Realizing Massive-Scale Conditional Access Systems Through Attribute-Based Cryptosystems

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The Y100 Phenomenon

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The Y100 Phenomenon

The Coming Wave

- The number and variety of *Conditional Access* (CA) systems are increasing.
  - IPtv
  - Satellite Radio
  - "Premium" Streaming Audio
- Security in these systems is often proprietary or requires dedicated hardware.
- A solution for general purpose computing platforms is needed...

Goals

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- Provide an easily manageable broadcast encryption mechanism to regulate access to the expanding set of CA systems.

- Demonstrate that *Attribute-Based Cryptosystems are capable of enabling real systems*, especially those at massive scale.

Broadcast Encryption

- Allows access management without requiring two-way communication.
- Techniques such as LKH and NNL trees dominate cable television.
- Boneh et al proposed an efficient pairing-based construction that grows linearly with the number of users.

Attribute-Based Encryption

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- Sahai-Waters Construction (Eurocrypt'05)
  - Generalization of Identity-Based Encryption
  - Anyone with *k-out-of-n* attributes can decrypt a ciphertext
- Random Oracle Construction (CCS'06)
  - Properly tuned, can reduce the cost of encryption 98%.
  - We can use this construction to simple boolean conjunction and disjunction:

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$$\text{Tall} \wedge \text{Dark} \wedge \text{Handsome}$$

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$$\text{Tall} \wedge \text{Dark} \wedge \text{Handsome}$$
$$\text{Alice} \vee \text{Bob} \vee \text{Carol}$$

ABE Details

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- Uses bilinear maps on elements of elliptic curves:

$$e : \mathbb{G} \times \mathbb{G} \rightarrow \mathbb{G}_T$$

- Construction works by computing efficient bilinear map between *k-out-of-n* attributes.
  - Interpolation using Shamir's Secret Sharing.
- Accordingly, encryption is a function of *n* and decryption is a function of *k*.
  - At least on paper...

An Example

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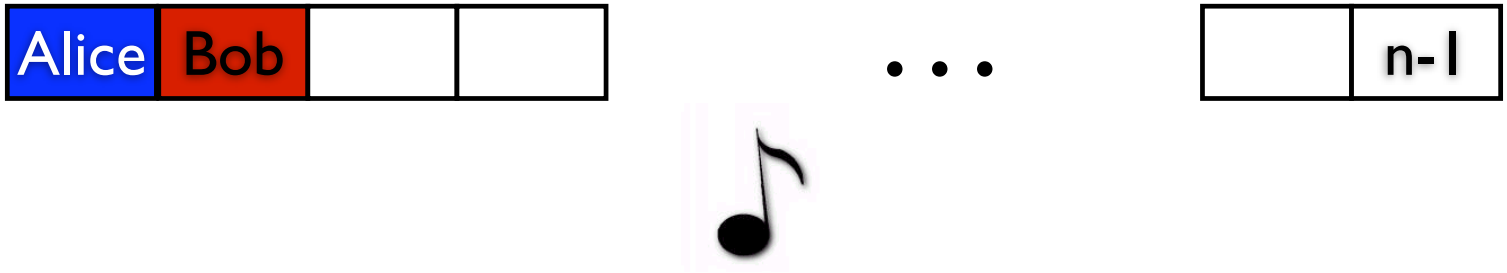
An Example

