

Using Distributed Ledger Technology for Command and Control and Decentralized Operations

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Outline

- Motivating scenario
- Requirements
- Solution – Distributed Ledger Technology
- CARDIAC – Exploratory study
  - Solution alternatives
  - Prototype systems
  - Experimental results
- Future work

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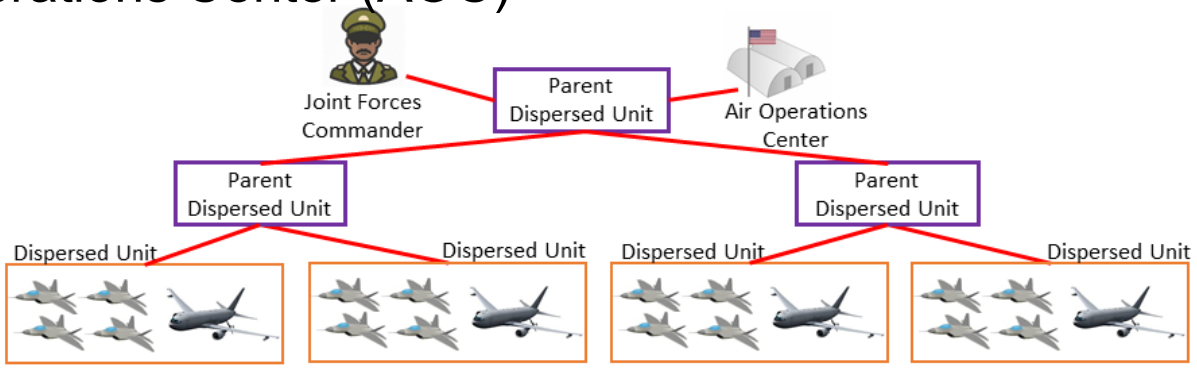
Motivating Scenario

- Air Force base is under threat of immediate attack
- Joint Forces Commander (JFC) splits forces, deploys them Forward Operating Bases
  - Divide forces into Dispersed Units (DU) – four fighters, one tanker, associated ground crews
  - Organize DUs into several levels of Parent Dispersed Units (PDU)
  - Top-level PDU includes JFC, air planning components in Air Operations Center (AOC)



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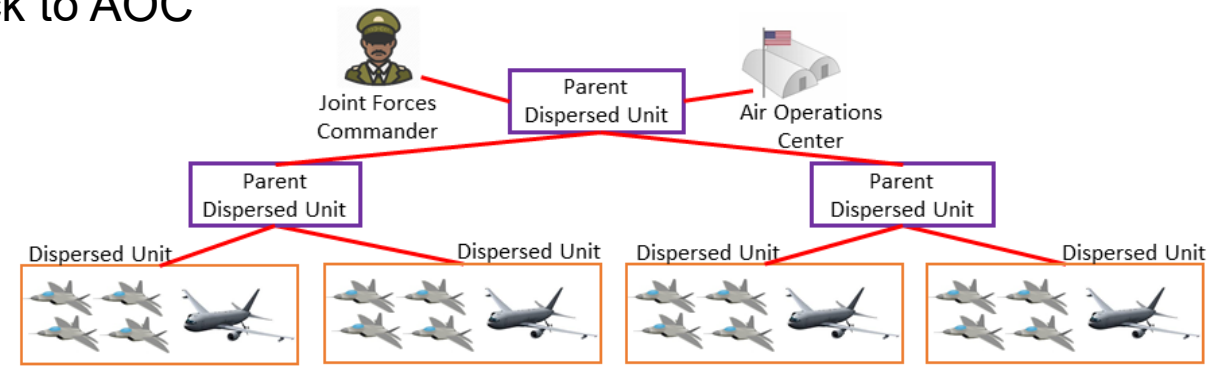
Motivating Scenario

- Prior to dispersion, AOC develops air campaign plan (Commander's Objective, target lists, target assignments) and pushes it to DU aircraft
- During the campaign, DU-PDU communication cut off by jamming, cyber attack, terrain
  - DUs need authority to modify plans in response to pop-up targets, changing battlefield conditions
  - Authority resides with AOC – need to delegate to DUs
  - When communications restored, plan changes must be communicated back to AOC



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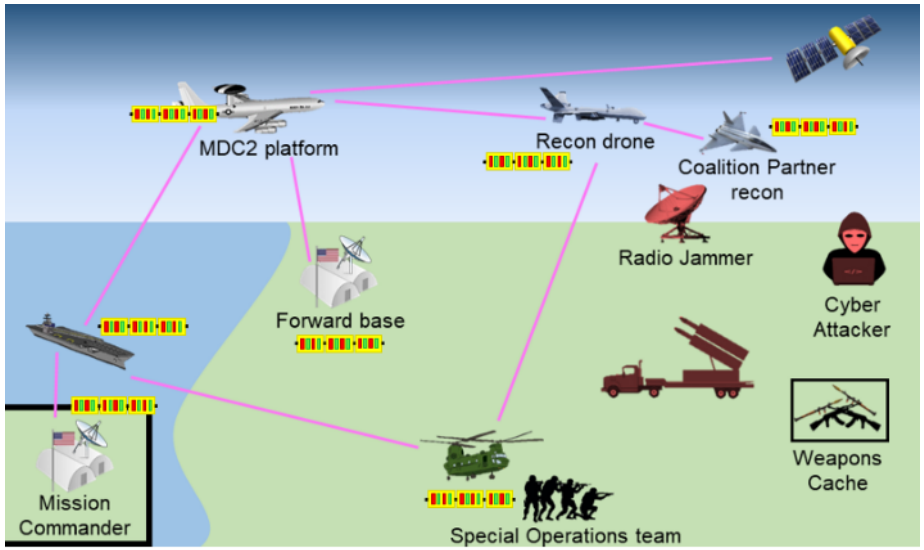
Dispersed C2 Requirements

- Air Force needs a next-generation Multi-Domain Command and Control (MDC2) system that provides…
  - Distributed information management
  - Conditional Authorities
  - Merging parallel data evolution histories
  - Data evolution provenance



