Privacy Preserving Enforcement of Sensitive Policies in Distributed Environments

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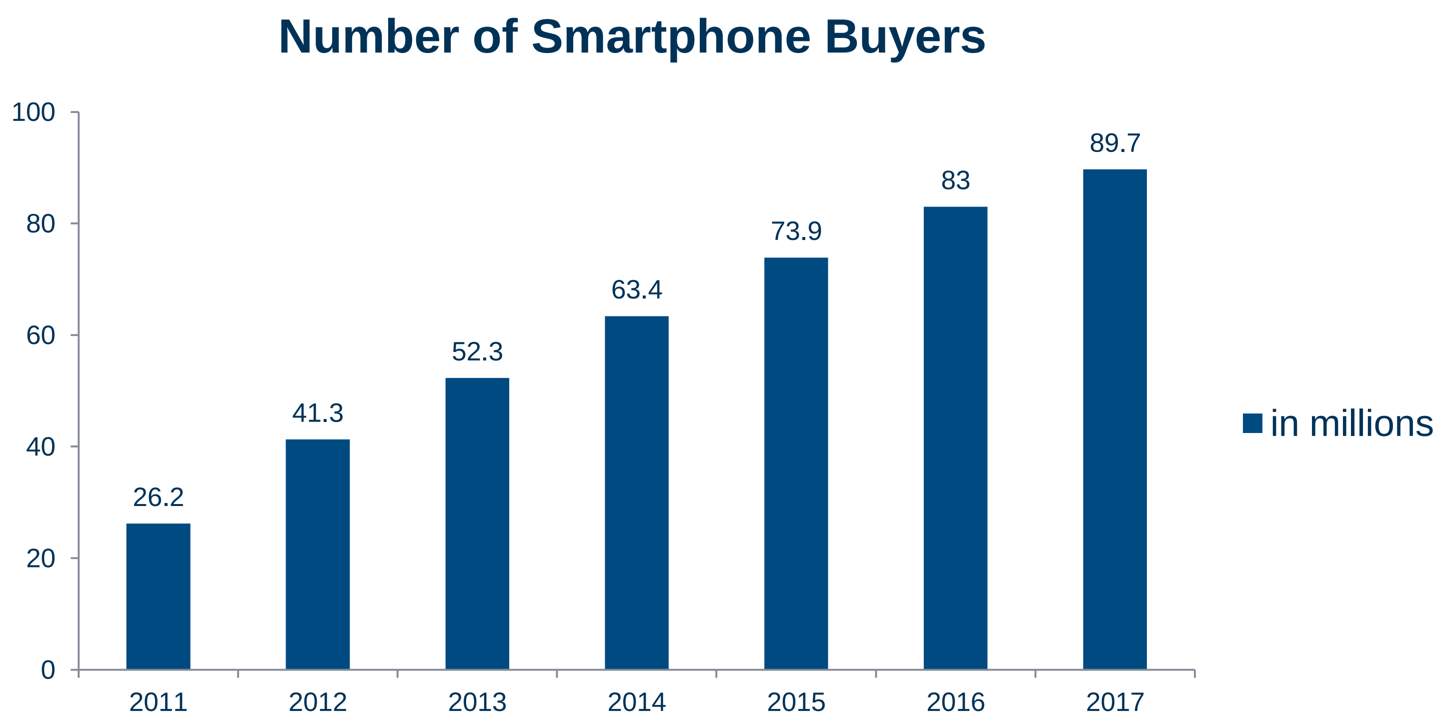
Growth of Smartphones



Source: EMarketer, April 2013

What is an Opportunistic Network?

