Deep Note: Can Acoustic Interference Damage the Availability of Hard Disk Storage in Underwater Data Centers?

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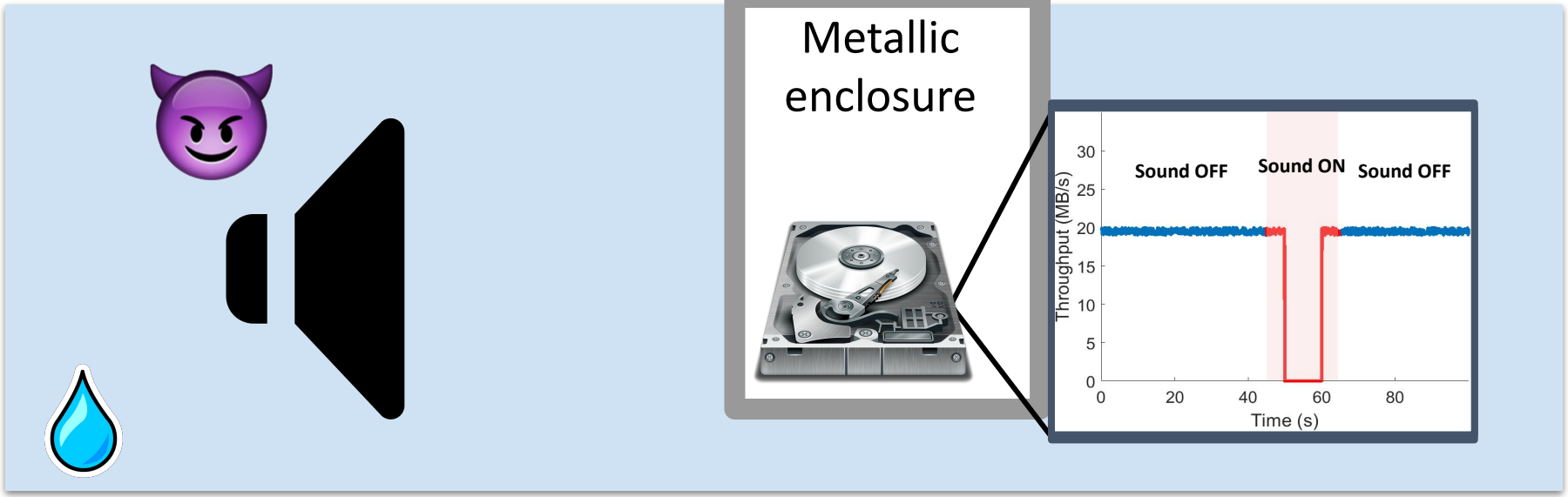
Research Overview and Contributions

- Hard Disks are susceptible to underwater acoustic injection attacks
- Effects on datacenter applications that use hard disk drives
  - **Throughput loss**
  - **Application crashes**



Subsea Cloud announces three underwater data center projects

And clarifies, it's not a cloud company

September 01, 2022 By: Peter Judge Have your say

[Source: https://www.datacenterdynamics.com/en/news/subsea-cloud-announces-three-underwater-data-center-projects/]

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Underwater data center in good condition

By CHEN BOWEN in Haikou | chinadaily.com.cn | Updated: 2023-06-06 16:16

China Daily App Downl

le of the Hainan Undersea Data Center is launched on March 31 in Lingshui Li autonomous county of Hainan province.

[Photo by Tang Fei/For chinadaily.com.cn]

[Source: https://www.chinadaily.com.cn]

Microsoft finds underwater datacenters are reliable, practical and use energy sustainably

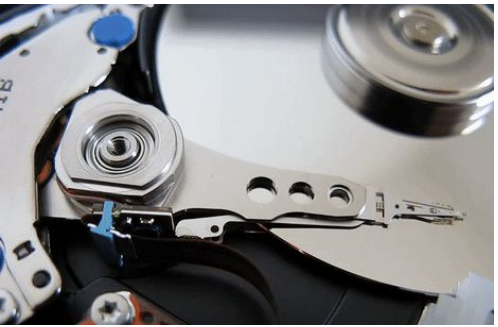
[Source: https://news.microsoft.com/source/features/sustainability/project-natick-underwater-datacenter/]

Underwater Data Center (UDC) Market is anticipated to expand at a CAGR of +31% by 2029