Dispersed C2 Solution

- Build next-gen C2 system that supports
  - Disconnected operations - Conditional authorities calculus
  - Data integrity/provenance
- Our solution – Leverage Distributed Ledger Technology (DLT e.g., blockchain) for C2
  - Leaderless distributed database - Permissioned Access control
  - Smart Contracts (conditional authorities) - Data provenance/integrity
- CARDIAC (Study)
  - Establish feasibility/calibrate C2 data handling on DLT
  - Identify C2 sweet spots/chart path for a full DLT-based C2 program

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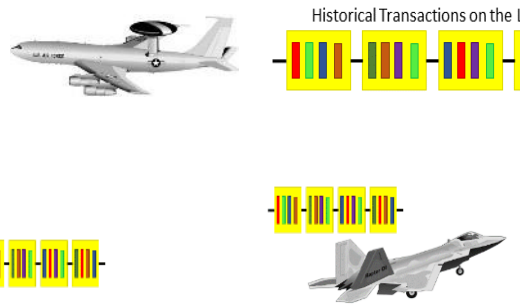
Distributed Ledger Technology

- What is DLT?
  - Distributed Ledger Technology is a distributed database
  - Multiple nodes maintain a copy of the database
  - Database transactions are bundled into “blocks”, which are appended into a “chain”
    - Blocks are cryptographically signed by their own contents and those of previous block – modifying the block will make these signatures invalid
    - Guarantees ***immutability*** – any tampering with blocks is easily detected
    - Transaction history can be traced – ***provenance traceability***
  - Any network node can be the leader for purposes of creating a block – ***decentralized*** operation



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CARDIAC Study Goals

- Develop Use Case
- Investigate DLT options
- Build Prototypes
  - DLT-based prototype
  - Traditional database baseline
- Experimentation
- Metrics
- Recommendations

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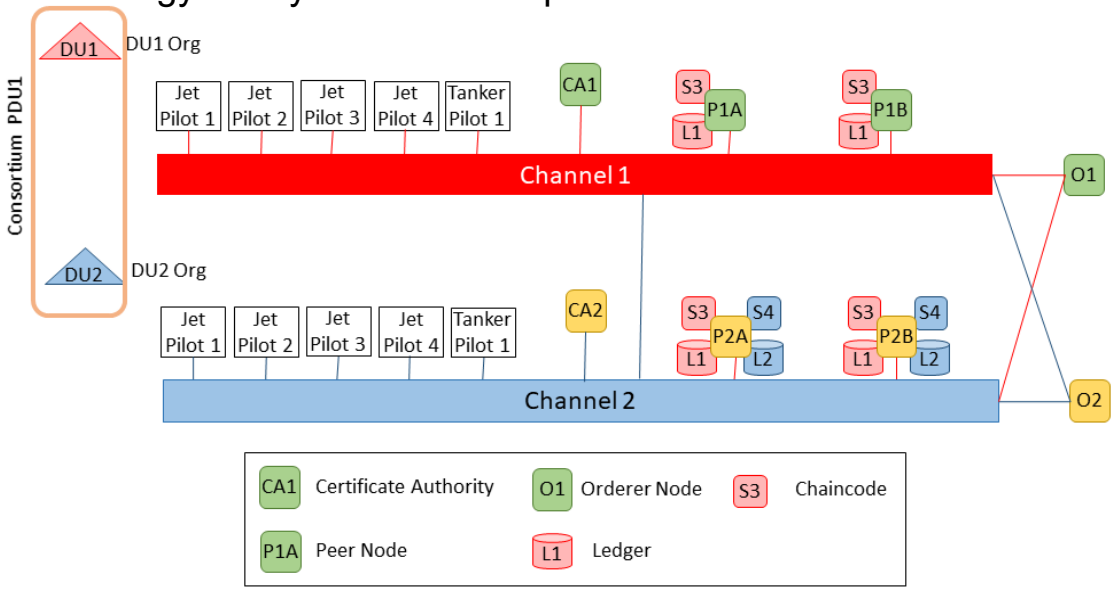
DLT Options

- Investigated multiple DLT options
- Selected blockchain – Hyperledger Fabric
  - Open-source blockchain sponsored by Linux Foundation, contribution from IBM
- Why Hyperledger Fabric?
  - Permissioned blockchain
    - Access is tightly controlled to authorized participants
  - Energy efficient
    - Avoids energy-heavy blockchain implementations like Bitcoin



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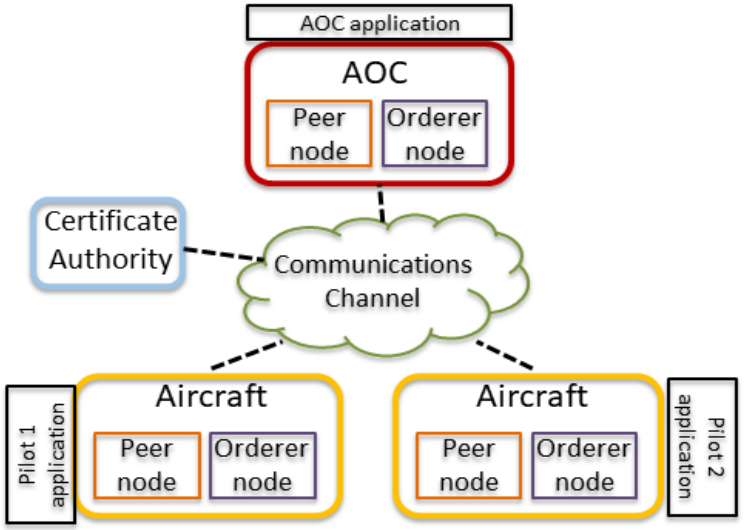
Prototype MDC2 systems

- Goal – Compare DLT to traditional database options
- Approach
  - Develop Hyperledger Fabric-based prototype
  - Develop baseline prototype (PostgreSQL)
  - Perform head-to-head experiments