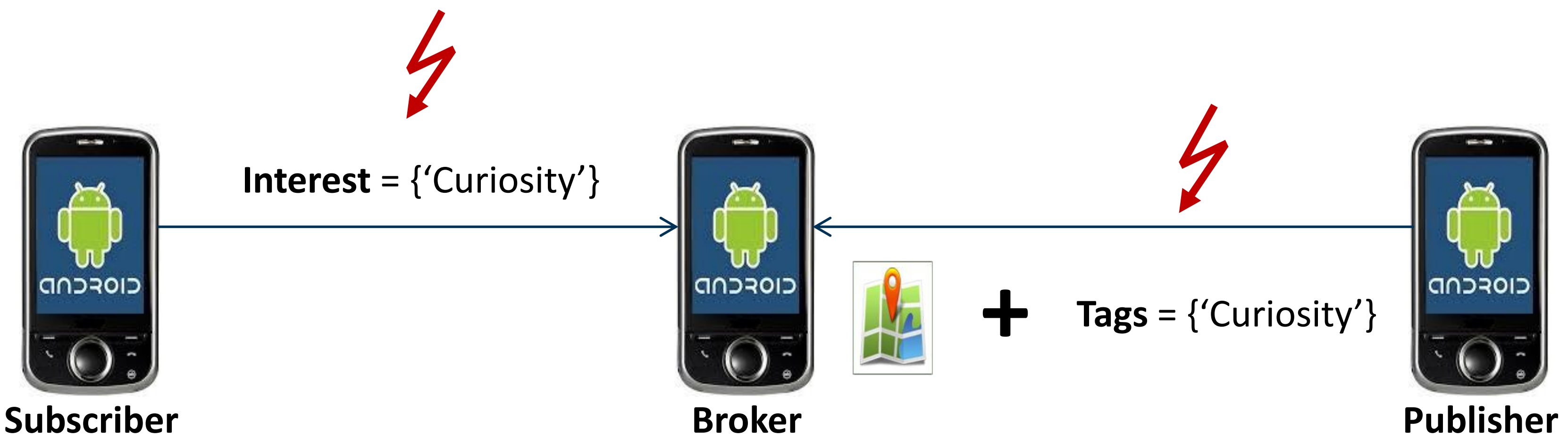
- A network where nodes connect **intermittently** and communicate even when no direct path exists
- It enables content exchange in a pub-sub fashion
  - **Publishers** publish content
  - **Subscribers** express interest
  - **Brokers** disseminate and match interest and content
- Typically **short-range** communication
- E.g., **Haggle** (an EU project from 2006 to 2010)
- DARPA - Content-Based Mobile Edge Networking (**CBMEN**)

Use case Scenario:
Curiosity – A Military Mission

- **No Internet** connectivity in the battlefield
- Every Soldier is equipped with a **smartphone**
- A Scout collects and **shares** sensitive information
  - For instance, enemy positioning
- Only **short-range** communication is possible
- We can leverage opportunistic networks
  - such as **Haggle**

Privacy and Confidentiality Issues

- Brokers (or attackers) may easily learn
  - interest of subscribers
    - **privacy** issue
  - published content
    - **confidentiality** issue



Research Challenges

- *C1:* In the presence of unauthorised brokers, how to **regulate access** to disseminated content?
- *C2:* Considering curious brokers, how to exchange content without compromising **privacy** of subscribers?
- *C3:* How can subscribers subscribe without exposing **interest** to routing brokers?
- *C4:* For **avoiding network flooding**, how do we ensure that a subscriber receives content that she can decrypt?
- *C5:* Assuming the loosely-coupled pub-sub model, how to address C1-C4 **without sharing keys**?

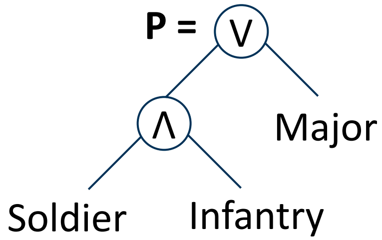
Threat Model

- Honest but curious brokers
- Nodes may collude
  - Broker-broker collusion
  - Broker-subscriber collusion
  - Subscriber-subscriber collusion
- Trusted key management authority
  - distributes key material to nodes out of the band
  - can stay offline
- Passive adversaries