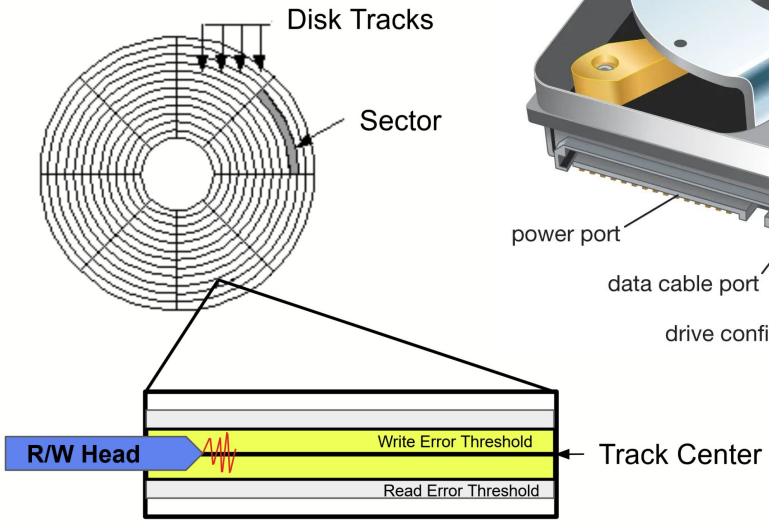
[Source: https://news.microsoft.com/source/features/sustainability/project-natick-underwater-datacenter/]

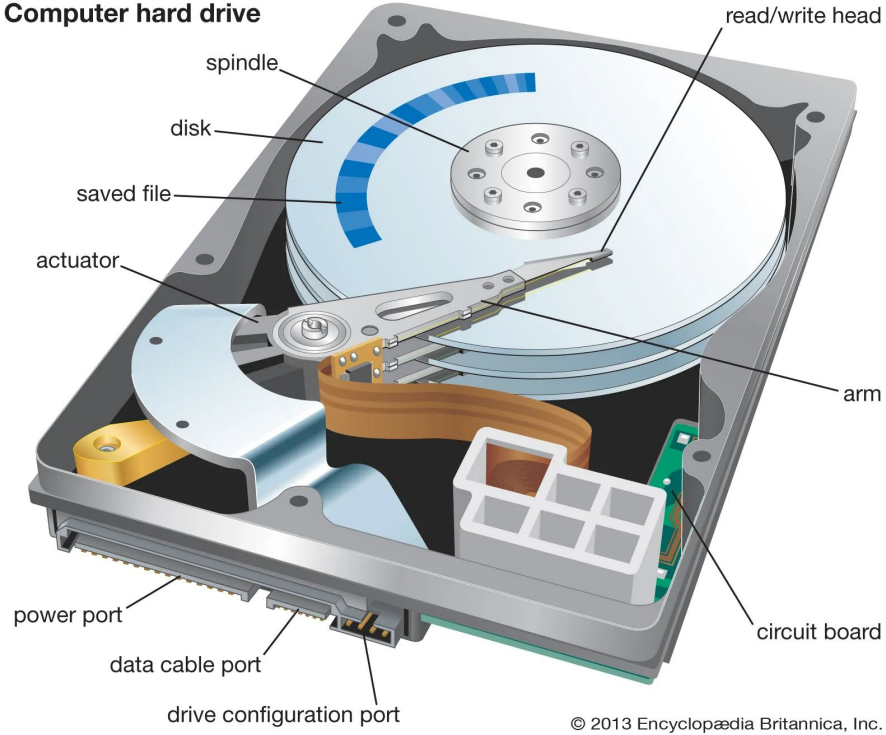
Storage Systems in Datacenter

- HDD Components
  - Disk platters
  - Read/Write Heads with actuators
  - Spindle Motor



[Source: https://www.youtube.com/watch?v=BlB49F6ExkQ]



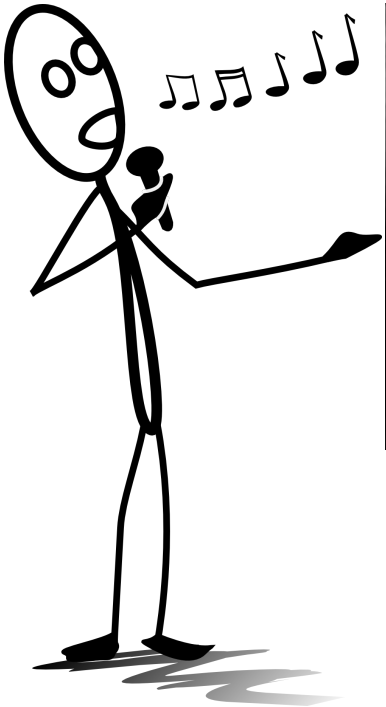


Resonant Frequencies

- Objects have natural frequencies of vibration (*resonance frequencies*)
  - Depend on material and structure

- Playing sounds at an objects' resonance frequency can causes them to vibrate at maximum amplitude

- Previous works have shown that acoustic vibrations can cause failures in sensors and actuators