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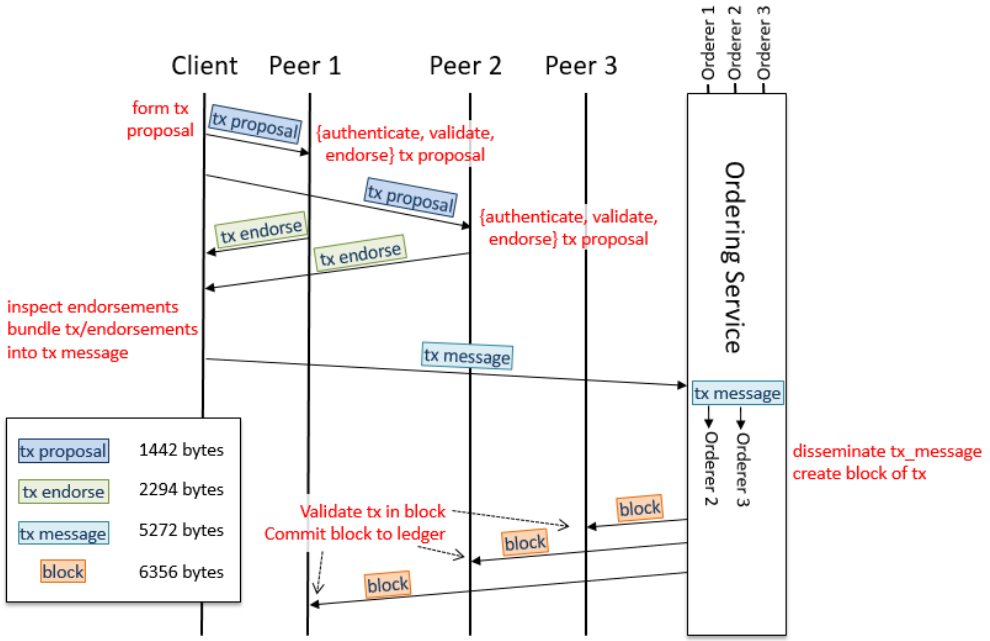
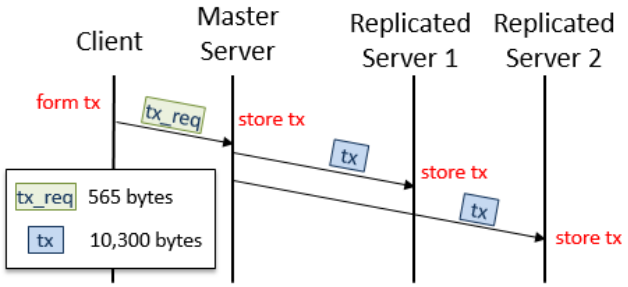
DLT vs. Traditional Approaches

- DLT adds complexity (consensus vs. single master)
  - Pro: Consensus compensates for disconnection, contested comms
  - Con: increased complexity, greater latency
- **Takeaway – DLT consensus is *high assurance* in contested comms environments but penalizes *latency***

DLT prototype message flow



Baseline (PostgreSQL) message flow



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Experimentation Plan

Performed Experiments

- **Experiment 0** – Determine Hyperledger Fabric optimal configuration for CARDIAC use case
  - Metrics: Latency, Throughput
- **Experiment 1** – Continuous write Link 16 J2.2 messages, fully-connected network, vary bandwidth
  - Metrics: Latency, Throughput
- **Experiment 3** – Continuous write Link 16 J2.2 messages, fully-connected network; disconnect one database node for a period of time, then re-connect (no writes to disconnected node); vary bandwidth
  - Metrics: DB reconciliation time, DB reconciliation network overhead

Future Experiments

- **Experiment 2** – Same as Experiment 1
  - Metrics: Disk storage, processing, network overhead
- **Experiment 4** – Same as Experiment 3, except (non-conflicting) Link 16 J2.2 messages also written to disconnected database node
  - Metrics: DB reconciliation time, DB reconciliation network overhead
- **Experiment 5** – Continuous write JIPTL messages, fully connected network; disconnect one database node, continue writing (conflicting) JIPTL messages to disconnected node; re-connect node, system must reconcile/de-conflict, database; vary bandwidth
  - Metrics: DB reconciliation/de-confliction time, DB reconciliation/de-confliction network overhead

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Results – Experiment 0

- Batch Timeout – wait for more transactions before bundling into blocks
  - High batch timeout: Fewer blocks → Less network overhead → Higher throughput, higher latency
  - Low batch timeout: More blocks → More network overhead → Lower throughput, lower latency
  - BUT Very low batch timeout: many blocks → much network overhead → higher latency
- **Takeaway – DLT is well-suited for low volume, limited bandwidth/compute power networks (battlefield C2), but not low-latency applications (Real time control systems)**