CP-ABE Policy: Building Blocks

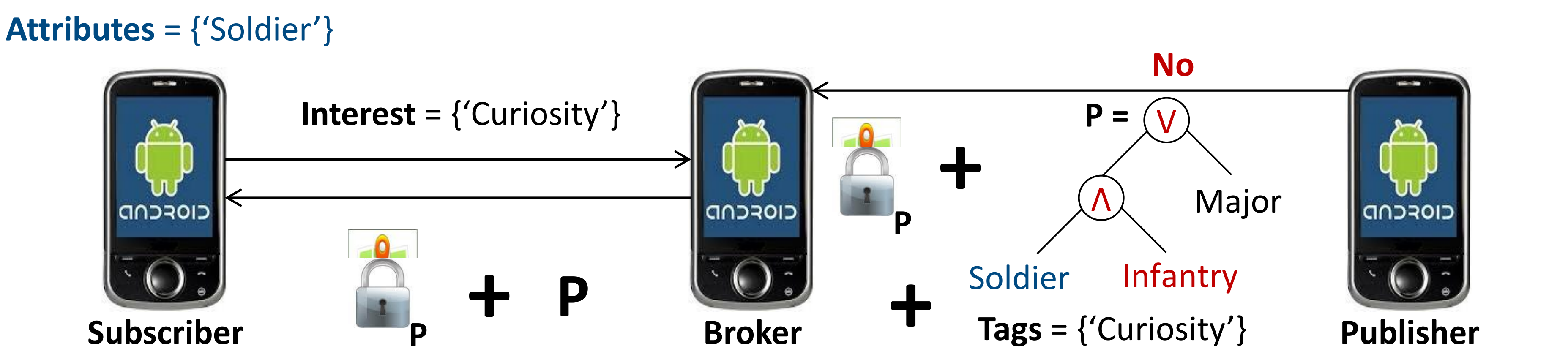
- Ciphertext-Policy Attribute-Based Encryption (CP-ABE)
- Data encrypting entity exerts control over who can gain access
- E.g., *a Major or a Soldier from the Infantry unit can get access*