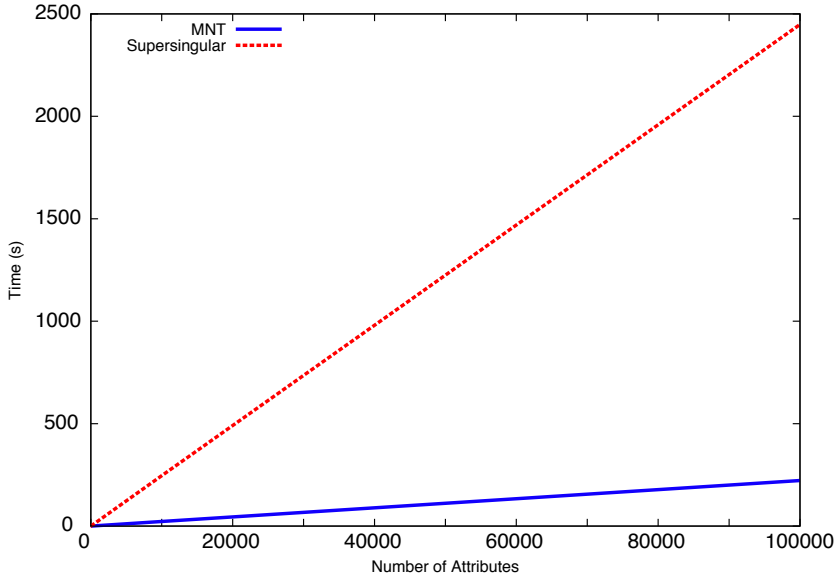
1-out-of-n

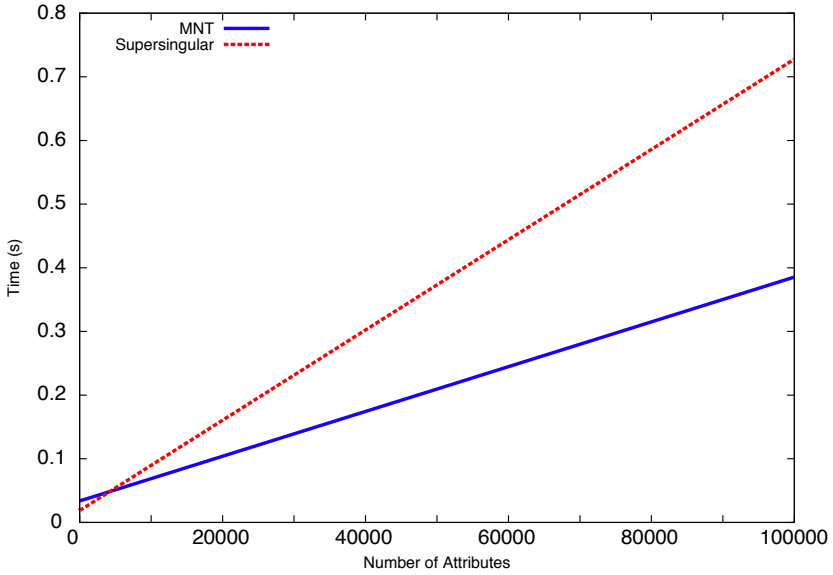
An Example

An Example



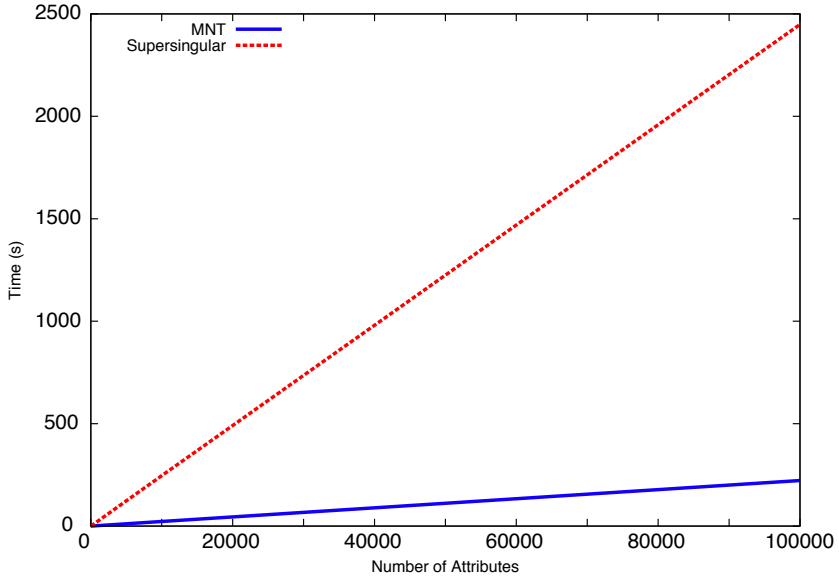
Scaling



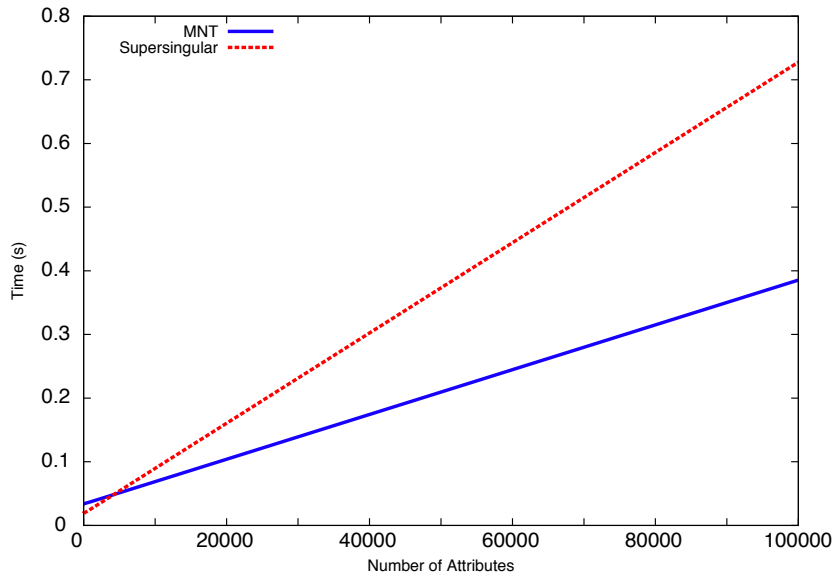


- As expected, MNT curves perform encryption faster.
- Contrary to previous work, MNT curves perform decryption faster than SS when the n > 1000.

Scaling



$$E = 2.2214 \times 10^{-3} n + 0.01804$$
$$r^2 = 0.99999997$$



$$D = 3.5159 \times 10^{-6} n + 0.033791$$
$$r^2 = 0.9999992$$

- As expected, MNT curves perform encryption faster.
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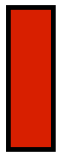
Performance

- Even with the random oracle construction, the performance of the primitives is too slow.
- Adding one new user to a group of 1,000,000 takes approximately 37 minutes.
  - This makes changing the content encryption key impossible during short programs (e.g., half-hour TV shows)
- A faster access structure is therefore necessary.

Tiered Construction

Tiered Construction



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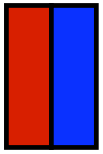

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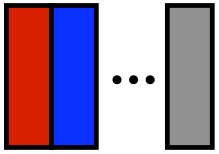

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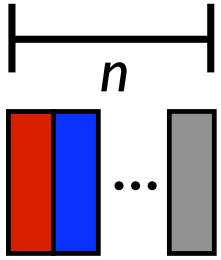

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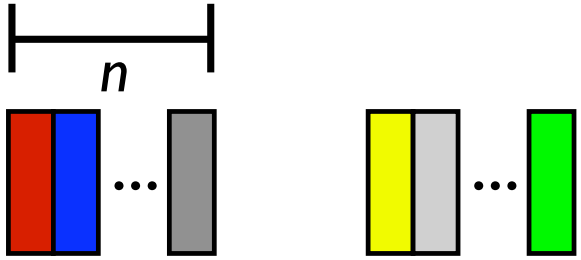