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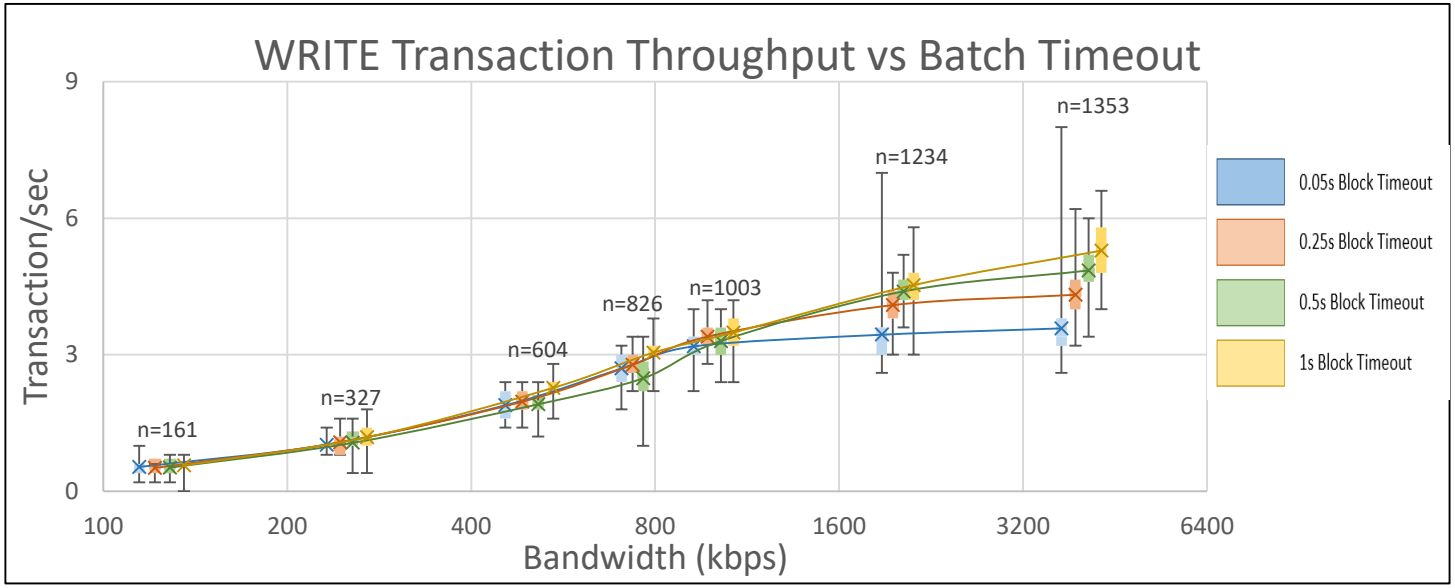
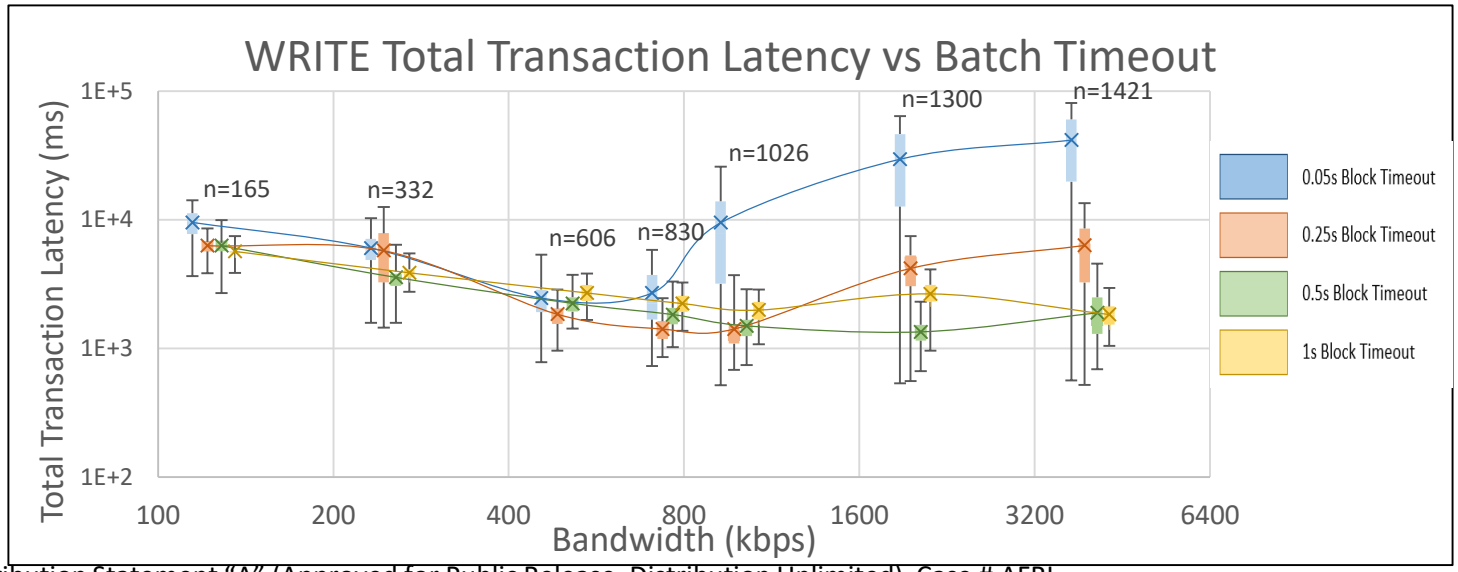
Results – Experiment 0, DLT Batch Timeout

Experimental Conditions

- 2 Clients writing to DB every 500 ms
- Experiment length: 300s





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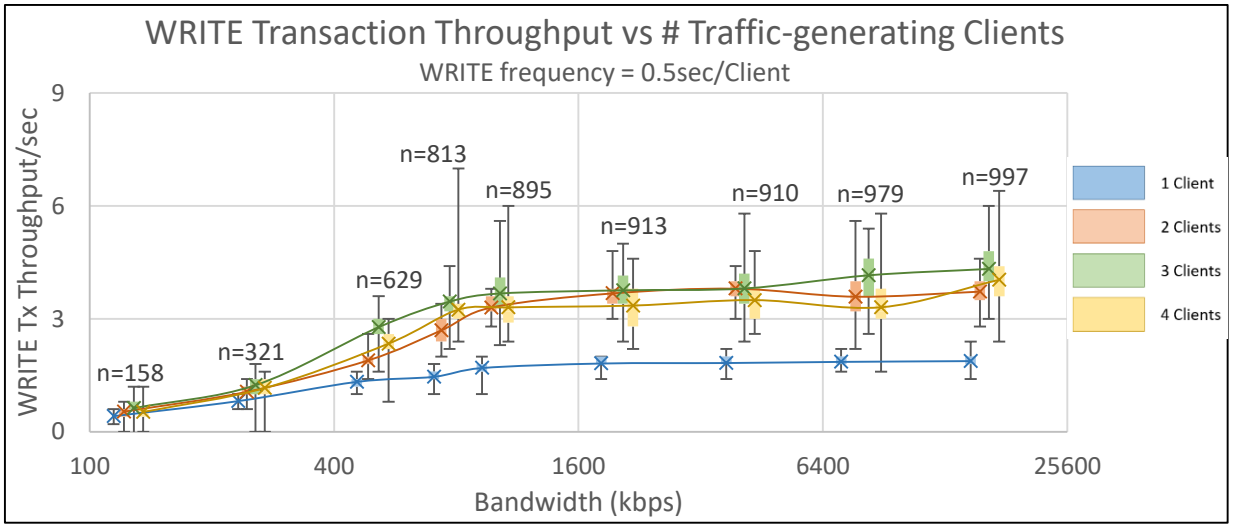
Results – Experiment 0