$\{\text{Content}\}_{\mathbf{P}}$



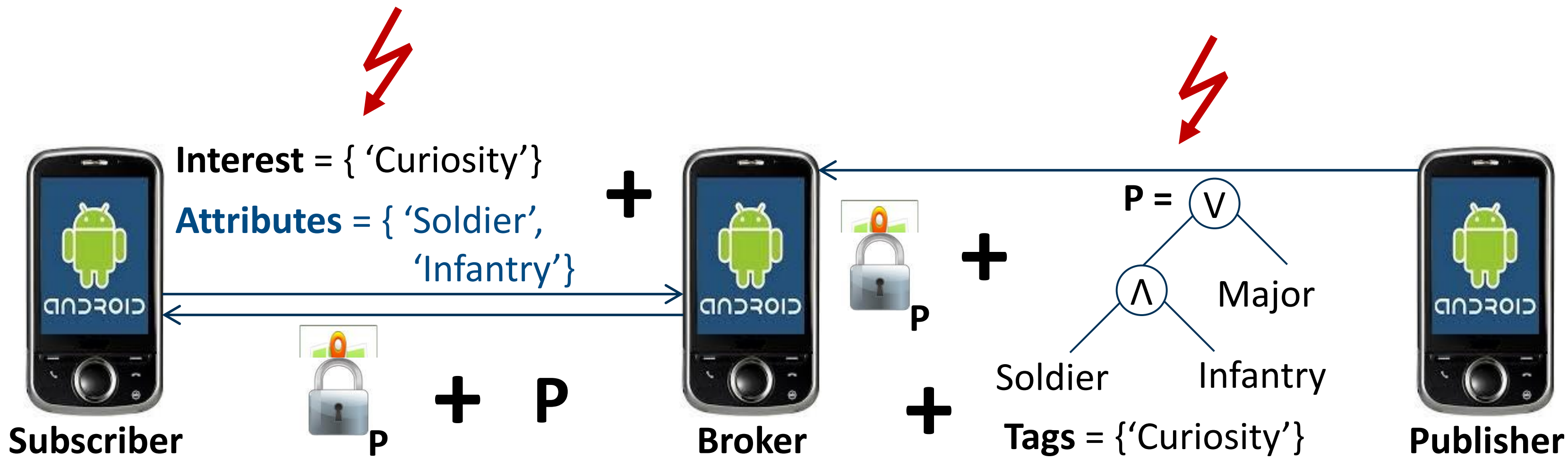
Scheme I: Regulate Access to Content

- Publishers encrypt content using **CP-ABE** policies
- Subscribers may decrypt if they satisfy policies
- It **regulates access to content (C1)**
- Issue: subscribers may receive content that they cannot decrypt – **the network flooding issue (C4)**



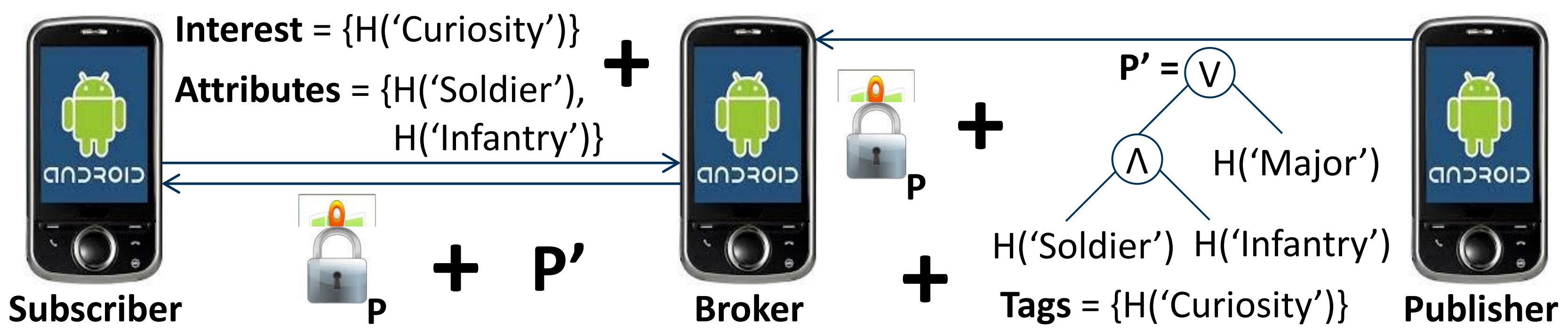
Scheme II: Authorisation Check

- Subscribers send **attributes** along with interest
- Brokers forward content if attributes satisfy policy, as well as interest matches with content
- It resolves **the network flooding issue (C4)**
- Issue: cleartext interest, attributes and policy leak privacy of subscribers (**C2 & C3**)



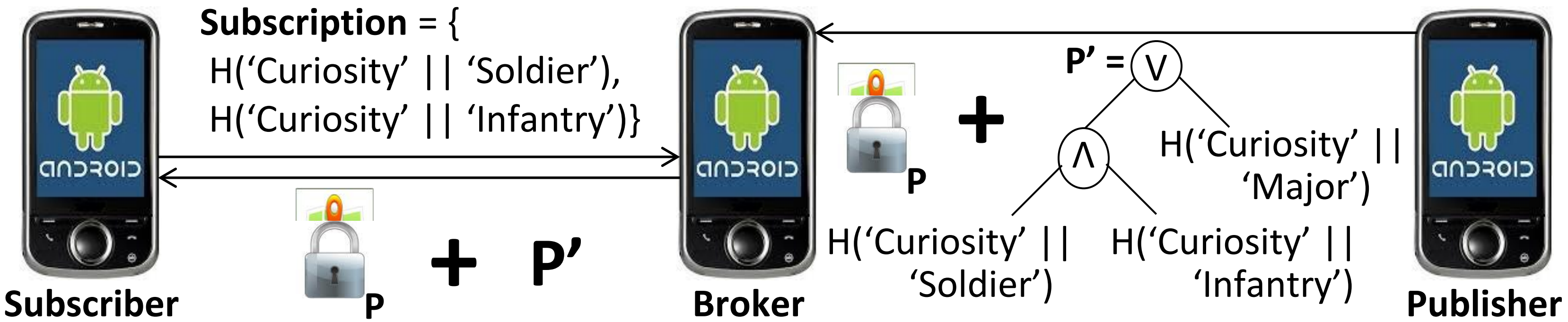
Scheme III: Hiding Private Information using a Hash