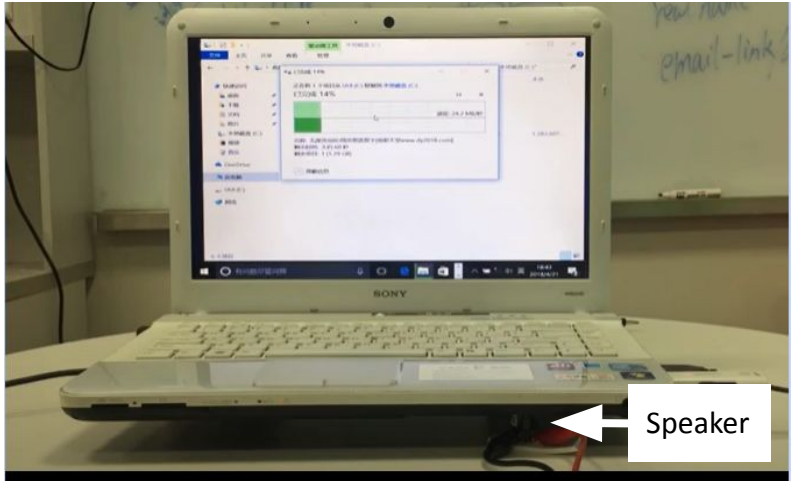


[Source:https://www.youtube.com/watch?v=CdUoFIZSuX0]

Strong Sound Inducing Mechanical Vibrations (in air)

- [Bolton at al., 2018 IEEE S&P]: Effect of strong sounds transmitted in air on computers:
  - Crashes of laptop operating systems
  - Missing security camera recordings

- **Can acoustic attacks affect storage devices in enclosed structures underwater?**



[Source Bolton et al., 2018 IEEE S&P]

Acoustic Propagation in Water

- Acoustic pressure: $p(t) = d \cdot c \cdot v$
  - d: density of medium
  - c: sound speed
  - v: particle velocity

- Water is denser than air
  - Sound travels **4 times faster** in water

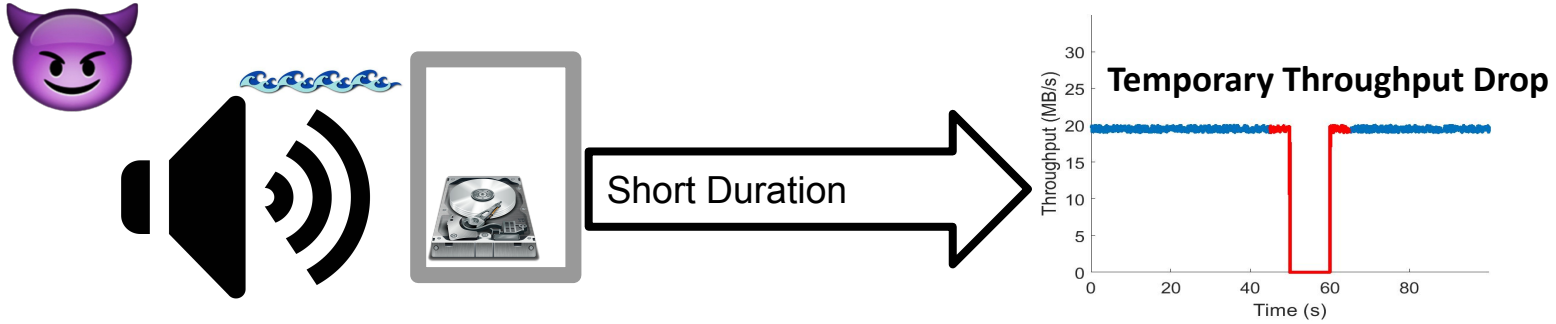
- 61 dB more energy required to transmit sound air vs water
  - Ex. **130 dB in water is equivalent to 70 dB in air**

[Source:https://www.youtube.com/watch?v=01QJXvH_iQY]

[Source:https://www.youtube.com/watch?v=THUMdToNWkI]

Threat Model

- **Attacker goal**: Affect the functioning of a storage system deployed underwater
- **Capabilities:**
  - Generate sounds at the required frequency and amplitude to cause resonance
  - Knowledge of the target storage device
- **Assumptions:**
  - No tampering
  - No malware/access to the storage applications