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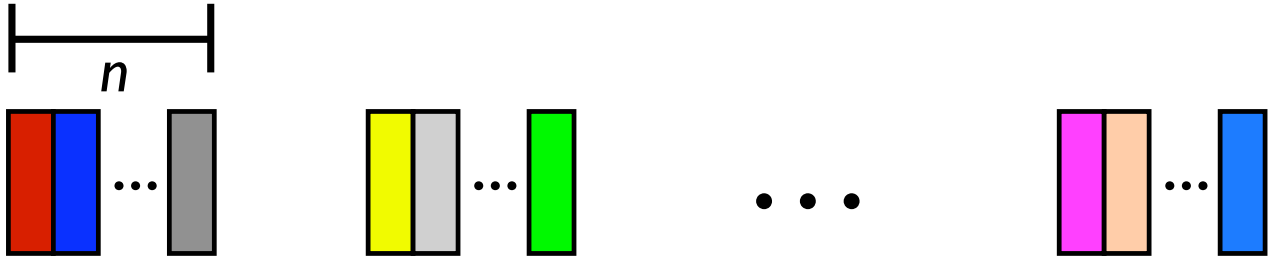

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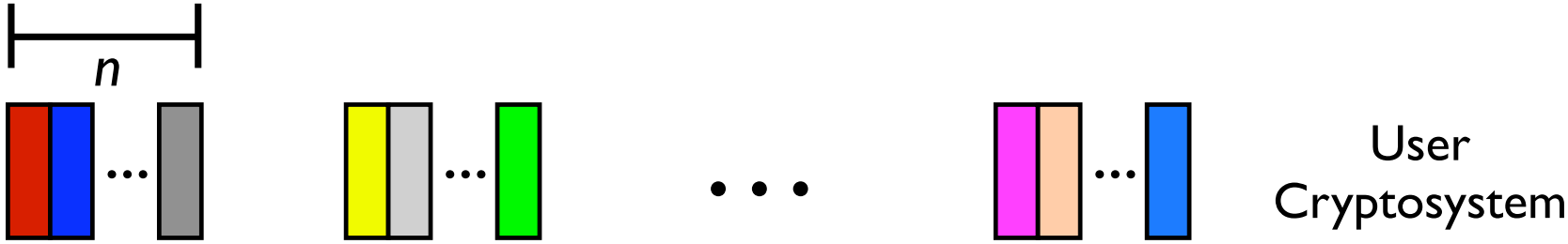

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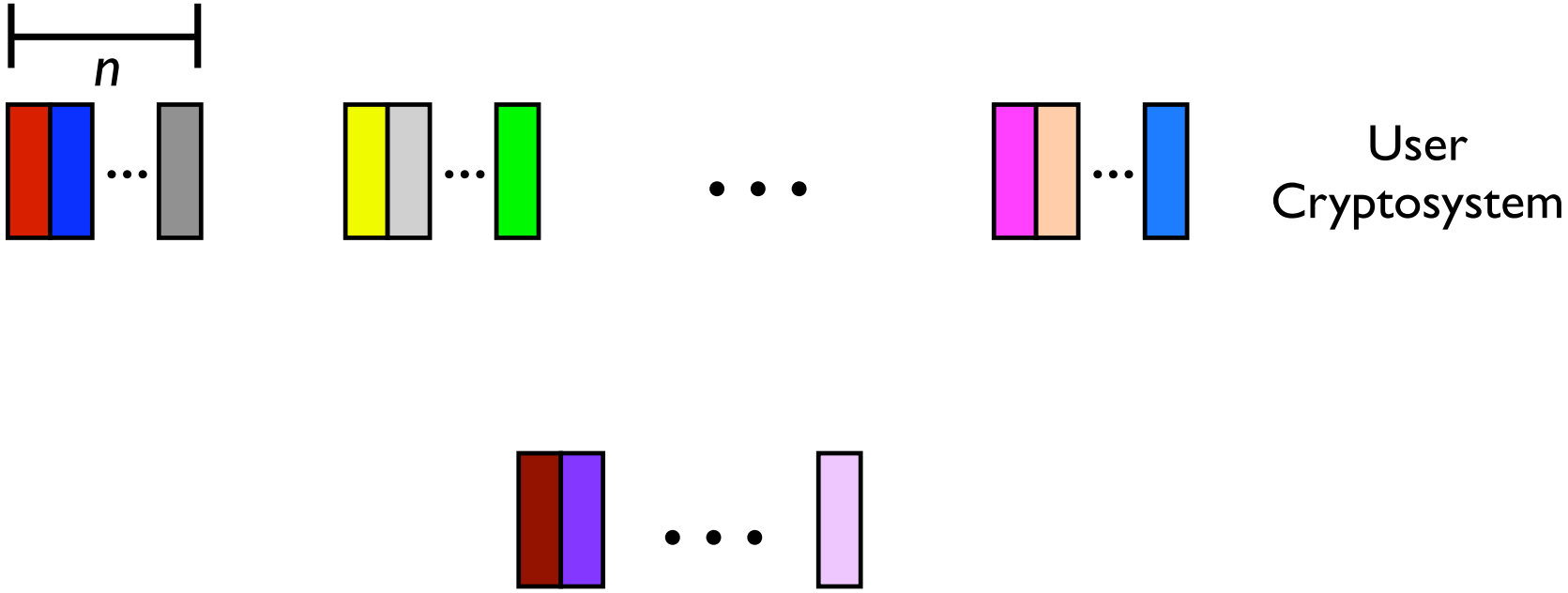