- Replace cleartext elements with hash
- Brokers matches hash values
- Issue: pre-computed dictionary attack



Scheme IV: Harden against a Pre-computed Dictionary Attack

- Publishers replace each leave node with a hash of concatenated pair of a tag and an attribute
- Subscribers subscribe using the hash of a concatenated pair of an interest item and an attribute
- It decreases number of comparisons at brokers
- Issue: still vulnerable to a pre-computed dictionary attack

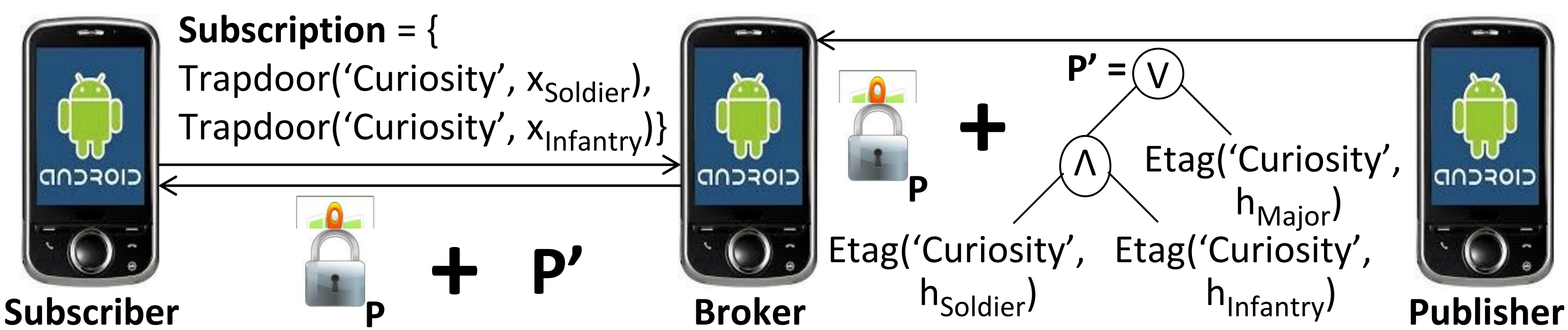


PEKS: Building Blocks

- Public-key Encryption with Keyword Search (**PEKS**) contains four algorithms
  - **Keygen** generates public ($h_{Soldier}$) and private ($x_{Soldier}$) keys
  - **Etag** encrypts tag given a public key
  - **Trapdoor** transforms a keyword into trapdoor using a private key
  - **Test** checks whether an encrypted tag matches with the trapdoor
- It performs encrypted matching without revealing plaintext values