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Application Crashing

```
WARNING: Assertions are enabled; benchmarks unnecessarily slow
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DB path: [/home/weidong/zwd/db]
db_bench: ./file/writable_file_writer.h:298: rocksdb::IOStatus rocksdb::Writable
FileWriter::AssertFalseAndGetStatusForPrevError(): Assertion `sync_without_flush
_called_' failed.
Received signal 6 (Aborted)
Invoking GDB for stack trace...
```
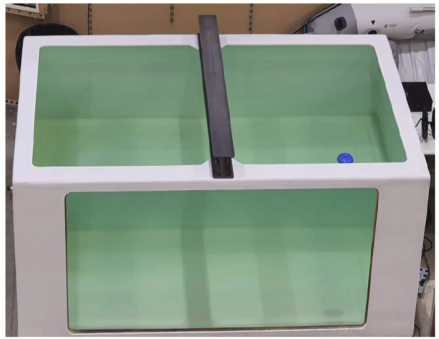
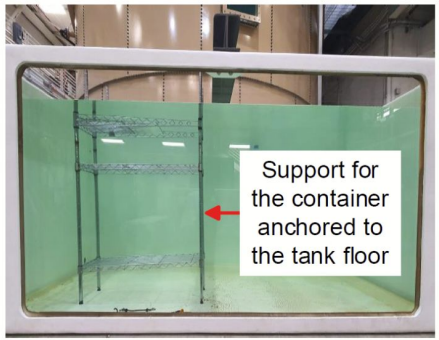
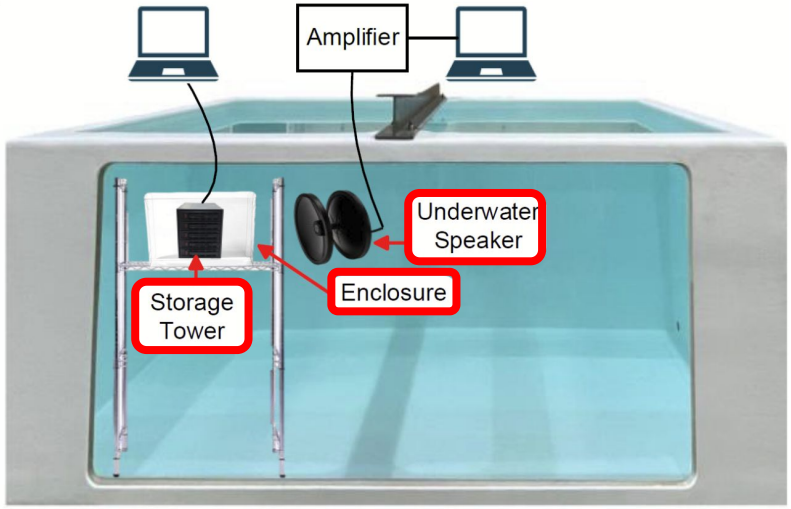