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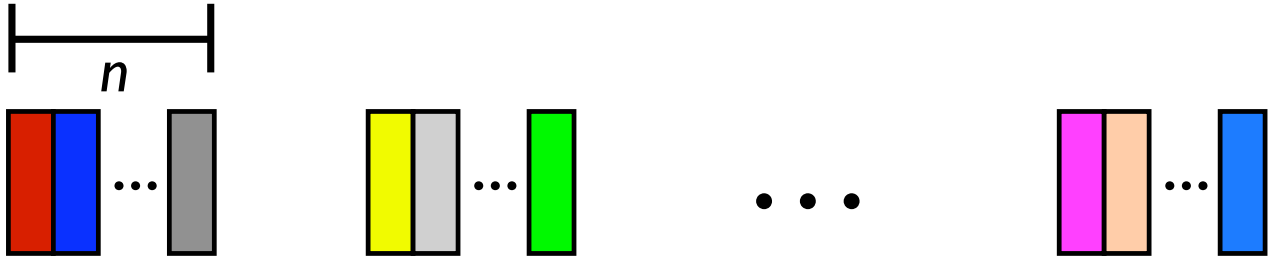
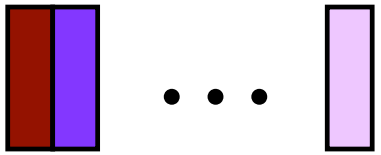
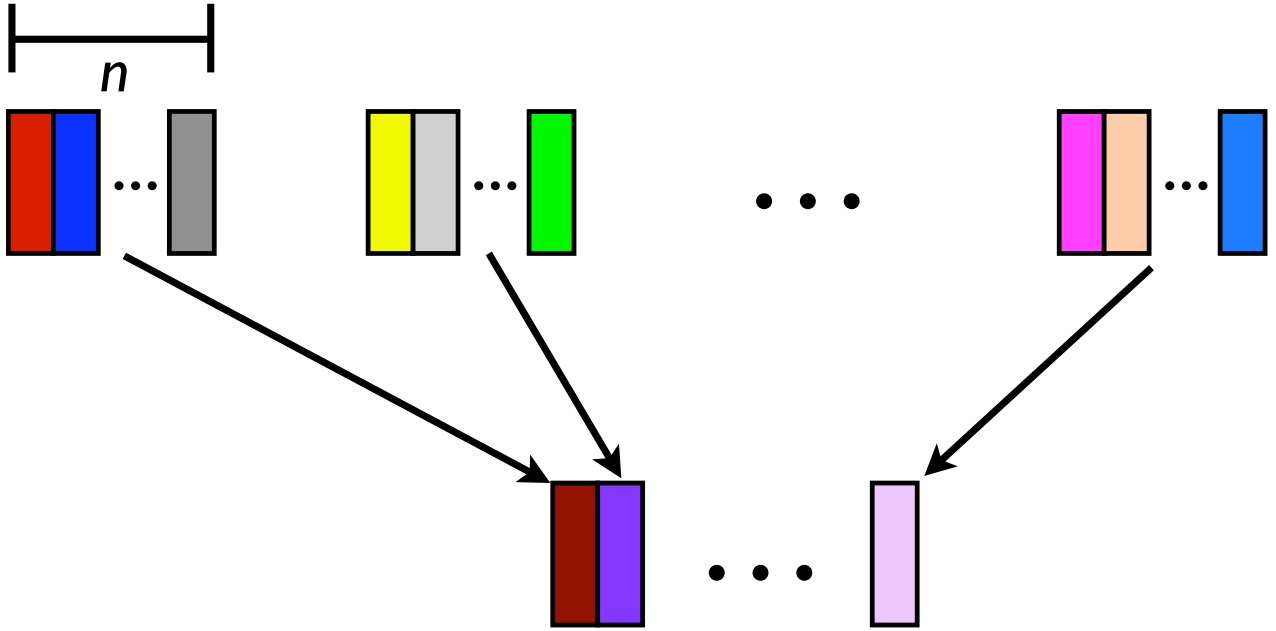


User Cryptosystem



Content Cryptosystem

Tiered Construction



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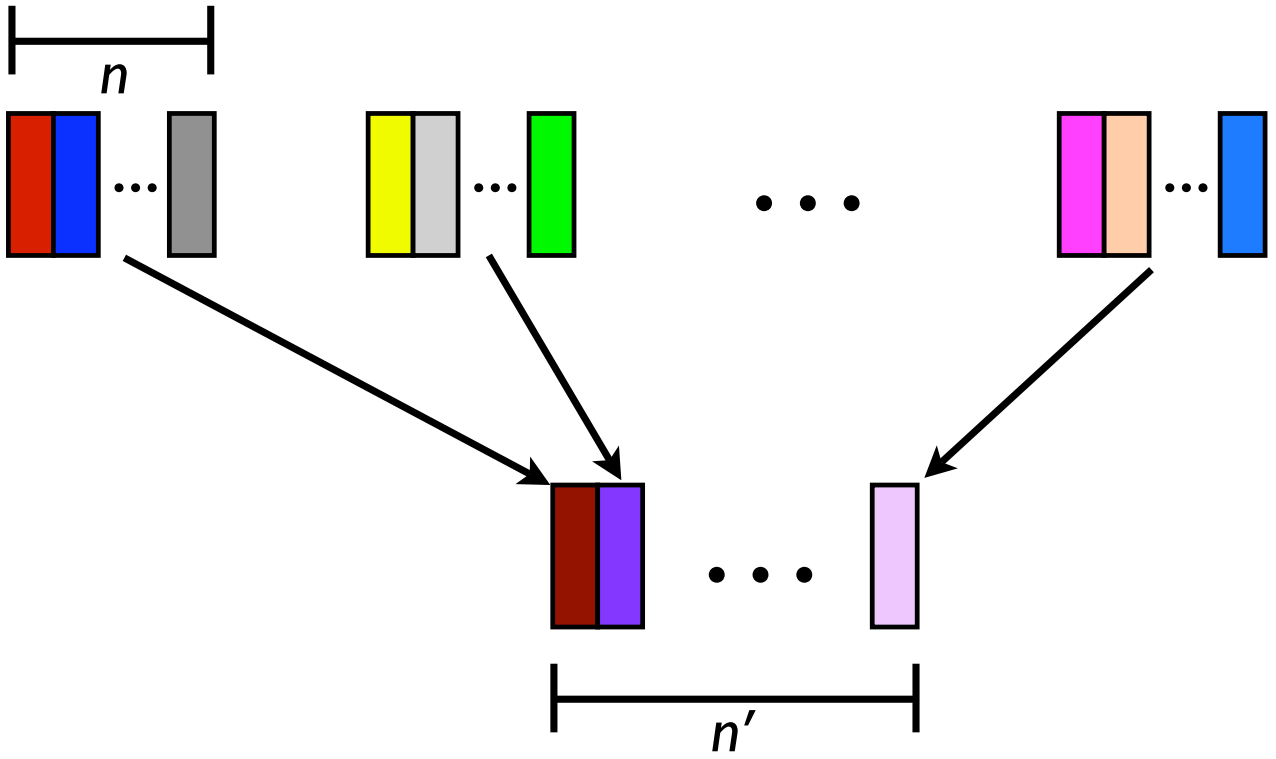