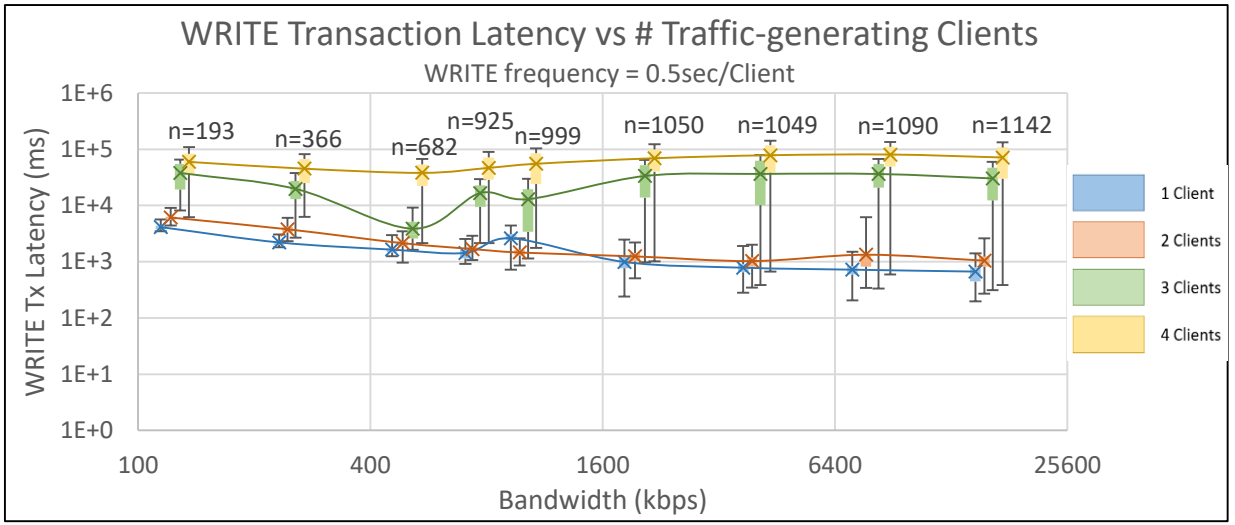
- Traffic density
  - consensus algorithm generates network overhead
  - Traffic density causes higher latency as message queues grow
- **Takeaway: DLT is more suitable for low volume, high value data (like air battle plans and target lists), not high volume data (like video streams)**

Results – Experiment 0, Traffic Density

Experimental Conditions

- Clients writing to DB every 500 ms
- Experiment length: 300s
- Batch Timeout: 0.5s





Results – Experiment 1

- DLT vs. PostgreSQL
  - Throughput – PostgreSQL outperforms DLT
  - Latency – PostgreSQL outperforms DLT by 1 order of magnitude
  - Key difference – PostgreSQL is single-master – single point of failure (not resilient to contested comms)
  - **Takeaway – DLT provides high integrity/assured propagation in resource-constrained/contested comms environments, as opposed to traditional database solutions**

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Results – Experiment 1

Experimental Conditions

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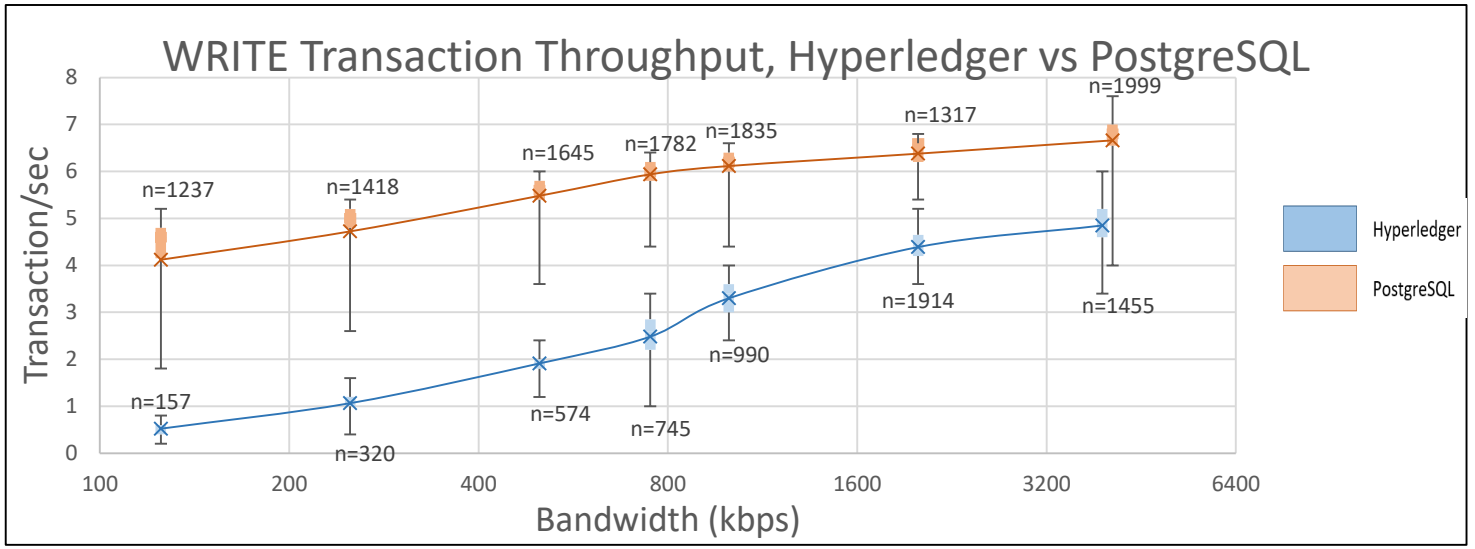
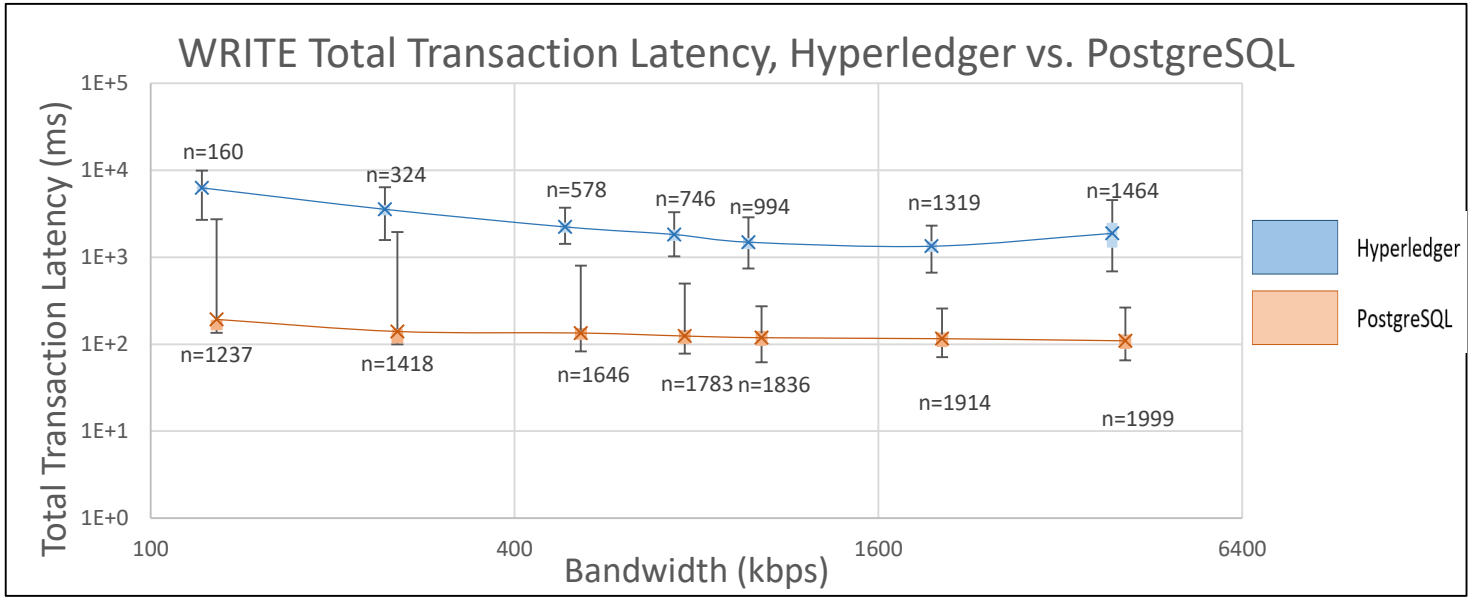
- Experiment length: 300s
- Batch Timeout: 0.5s