Testbed



Testbed
5x10x4 ft

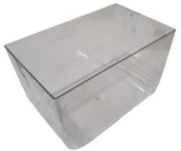




Full Setup

Metal Enclosure

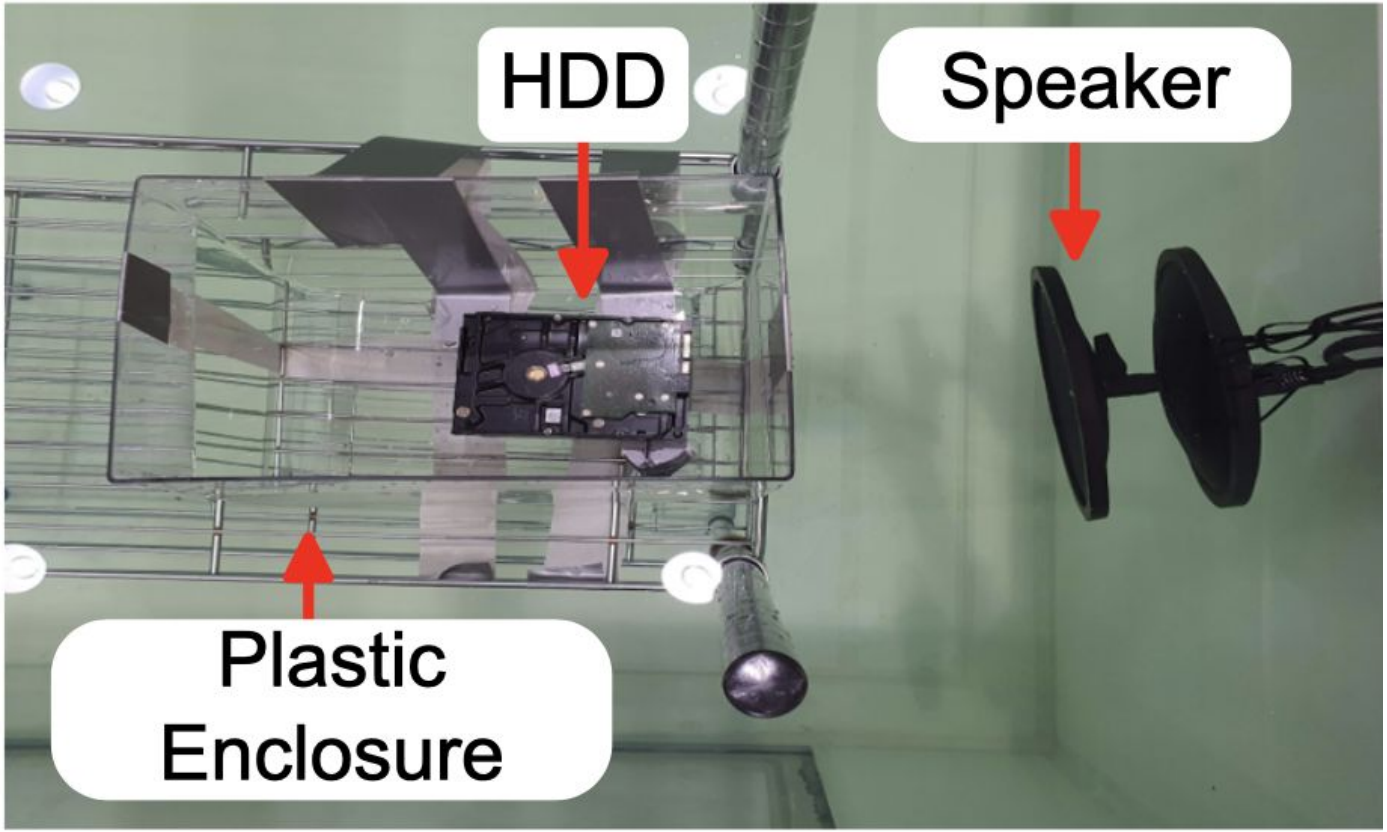
Storage Tower



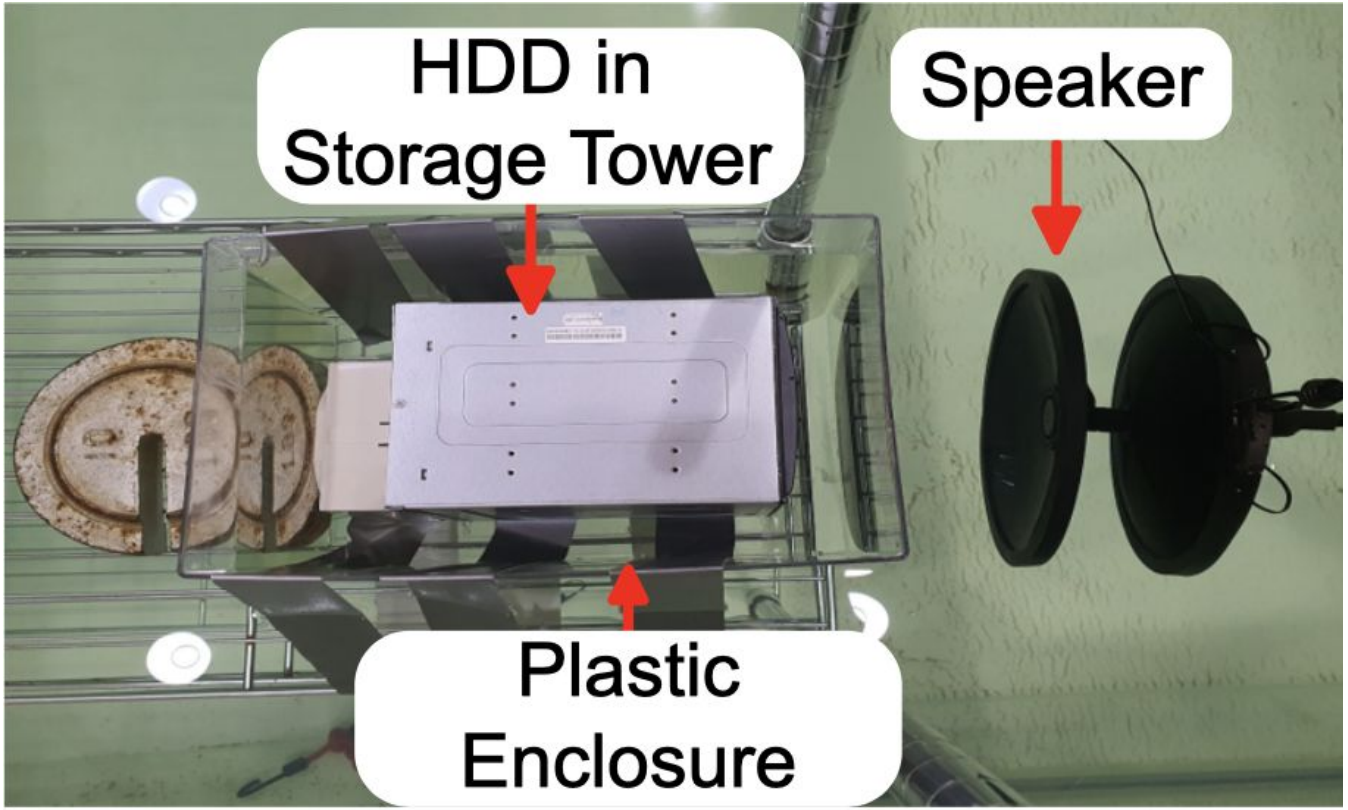
Plastic Enclosure

HDD