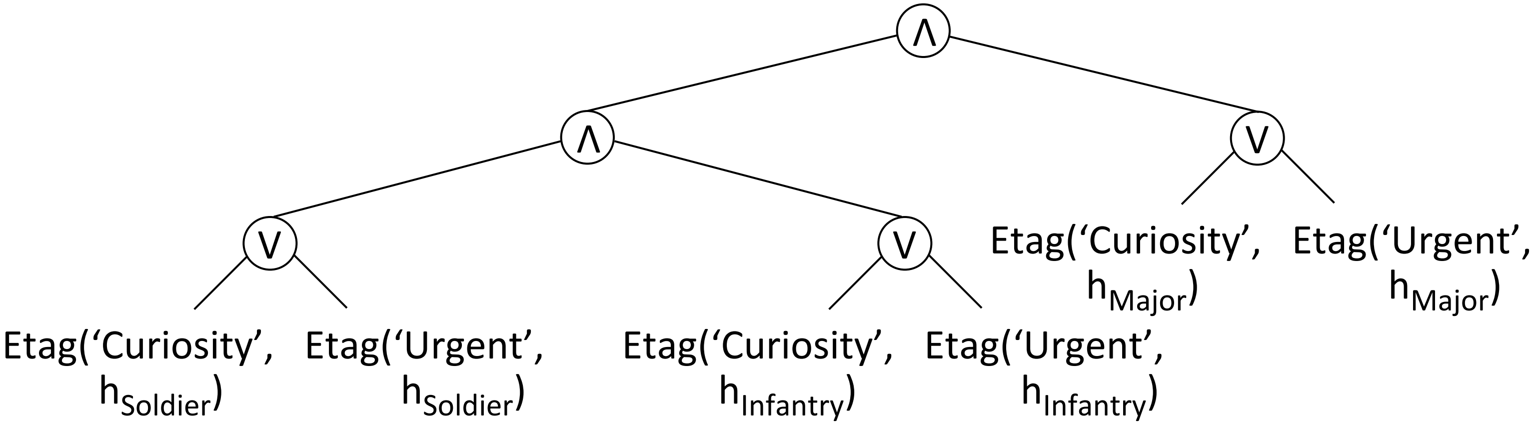
Proposed Scheme: PIDGIN

- **PIDGIN: P**rivacy Preserving **I**nterest an**D** content sharin**G** in opportun**I**stic **N**etworks *[Asghar et al. ASIACCS'14]*
- The main idea is to employ PEKS for protecting policies, tags and subscriptions (**C2 & C3**)
- Publishers encrypt leaf nodes in a policy using **Etag**
- Subscribers protect subscription using **Trapdoor**
- Brokers perform matching using **Test**



Complex Policies

- Policy with multiple tags
- E.g., ‘Curiosity’ and ‘Urgent’



PIDGIN – Implementation Details

- We **developed** a prototype of PIDGIN in **C**
  - Using open source libraries: libfenc and pbc
- We **tested** PIDGIN on Samsung **Galaxy SIII**
  - Cross-compiled gmp, pbc, libfenc and PIDGIN
  - Ported libraries and binaries on smartphone
- Content is encrypted with a symmetric key $\{\text{Content}\}_{\mathbf{K}}$
- Symmetric key is encrypted under a policy $\{K\}_{\mathbf{P}}$
- Policy is encrypted using PEKS $\{P\}_{\mathbf{PEKS}}$

PIDGIN – Overhead

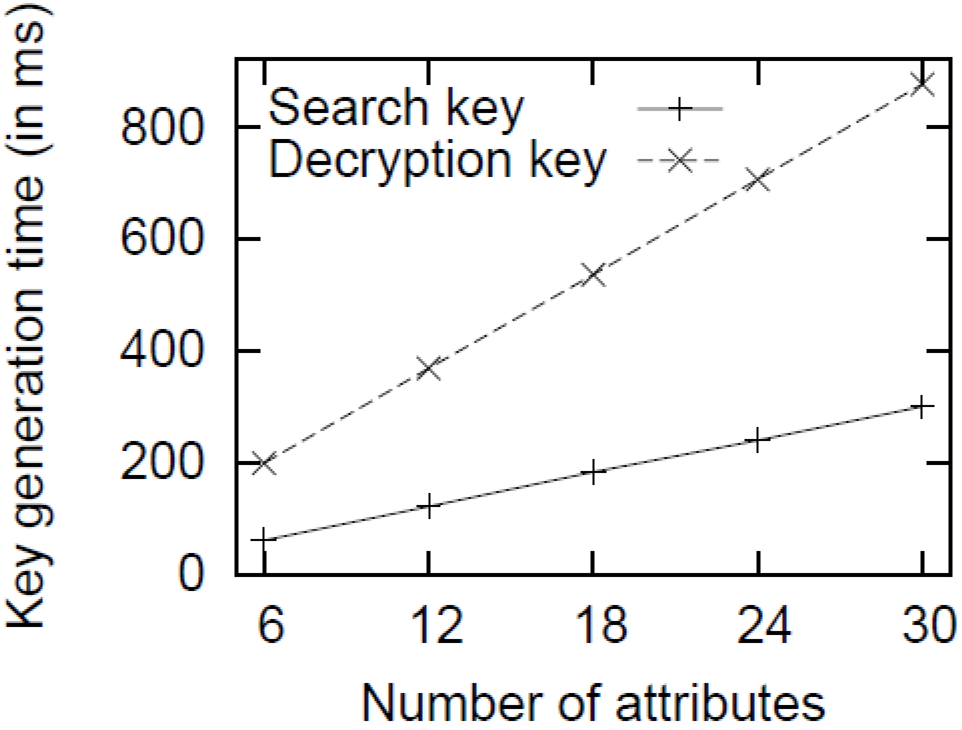
- **Publisher**'s encryption incurs **< 0.3 s**
- **Subscriber**'s encryption incurs **< 0.04 s**
- Broker's **matching** takes **~0.04 s**
- Subscriber's **decryption** takes **< 0.05 s**