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Results – Experiment 3

- DLT vs. PostgreSQL
  - Reconciliation time for disconnected node to catch up on transactions it is missing
  - **Takeaway – DLT introduces complexity over traditional database solutions, but that complexity is an acceptable tradeoff in high-disconnection scenarios**

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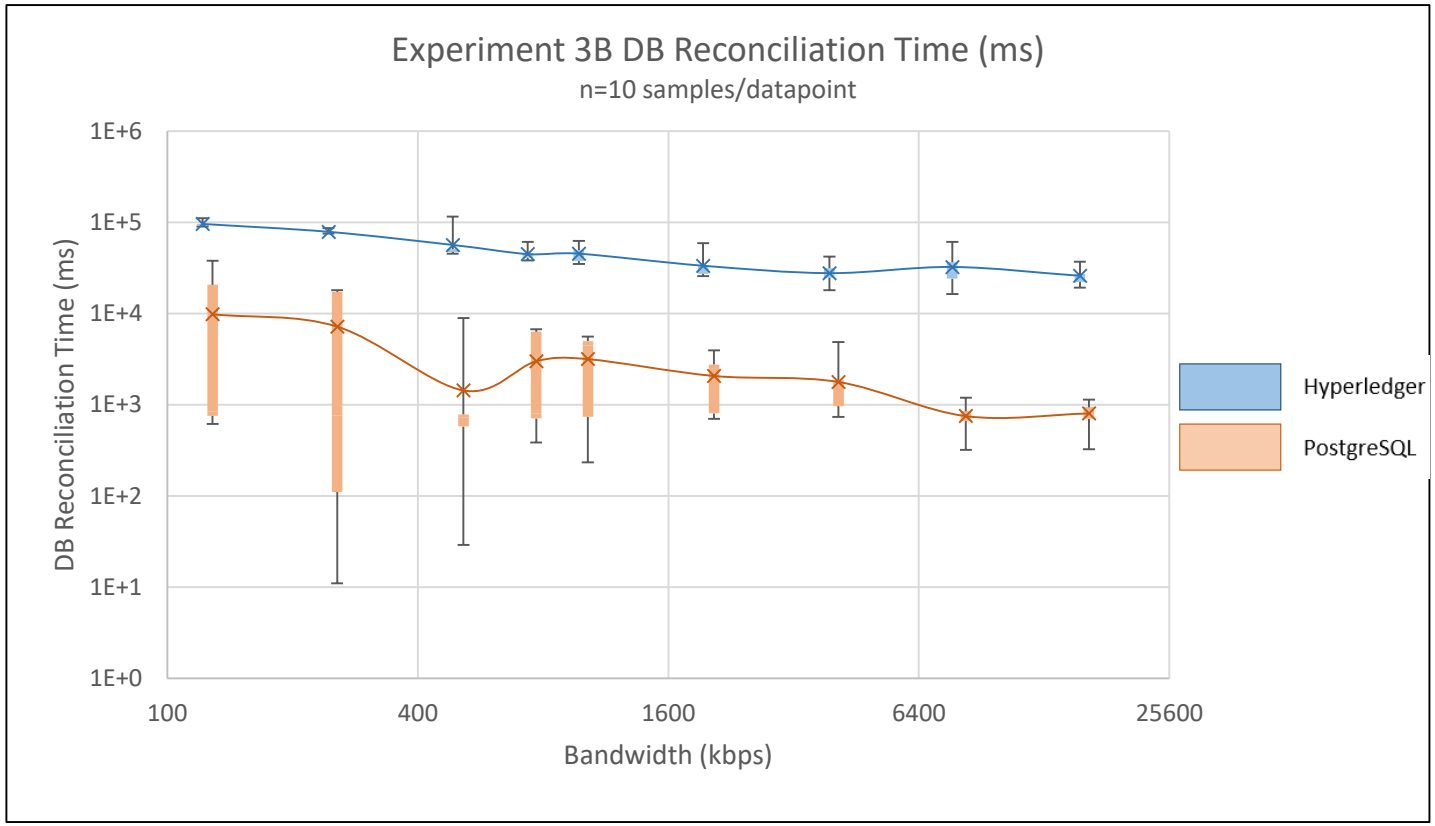
Results – Experiment 3

Experimental Conditions

- Client writes 500 messages
- One node disconnected
- Client writes another 500 messages
- Disconnected node reconnects, downloads new messages



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Future Work

- CARDIAC prototype
  - Self-contained CARDIAC node
  - Configurable network size/topology
  - Deliverable to third parties
- CARDIAC functionality
  - Data evolution
  - Conditional authorities
  - Blockchain forking/merging
- Additional experiments