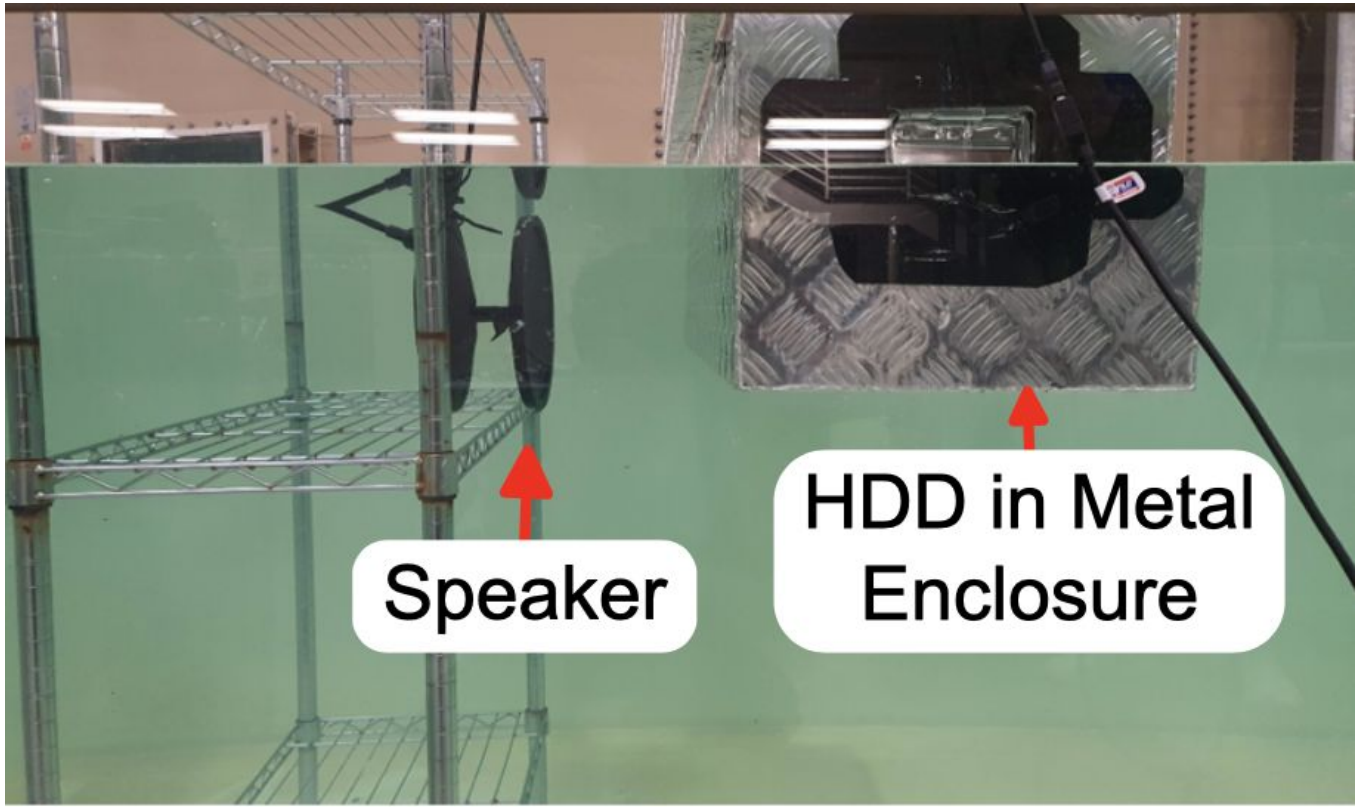
Scenario 1



Scenario 2



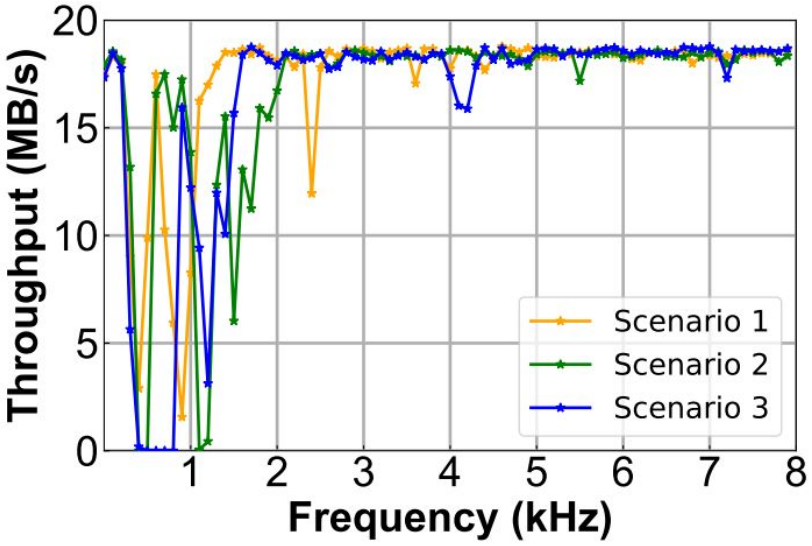
Scenario 3

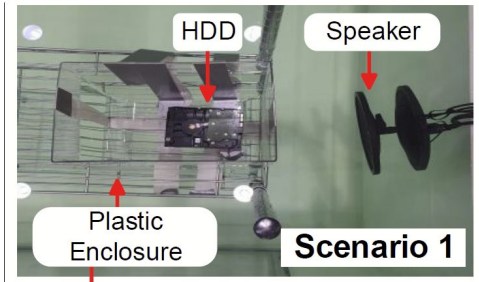


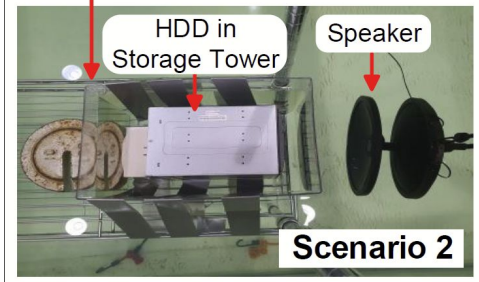
Finding the Vulnerable Frequencies

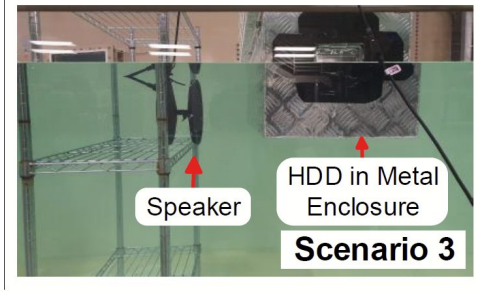
- Throughput for reads and writes monitored using FIO (Flexible I/O Tester)
  - **300 - 800 Hz has an average throughput drop of 94% in Scenario 3 (metal structure)**