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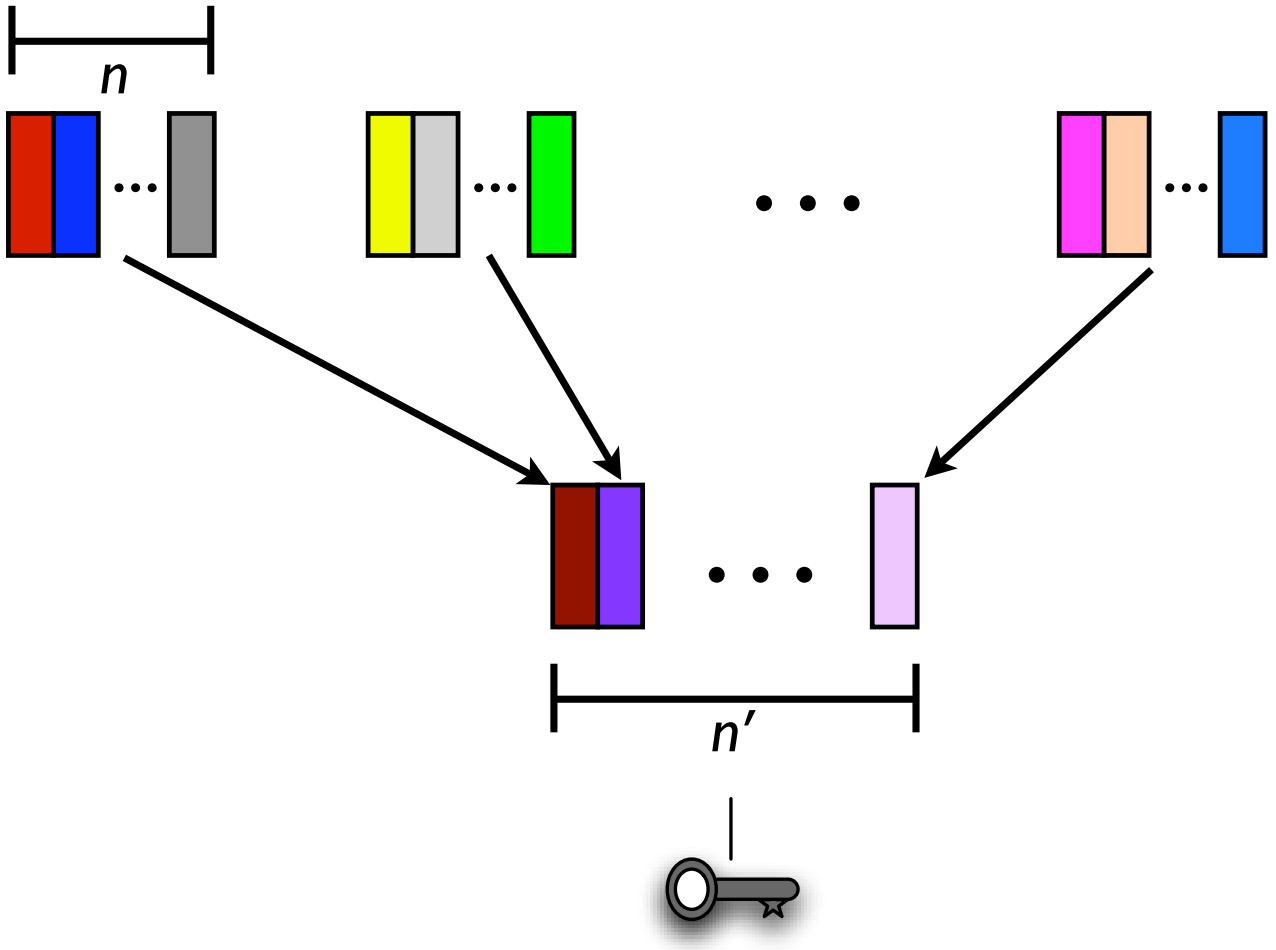
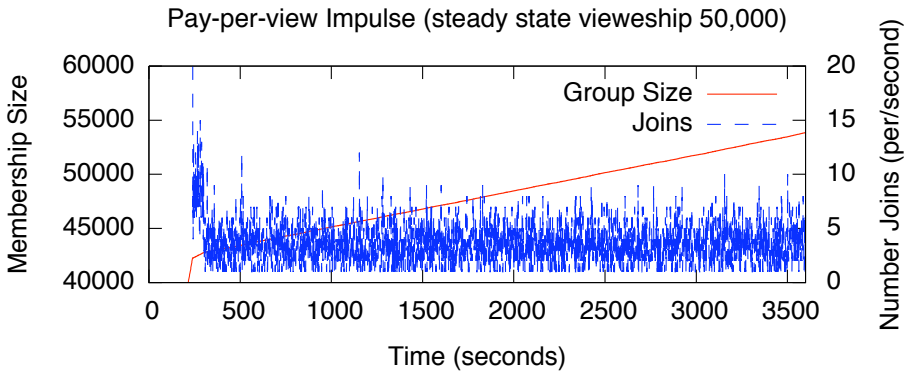
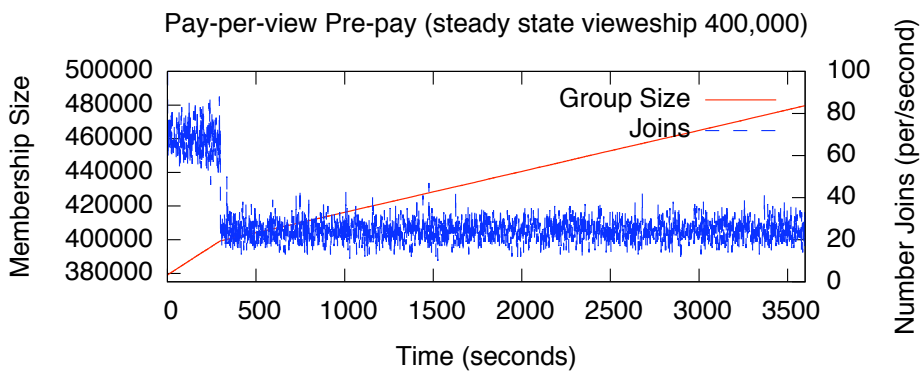


