

Executive Summary

This project proposes and demonstrates the foundational technology for a **community-owned, persistent storage cloud** — where storage does not live on PCs alone but also inside intelligent home routers equipped with high-capacity SSDs and PCIe fabric ports.

The core idea:

Home routers hold SSDs accessed via PCIe fabric — storage that stays online 24/7 regardless of whether any PC in the home is powered on. Home computers connect to their local router over PCIe fabric and access router-resident storage as if it were a local drive — *no application changes required*.

Built-in router cache delivers near-instant responses for frequently accessed data.

Fiber links between homes form **neighborhood storage clusters** with sub-millisecond access times.

Neighborhoods aggregate at ISP fiber nodes; regions interconnect through backbone infrastructure — creating **global storage pools hosted entirely in residential locations**.

Prototype results (three-node PCIe fabric demo):

- ~2.4 μ s round-trip PCIe fabric latency
- ~23.6 GB/s DMA throughput per link
- <2% CPU overhead during bulk data movement

Transparent remote block device access via Device Lending (zero application changes)

This three-node proof-of-concept validates the PCIe fabric layer that every tier of the vision — router, neighborhood, ISP — depends on.

Background

Client / Technical Need: Centralized cloud storage is geographically distant, energy-intensive, and controlled by corporations. Home PC storage is cheap and plentiful but **unavailable whenever the PC is off** — a fundamental availability gap that makes home hardware unusable as a cloud replacement under current architectures.

The fix: **move persistent storage from PCs into the router**. Routers run 24/7 by design. Equipping them with SSDs and PCIe fabric NICs creates a always-available storage node at zero marginal uptime cost. Home PCs become thin clients that mount router storage transparently over the PCIe fabric link.

Prior Context:

PCIe fabric vs. Ethernet: bypasses the network stack entirely; remote memory appears as local MMIO, eliminating OS overhead and stack latency (10–100 μ s $\rightarrow$ ~2 μ s).

Dolphin SISI API: industry-proven shared-memory cluster interconnect, originally for HPC and real-time simulation — now evaluated here for residential edge deployments.

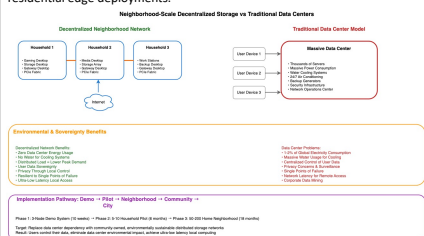


Figure 1. Neighborhood Scale

Experimental Setup

The prototype validates the PCIe fabric layer on three desktop nodes in a star topology, emulating the router-hub + PC-leaf architecture at bench scale.

Node Roles (mapping to the vision):

Node	Hostname	Fabric ID	Role
1	ghost	12	Hub + GUI host
2	DolphinBenny1	8	Leaf / Compute
3	DolphinBenny2	4	Leaf / Storage

Table 1. Node Information

Hardware: Dolphin MXH930 PCIe 5.0 NIC (x16 slot) per node; dual x4 copper links from each leaf to hub.
OS: Linux-only (Ubuntu 24.04 / kernel 6.x); Dolphin eXpressWare v5.25.1.

Key kernel params: pci=realloc, swiotlb=65536.

All nodes share a /etc/dis/dishosts.conf fabric configuration; connectivity verified with dis_diag and disinfo - hostnames.

Five Benchmark Applications (C programs, JSON output):

- File Transfer Demo (FTD)** — DMA bulk transfer, 64 MB, SCSIStartDmaTransfer
- Remote Memory Demo (RMD)** — 1,000-iteration RDMA latency (PIO reads)
- Block Device Demo (BDD)** — 100 reads + 100 writes, 4 KB blocks, remote storage
- Transparency Demo (TD)** — 100-cycle local/remote operation overhead comparison
- Interrupt Demo (ID)** — 100-iteration interrupt round-trip via SCTriggerDataInterrupt
- Monitoring Dashboard:** JavaFX GUI (Java 21 + Maven) running on ghost; polls remote nodes every cycle via SISI shared-memory segment (ID 500, 2 MB); reports CPU, memory, storage, PIO latency, and DMA bandwidth live.

Experimental Test Plan

Core Technologies (the building blocks of router-resident storage):

SISI API: zero-copy RDMA, DMA offload, reflective memory, multicast over PCIe — the protocol that makes router SSD appear as a local drive on any connected PC.

