics
- Usage statistics
- ...

Summary

Key Attributes

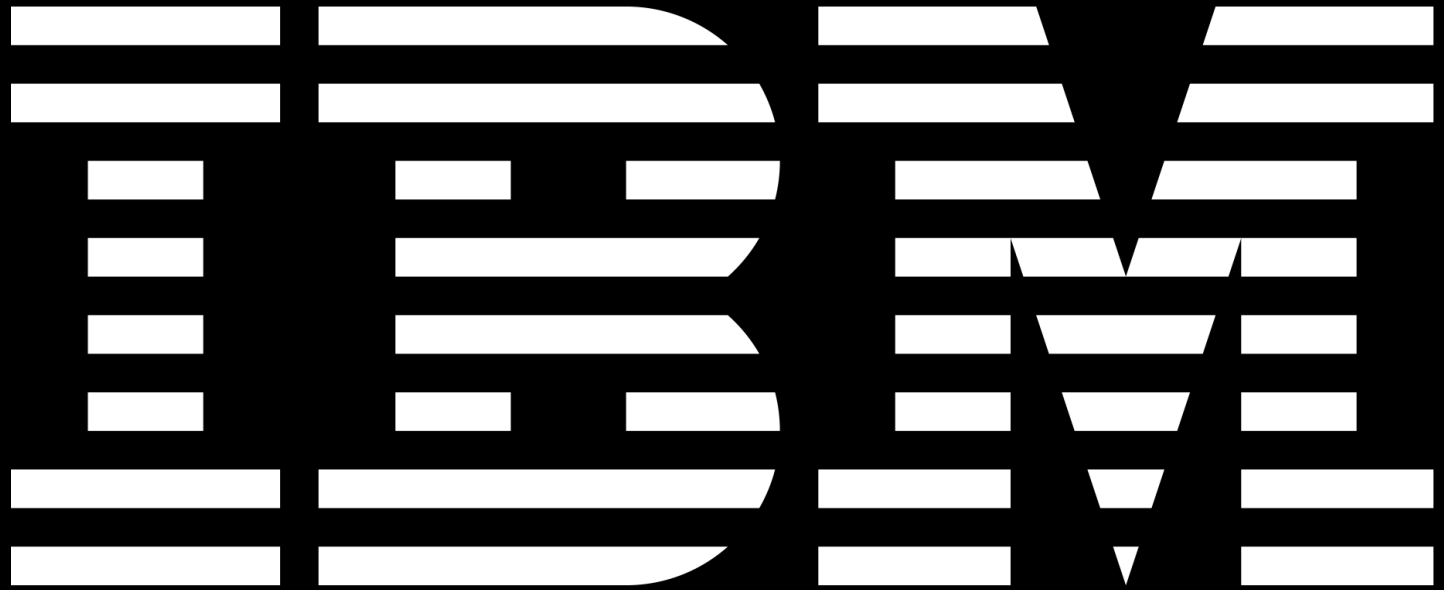
- Leverages existing Ethernet infrastructure (SMC-R)
- Transparent to (TCP socket based) application software
- Preserves existing network addressing-based security models
- Preserves existing IP topology and network administrative and operational model
- Transparent to network components such as channel bonding and load balancers
- Built-in failover capabilities (SMC-R)

Typical Workloads To Benefit

- *Transaction-oriented*,
- *latency-sensitive*, and
- *bulk data streaming*, e.g. when running backups.

References

- ***smc-tools* Homepage**
  https://www.ibm.com/developerworks/linux/linux390/smc-tools.html
- **Whitepaper: Performance Evaluation of SMC-D with SAP Banking on IBM Z**
  http://www-03.ibm.com/support/techdocs/atsmastr.nsf/WebIndex/WP102792
- **RFC7609 (SMC-R)**
  https://tools.ietf.org/html/rfc7609
- **Linux on Z (technical):**
  https://www.ibm.com/developerworks/linux/linux390/
- **SMC for Linux on Z:**
  http://linux-on-z.blogspot.com/p/smc-for-linux-on-ibm-z.html
- **Blogs**
  - **Linux on z distributions new**
    http://linuxmain.blogspot.com/
  - **Linux on Z latest development news**
    http://linux-on-z.blogspot.com/
  - **KVM on Z**
    http://kvmonz.blogspot.com/
  - **Containers on Z, primarily *Docker***
    http://containersonibmz.com/