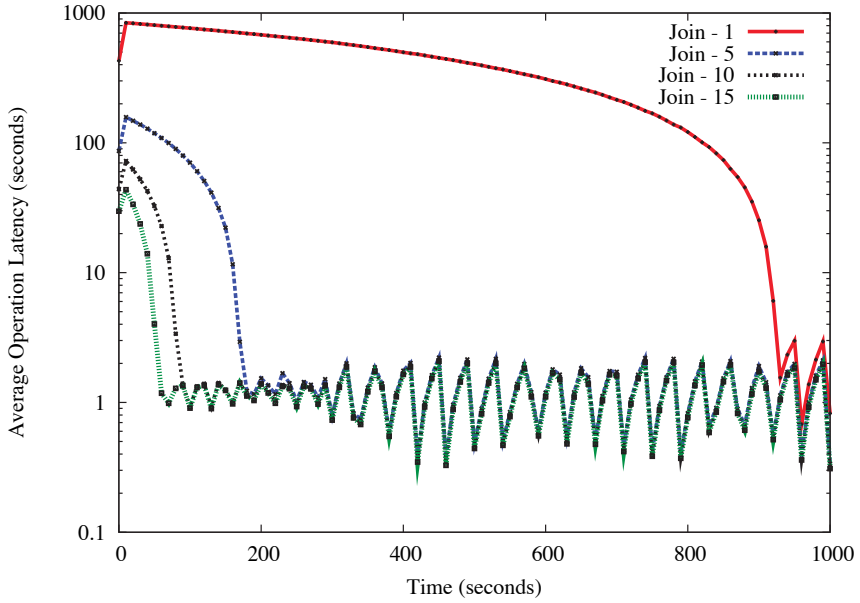
Traffic Model: PPV





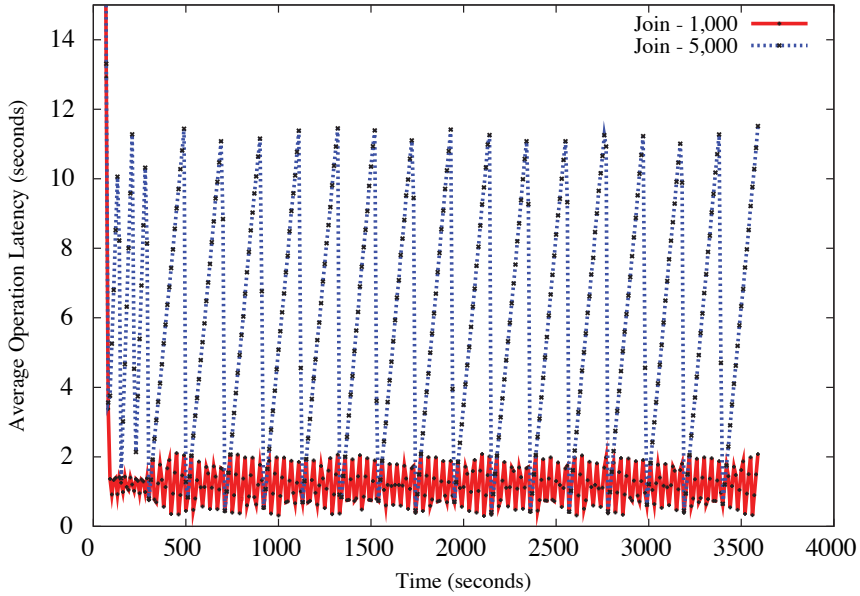
- Pay Per View (PPV) programs exhibit two types of joins: impulse and pre-pay.
  - There are no leaves - users purchase entire programs.
- We use well-known ratings to make results realistic:
  - PPV Boxing (400k) and Tyson vs Holyfield II (1.99M)

How Many Processors?



