Safety and Consistency of Mutable Attributes using Quotas: A Formal Analysis

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Introduction & Motivation
What is Attribute Based Access Control?
Why I should care about consistency problem?

Background and Preliminaries
Previous Research
Preliminaries: Mutability and Quota-based Approach

Underlying Assumptions and Proposed Solution
System Assumptions and Practical Use Cases
Consistency Considerations, Level details and properties

Discussion, Conclusion and Future Work
Limitations and Practical Issues
What has been done? What to do next?
• Access control regulates access to protected resources in the system with respect to the policy.

**SUBJECT**
Generally an individual, process, or device causing information to flow among objects or change to the system state.

**OBJECT**
System-related protected entity (e.g., devices, files, records, tables, processes, programs, domains) containing or receiving information.

**Policy**
A set of rules which regulates access of subjects to protected objects in the system.
• **Consistency Problem**: When multiple attributes are involved, consistency problem results in granting access when it should be denied (safety violation) or denying access when it should be granted (availability violation), due to following reasons:

  • Asynchronous nature of distributed systems
  • Cached values of attributes
  • Network and system failures
  • Incremental assembly of subject attributes
  • Differing validity periods for subject attribute values
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• Safety and consistency in trust negotiation [Lee-Winslett, CCS’06]

• Safety and consistency in ABAC
  • Revocation-based
  • Refresh-based

• Consistency of Mutable attribute: this work
Mutability and Consistency

• First introduced in UCON\textsubscript{ABC}: a family of access control models to extend traditional access control.

• Mutability: attribute changes as a side effect of access
  • Account balance changes after each payment

• Mutability adds further complication to safety and consistency management, as modification of attribute values should be done in a trusted way to avoid outdated values
Quota-based Approach

• Quota:
  • For reusable resources
  • For consumable resources

• Each mutable attribute has a global limit known to AA which could be managed centrally or be distributed to local servers

• Quota apportion could be done through:
  • Service-based
  • User-based
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4. Limitations and Practical Issues
4. What has been done? What to do next?
Underlaying Assumptions

• An ABAC model is in place
• Attribute credential provision is through multiple authorities
• Administrative changes are always done through AA
• Quota-based approach has been applied to manage concurrency while using multiple authorities
• Decision point is the entity which determines the set of relevant attributes
Centralized Approach

\( U \) : set of Users
\( S \) : set of all Services
\( ATT(S) = \{ \text{globalLimit, usageCount} \} \)
\( \text{globalLimit} : S \rightarrow \{1, 2, \ldots, N\} \)
\( \text{usageCount} : S \rightarrow \{0, 1, 2, \ldots, M\}, \ \forall s \in S: s.\text{usageCount} \leq s.\text{globalLimit} \)

allowed\((u, s, \text{utilize}) \Rightarrow s.\text{usageCount} < s.\text{globalLimit} \)
preUpdate\((s.\text{usageCount})\):
\( s.\text{usageCount} = s.\text{usageCount} + 1 \)

allowed\((u, s, \text{endUse}) \Rightarrow True \)
postUpdate\((s.\text{usageCount})\):
\( s.\text{usageCount} = s.\text{usageCount} - 1 \)

\( u.\text{usageCount} : U \rightarrow \{0, 1, 2, \ldots, M\}, \ \forall u \in U: u.\text{usageCount} \leq u.\text{globalLimit} \)

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\( u.\text{usageCount} = u.\text{usageCount} - 1 \)
Practical Use Case Scenarios (2)

- Distributed approach:

\[
U : \text{set of Users} \\
S : \text{set of Services} \\
\text{SIO} : \text{set of Service Instance Objects} \\
\text{ATT}(S) = \{\text{globalLimit, SIOSet}\} \\
\text{ATT}(\text{SIO}) = \{\text{Quota, usageCount, SIOUsers}\} \\
\text{globalLimit} : S \rightarrow \{1, 2, \ldots, N\} \\
\text{SIOSet} : S \rightarrow 2^{SIO} \\
\text{Quota} : \text{SIO} \rightarrow \{0, 1, 2, \ldots, M\} \\
\text{usageCount} : \text{SIO} \rightarrow \{0, 1, 2, \ldots, C\} \\
\text{SIOUsers} : \text{SIO} \rightarrow 2^{U} \\
\]

allowed(s, sio, create(q)) => \( \{(q \leq s.\text{globalLimit}) \land (s.\text{globalLimit} - \sum_{sIO \in s.\text{SIOSet}} sIO.\text{Quota}) > q\} \)

\[
\text{preUpdate}(sio, \text{Quota}) : sio.\text{Quota} = q \\
\text{preUpdate}(sio, \text{usageCount}) : sio.\text{usageCount} = 0 \\
\text{preUpdate}(sio, \text{SIOSet}) : s.io.\text{SIOSet} = s.\text{SIOSet} \cup \{sIO\} \\
\text{preOB} : \text{OBS} = \{\text{null}, \text{enduse}\} \\
\text{OBS} = \{\text{null}\} \\
\text{OBO} = \{\text{null}\} \\
\text{OB} = \{\text{enduse}\} \\
\text{allowed}(sio, \text{delete}) => \text{preFulfilled}(\text{getOB}(sio.\text{SIOSet})) \\
\text{postUpdate}(s.\text{SIOSet}) : s.\text{SIOSet} = s.\text{SIOSet} \setminus \{sIO\} \\
\]

\[
\text{allowed}(sio, \text{utilize}) => \text{postUpdate}(sio, \text{usageCount}) : sio.\text{usageCount} = \text{usageCount} + 1 \\
\text{preUpdate}(sio, \text{usageCount}) : sio.\text{usageCount} = \text{usageCount} - 1 \\
\text{allowed}(sio, \text{enduse}) => \text{True} \\
\text{postUpdate}(sio, \text{usageCount}) : sio.\text{usageCount} = \text{usageCount} - 1 \\
\text{postUpdate}(sio.\text{SIOUsers}) : sio.\text{SIOUsers} = sio.\text{SIOUsers} \setminus \{u\} \\
\]
Distributed vs. Centralized Approach

• Property 1:
  Centralized quota management provides correct access control decision.

• Property 2:
  Distributed quota management approach provides less availability and less utilization, comparing to the centralized approach.

• Property 3:
  Distributed quota management access provision is correct.
Proposed Consistency Levels

- **Lifetime Overlap**

![Diagram showing proposed consistency levels with lifetime overlaps](image)
• Freshness Overlap
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• We observe revocation as inappropriate for mutable attributes, so we used refresh.
• As for immutable attribute, consistency problem arise only if there are multiple attributes in relevant attribute sets
Conclusion and Future Work

• The safety and availability of mutable in multi-authority distributed ABAC systems has been formally characterized.
• The revocation scenario claimed to be inappropriate for mutable attributes.
• We proposed two consistency levels which are totally ordered in strictness.

Some future research directions:
• Other access control information is subject to staleness, e.g. policy and object attributes.
• Models could be developed for ongoing authorization.
Thank You