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Conclusion

- Air Force needs a decentralized MDC2 solution
  - Resilient to disrupted communications
  - Empower frontline units with dynamic authroities
- Distributed Ledger Technology is a promising option for these requirements
- CARDIAC study investigated feasibility
- Results – DLT is slower, but more resilient to disrupted environments

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Q&A

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Test harness stats for experiments

- Single Ubuntu Linux VM running on Virtual Box
  - 4096MB RAM
  - 4 CPUs, 1.9 GHz, 100% execution cap
  - 21GB Hard Drive

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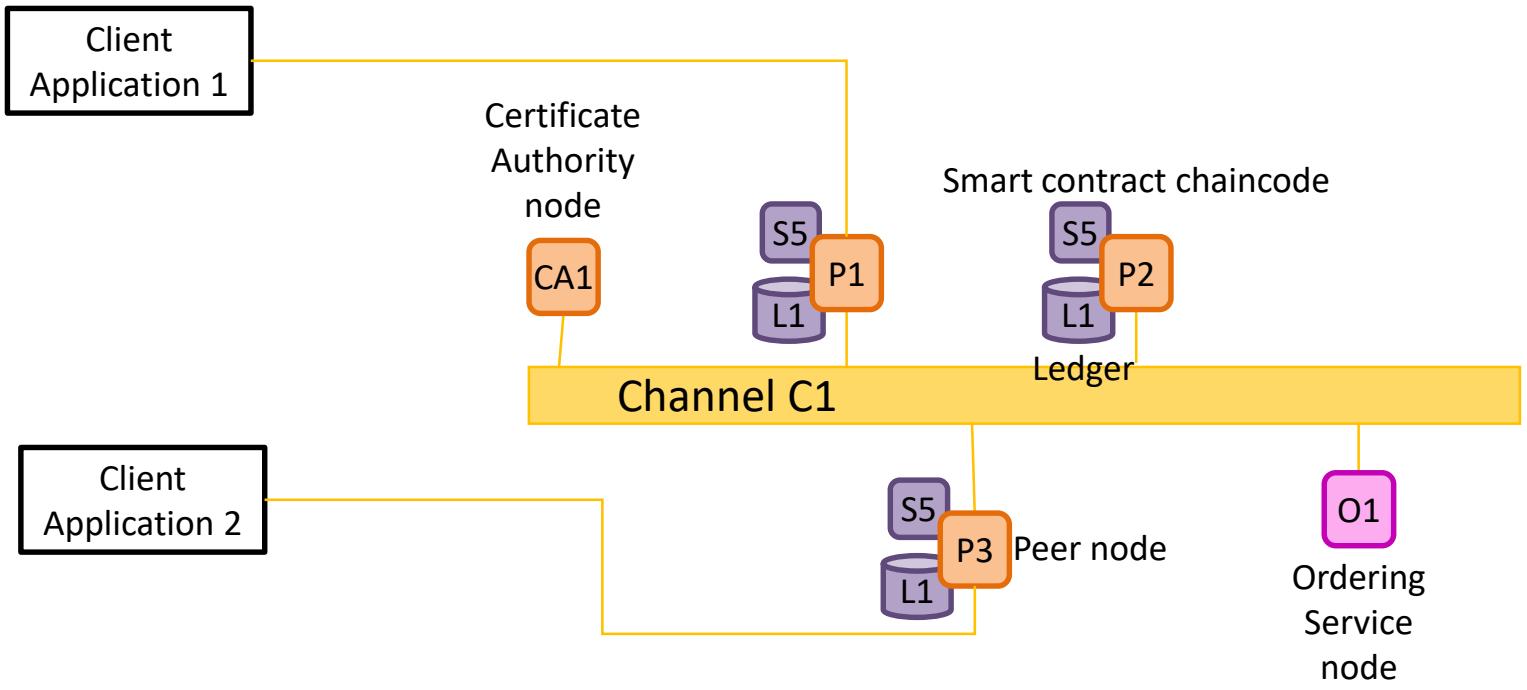
Hyperledger Network



Results – Experiment 0, Traffic Density

Experimental Conditions

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- Experiment length: 300s
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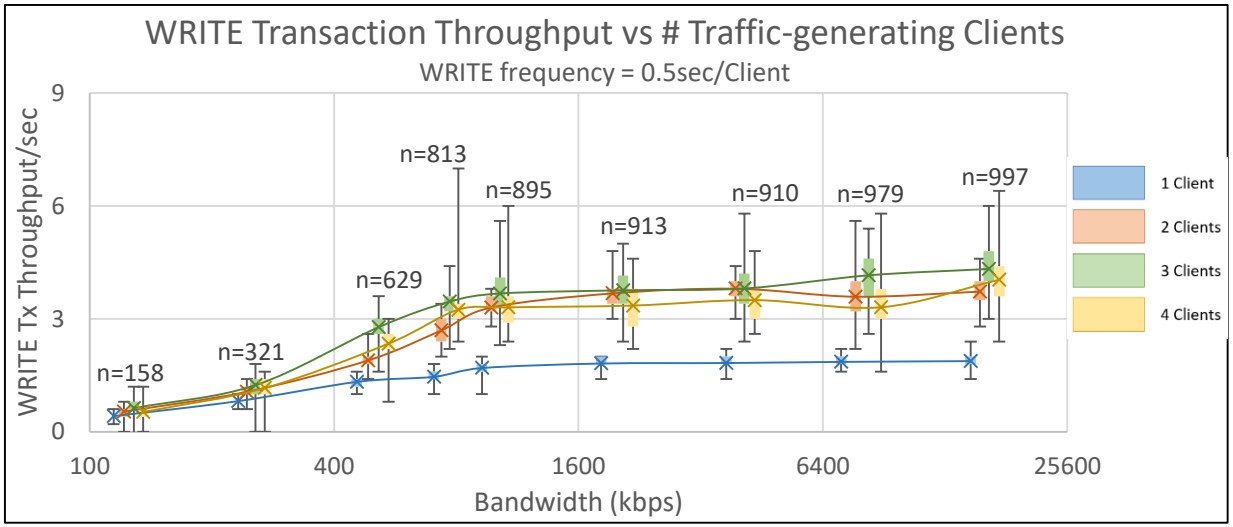