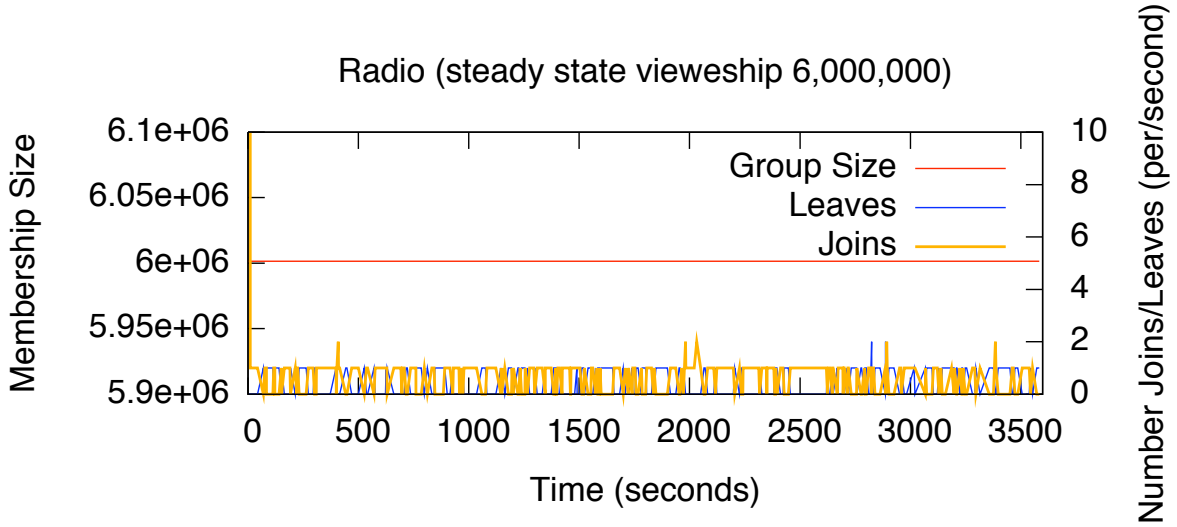
- Extra processors help the system reach quiescence faster as joins are parallelized.
- After quiescence, however, extra processors lay idle.
  - If steady state joins are less than ~400/minute, one processor is more than sufficient.

Group Size?



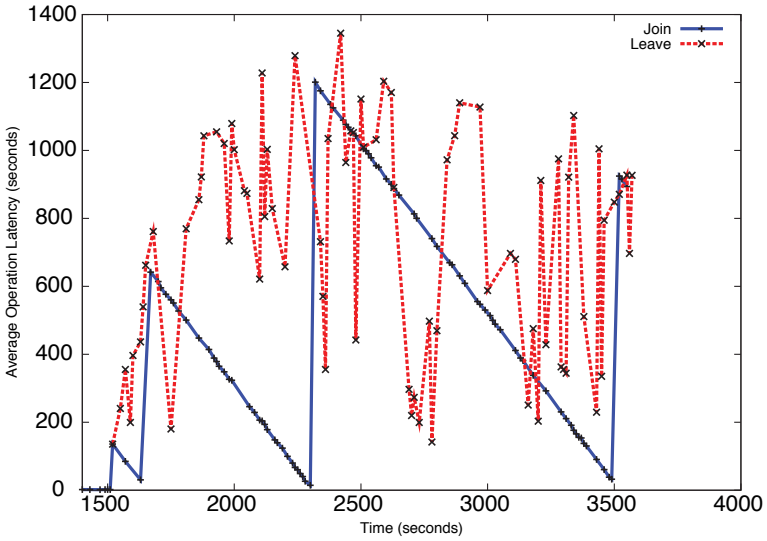
- Larger user groups yield higher latencies throughout the initial surge and quiescence.
- There is no advantage to using large user groups.

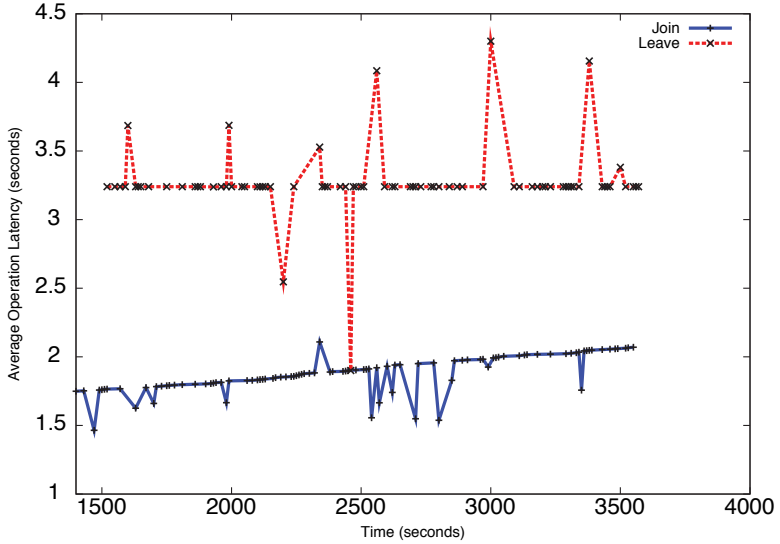
Traffic Model: Satellite Radio



- Satellite Radio users purchase subscriptions.
  - Joins and leaves happen at any time (macro-scale).
- We use Sirius Satellite Radio quarterly reports.
  - 6 million users with 2.8% join and 2% leave rates.