Backup

How to verify Hardware Setup

- Use `lspci` to check RoCE and ISM device availability:

```
$ lspci
0000:00:00.0 Ethernet controller: Mellanox Technologies MT27500/MT27520 Family \
                                  [ConnectX-3/ConnectX-3 Pro Virtual Function]
0001:00:00.0 Non-VGA unclassified device: IBM Internal Shared Memory (ISM) virtual PCI device
```

- (z/VM only) Verify card attachment

```
$ vmcp 'QUERY PCIFUNCTION'
PCIF 00000280 ATTACHED TO S8360018 00000280 ENABLED  10GbE RoCE
PCIF 000002E2 ATTACHED TO S8360018 000002E2 ENABLED  ISM
```

- Verify PNET IDs are set and match (use smc_rnics and/or smc_dbg if available)

```
# RoCE device
$ cat /sys/class/net/ens1/device/util_string | iconv -f IBM-1047 -t ASCII
NetworkA

# ISM device with PCI ID 0001:00:00.0 according to lspci:
$ cat /sys/bus/pci/devices/0001:00:00.0/util_string | iconv -f IBM-1047 -t ASCII
vNetB

# OSA or HiperSockets device
$ cat /sys/devices/css0/chp0.`cat /sys/class/net/enccw0.0.f500/device/chpid`/util_string \
                                                          | iconv -f IBM-1047 -t ASCII
NetworkA
```

How to verify OS Setup

- RoCE Express cards: Verify port and NIC states:

```
$ cat /sys/class/infiniband/mlx4_0/ports/1/phys_state
5: LinkUp
$ cat /sys/class/infiniband/mlx4_0/ports/1/state
4: ACTIVE
$ ip link show ens2
3: ens2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 \
  qdisc mq state UP mode DEFAULT group default qlen 1000
    link/ether 82:03:14:32:f1:a0 brd ff:ff:ff:ff:ff:ff
```

- RoCE Express cards with VLANs: Verify VLAN interface exists and has IP address assigned (interface can be down)

```
$ ip addr show ens2.201
7: ens2.201: <BROADCAST,MULTICAST,DOWN,LOWER_UP> mtu 1500 \
  qdisc fq_codel master virbr0 state UNKNOWN group default \
  qlen 1000
    link/ether fe:54:00:f9:cf:be brd ff:ff:ff:ff:ff:ff
    inet 192.168.23.42/24 scope global vnet3
       valid_lft forever preferred_lft forever
```

- Check available free memory via `/proc/meminfo`:

```
$ grep "^Mem" /proc/meminfo
MemTotal:        1710584 kB
MemFree:           83404 kB
MemAvailable:    1125752 kB
```

- Check smcss output for reason code:

```
$ smcss -a
State  UID   Inode  Local Address    [...] Intf Mode
ACTIVE 20000 115762 10.101.4.8:60594 [...] 0000 TCP 0x05000000/0x0000521e
```

- Troubleshooting z/OS
  - "*Autonomics*" function might disable connections to peers that are unlikely to benefit from SMC (most typically: Short-lived connections exchanging few data) for a certain period of time. In the TCP/IP profile change

    ```
    GLOBALCONFIG SMCGLOBAL NOAUTOSMC
    ```

  - See https://ibm.biz/BdZts8 for further details.

How to enable unruly Applications

- Some applications have involved startup procedures that will not easily work with `smc_run`
- **Example**:
  DB2 requires registration of environment variables through `db2set` command.

```
$ db2set –i db2inst1 \
    DB2ENVLIST="LD_LIBRARY_PATH \
    LD_PRELOAD"
$ smc_run db2start
```

- If `smc_run` does not work for an application with PID <p>:
  - Check `/proc/<p>/environ` whether `LD_PRELOAD` is set correctly!

- Alternative approaches:
  - Set LD_PRELOAD in the user ID's profile that starts the respective processes, e.g. the DB2 instance owner:

```
$ echo "export LD_PRELOAD=\
libsmc_preload.so" >> ~/.profile
```

  - Use `/etc/ld.so.preload` to enable the entire system:

```
$ cat /etc/ld.so.preload
libsmc_preload.so
```

- **Note**: This will add the preload library to ***all*** processes on the entire system or started by the respective user! This includes processes not performing any socket operations at all, e.g. the `ls` command.
- Therefore, always prefer usage of `smc_run`