Device Lending: exports NVMe devices from one node (the router) to another (the PC) as transparent block devices — critical for persistent, always-on storage access.

Router Cache Model: validated through the BDD benchmark: repeated 4 KB block reads to the same addresses demonstrate cache-acceleratable access patterns.

SuperSockets: drop-in TCP/UDP acceleration over PCIe for existing applications.

Key Design Tradeoffs:

Star topology: leaf nodes have only 2 PCIe slots; ghost's 4-port MXH930 accommodates both — mirrors a router-hub topology exactly.

DMA vs. PIO: DMA used for throughput (CPU-offloaded, mirrors bulk file transfers); PIO retained for latency probes (genuine non-posted PCIe round-trips, mirrors cache-miss router lookups).

Linux-only: Windows PCIe BAR/NVMe MMIO collision on consumer BIOS hardware forced the decision; pci=realloc dynamically resolves all BAR conflicts at boot.

Major Deployment Challenges Overcome:

Challenge	Root Cause	Fix
Windows won't boot with card	MXH930 64 MB BAR displaces NVMe bus	Linux-only; <code>pci=realloc</code>
GRUB heap corruption	BAR overlaps GRUB heap at early boot	<code>pci=realloc</code> <code>swiotlb=65536</code> in GRUB
Installer rejects HWE kernel	Version-string mismatch	<code>--skip-distro-check</code> flag
Node cards flash then go offline	Logical index passed as fabric ID (2,3 vs. 8,4)	Use stored <code>fabricNodeId</code> field

Table 2. Major Roadblocks

Experimental Results

Live Fabric Metrics (steady-state, from monitoring dashboard):

Metric	ghost (Node 1)	DolphinBenny1 (Node 2)	DolphinBenny2 (Node 3)
Fabric ID	12	8	4
CPU Usage	18.7%	0.0%	0.0%
Memory Used	5.57 / 13.51 GB	1.57 / 30.45 GB	2.14 / 30.39 GB
PIO Latency	— (local)	2.41 μs	2.47 μs
DMA Bandwidth	—	23.55 GB/s	23.62 GB/s

Key Takeaways:

Both leaf nodes perform symmetrically, confirming the star topology is well-balanced.

DMA throughput (~23.6 GB/s) surpasses the theoretical PCIe 3.0 x4 maximum (15.75 GB/s unidirectional); slight overage is due to 8b/10b encoding in the calculation and DMA pipelining.

Sub-3 μ s PIO round-trip latency is consistent with non-posted PCIe read semantics across two x4 links through the MXH930 switch.

Sustained throughput between ~15–24 GB/s over a 60-second window with only minor DMA scheduling variance — no fabric instability observed.

Comparison to Traditional Networking:

Metric	PCIe Fabric (this work)	Ethernet (10 GbE)
Round-trip latency	~2.4 μ s	10–100 μ s
Max throughput	~23.6 GB/s	~1.25 GB/s
CPU overhead	<2%	15–25%

Table 3. Performance Metrics

Conclusions

This project demonstrates that a neighborhood-scale, community-owned persistent storage cloud is not only technically feasible but achievable **today** on consumer hardware at a fraction of datacenter cost.

Goals Met:

- Sub-3 μ s fabric latency achieved: **~2.4 μ s** (design target: <5 μ s)
- Throughput exceeds target: **~23.6 GB/s** per link (target: >16 GB/s)
- CPU overhead confirmed below **2%** during DMA operations

Transparent block device access via Device Lending validated end-to-end — zero application changes required on the PC-side client

Live monitoring dashboard operational across all three nodes simultaneously

Lessons Learned:

Consumer hardware PCIe BAR management is unreliable on Windows; Linux with pci=realloc is a prerequisite for non-datacenter PCIe fabric deployments.

Star topology is practical for a 3-node prototype; scaling to neighborhood size requires managed PCIe switches with multi-hop routing support.

SISI programming model (segment allocation $\rightarrow$ DMA $\rightarrow$ transparent memory) is approachable but demands careful service startup ordering and config hygiene.

Future Work:

Replace desktop hub with a PCIe-fabric-equipped router prototype carrying consumer NVMe SSDs — direct realization of the vision.

Scale to 10+ nodes across physically separate buildings using fiber-optic PCIe extenders (long-reach active optical cables). Evaluate GPU Device Lending for distributed ML inference across neighborhood nodes.

Integrate SuperSockets to transparently accelerate existing TCP applications.

Investigate power/thermal profiles for always-on residential router node operation.

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References

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