Read operations





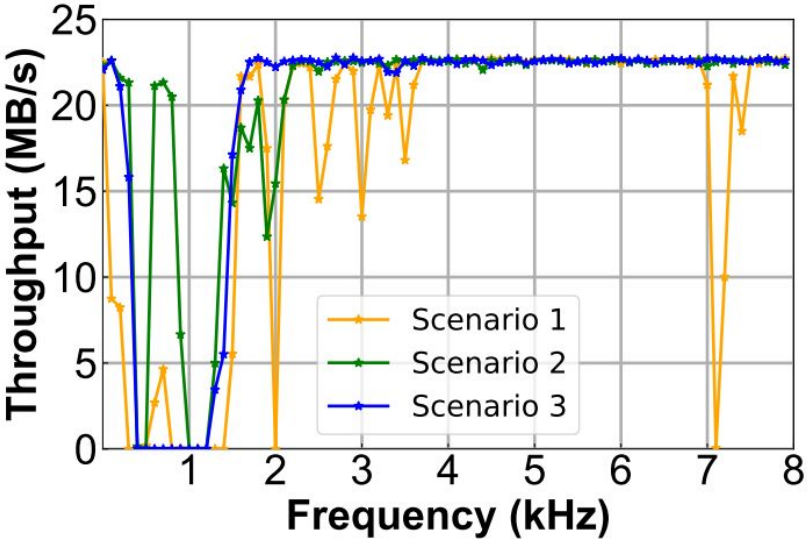


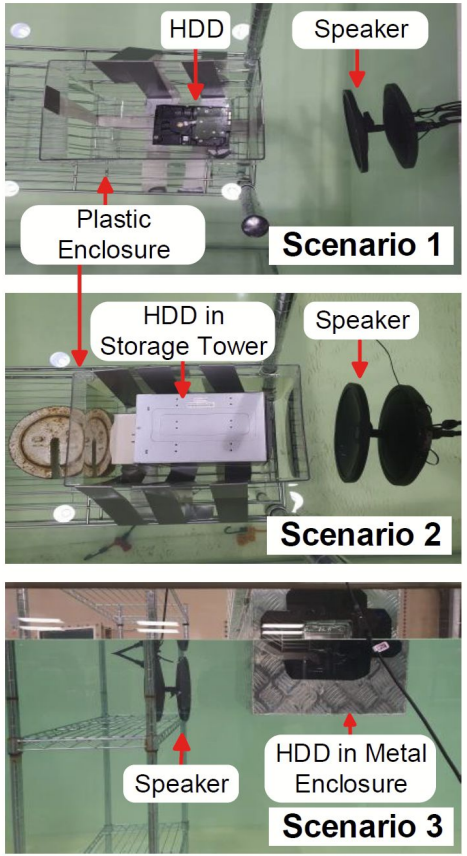


Finding the Vulnerable Frequencies

- Throughput for reads and writes monitored using FIO (Flexible I/O Tester)
  - **300 - 1300 Hz has an average throughput drop of 92% in Scenario 3 (metal structure)**

Write operations

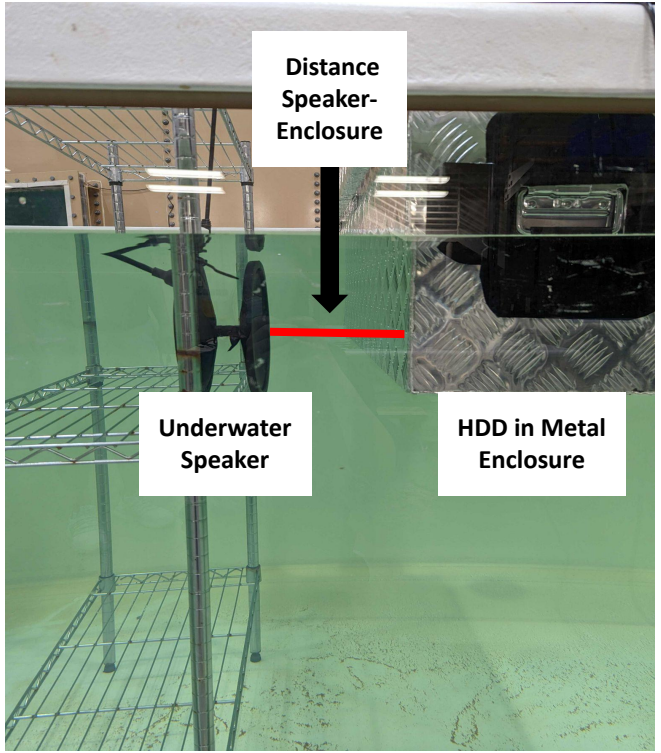




Attacker Capability: Distance Testing with FIO

- 140 dB SPL underwater
  - Maximum attack distance 25 cm with **a commercial swimming pool speaker**
  - Maximum distance for 100% throughput loss = 5 cm

- Potential further distance possible using powerful equipment (e.g., sonar 220 dB SPL)
  - 1740 km theoretical distance



Data-Center Applications: Time-To-Crash Testing

Application	Description	Time-to-crash	Operation
Ext4	Journaling filesystem	80.0 seconds	*ls* command
Ubuntu	Ubuntu server 16.04	81.0 seconds	Idle running
RocksDB	Key-value database	81.3 seconds	Db_bench benchmark with readwhilewriting workload

```
WARNING: Assertions are enabled; benchmarks unnecessarily slow
------------------------------------------------
DB path: [/home/weidong/zwd/db]
db_bench: ./file/writable_file_writer.h:298: rocksdb::IOStatus rocksdb::Writable
FileWriter::AssertFalseAndGetStatusForPrevError(): Assertion `sync_without_flush
_called_' failed.
Received signal 6 (Aborted)
Invoking GDB for stack trace...
```

Open Challenges & New Research Directions

- **Attacker Capability**
  - Commercial vs military-grade speaker
  - Underwater environment (pressure, salinity, temperature, obstacles)
  - Data center structure
  - Robotic attack
- **Storage systems and datacenter configurations**
  - RAID
  - Enterprise vs consumer HDDs vs SSDs
- **Effectiveness of known in-air defenses**
  - Feedback controller
  - Dampening materials

Takeaways

- Acoustic injection attacks against storage system deployed underwater are feasible
- Attackers may disrupt throughput or cause critical application to crash
- Further research is needed to clarify attacker capabilities and defense effectiveness

[Source: https://www.theverge.com/2020/9/14/21436746/microsoft-project-natick-data-center-server-underwater-cooling-reliability]

Thank you!

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