Improving Performance

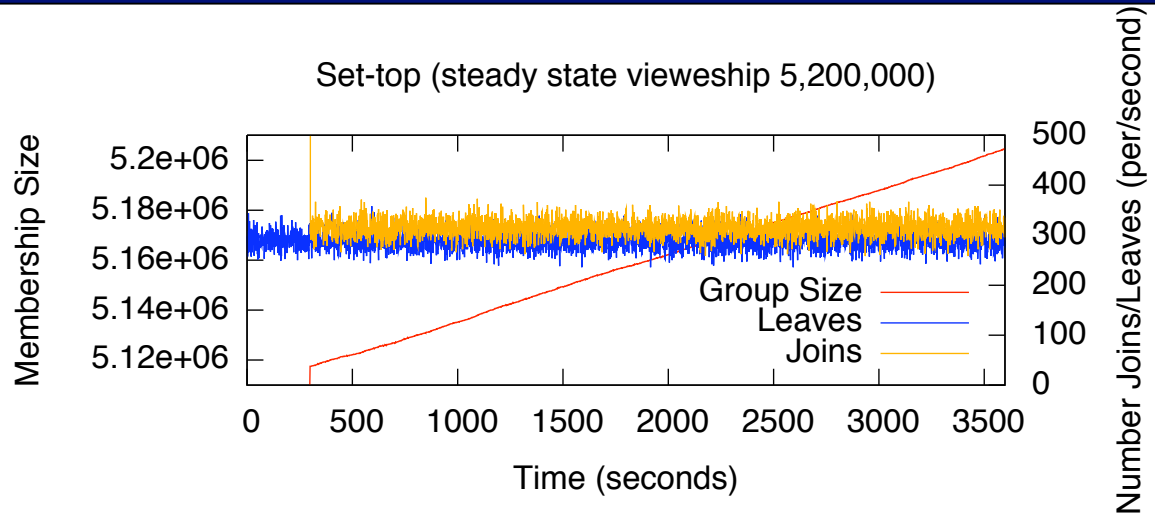




- Performance gains can be achieved both by adding processors and increasing the size of n'.

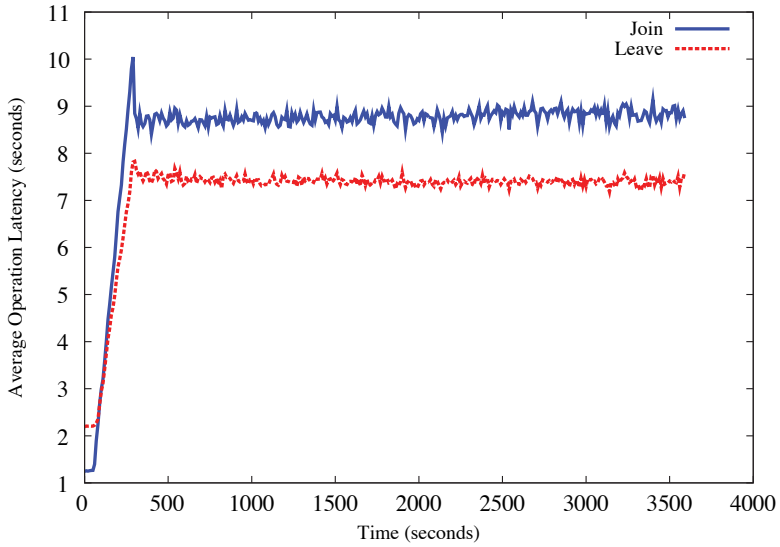
- The use of 100 processors and n'=100 makes such systems efficient.

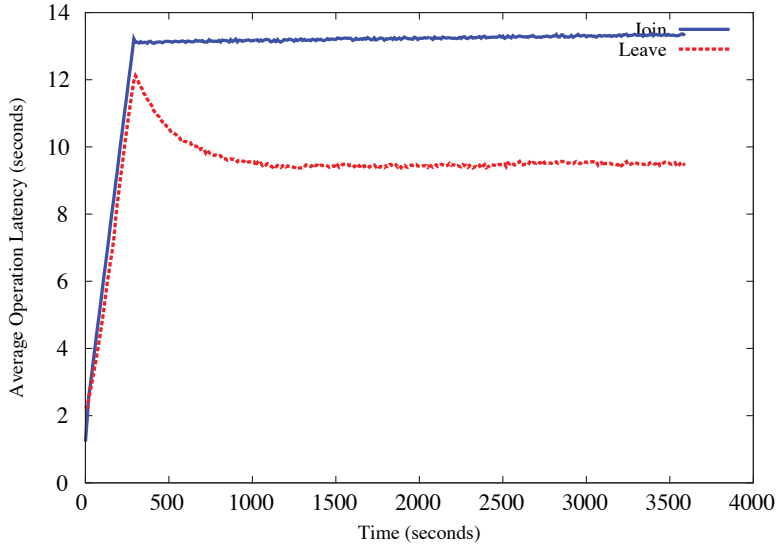
Traffic Model: IPtv



- Attempts to model a "Pay-Per-Channel" scenario.
- We use Nielsen Ratings for popular programs as the source of our data.
  - The Tonight Show: 5.22 million
  - American Idol: 26.9 million
- 2% join and leave rates throughout.

Taxing the Scheduler

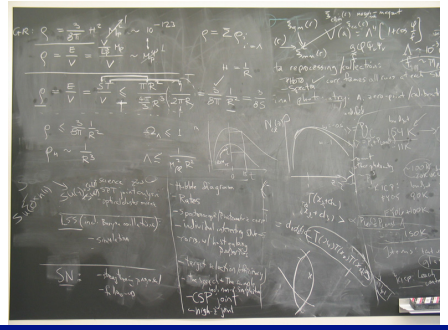




- To simplify management, we performed leaves before joins.
- Joins unfortunately became delayed by massive leaves.
- Even in this worst case scenario, performance is reasonable.

Lessons Learned

- ABE constructions can be made efficient enough to support massive-scale systems.
  - ...if you design carefully...
- Let the system do batching.
- Be aware of key exhaustion for massive systems.



Future Work

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- Reduce bandwidth using more compact attribute representation.
- Develop/Incorporate smart grouping strategies to lessen the cost of leaves.
- Compare delayed leave strategy to better understand hardware tradeoffs.

Y100 (redux)

Questions

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Joins and Leaves

- A user joining the system requires a single encryption in the user cryptosystem.
- A leave/eviction requires two operations:
  - Generation of a new group attribute.
  - Encryption of that attribute in the user cryptosystem.
- Current users are not affected by joins, but must rekey on leaves.

Sizing n' For Performance

- We want the size of the content cryptosystem to be bound by the performance requirements of our system.
- We experiment with the size of the content cryptosystem under 1,000 unique groups.
- Cost of Crypto Operations:
  - Encryption: 2.24 seconds
  - Decryption: 33 ms