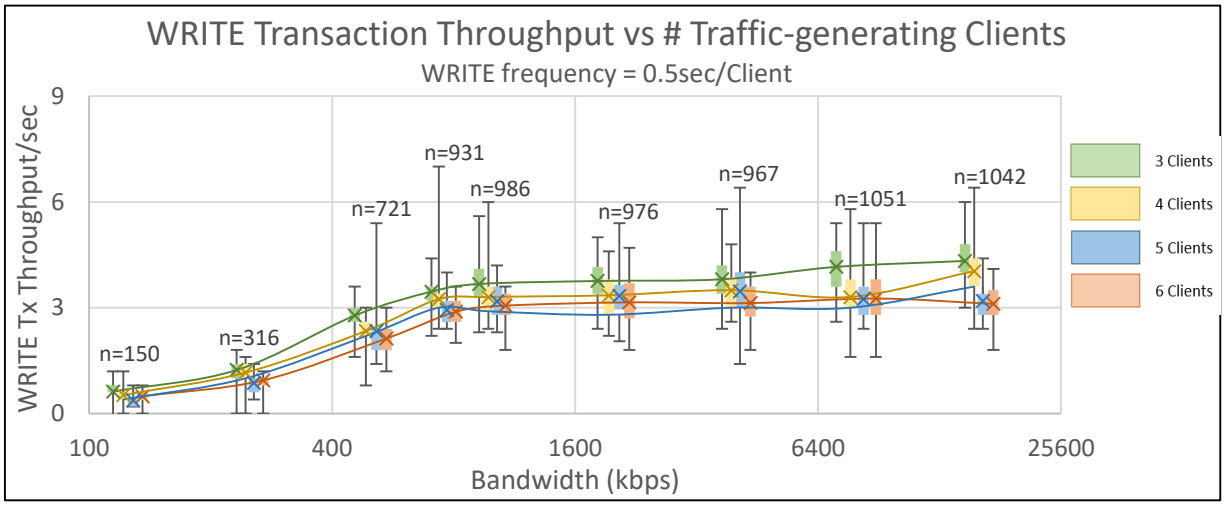

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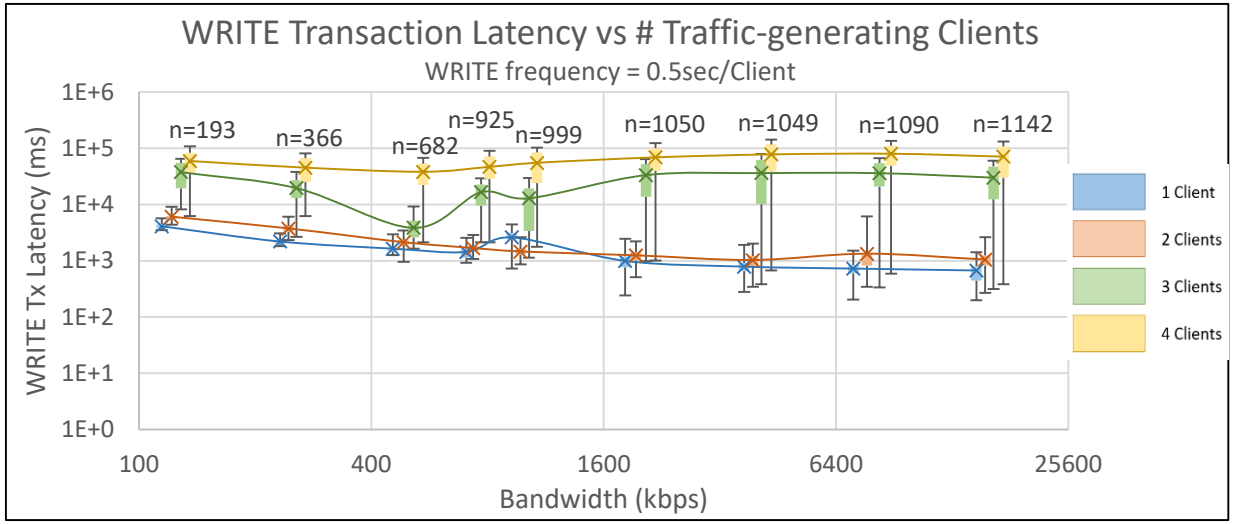

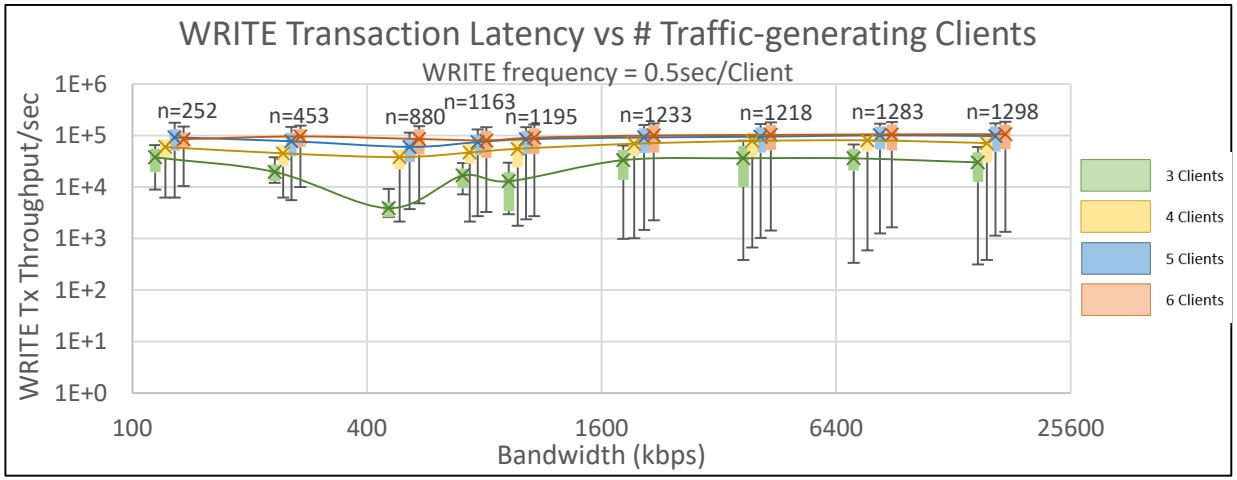

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