- We considered
  - Content: *200 KB file*
  - Policy: *(Soldier Λ Infantry) V Major*
  - Attributes: *{Soldier, Infantry}*
  - Tags/Interest items: *{Curiosity}*

- We ran PIDGIN on Samsung Galaxy SIII
  - Operating system: *Android 4.1.2*
  - Processor: ***1.4 GHz***
  - RAM: *1 GB*

Evaluation: Key Generation

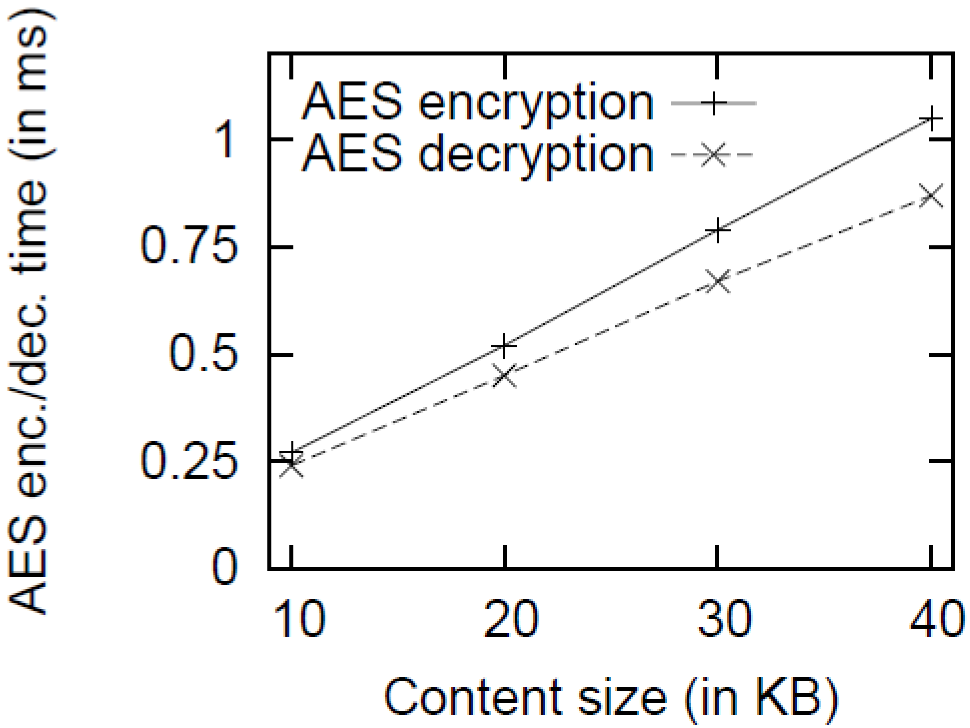
- Key generation authority generates search and decryption keys
- Complexity
  - **Linear**
  - **O (|Attributes|)**



Evaluation: Content Encryption and Decryption

- Encryption and decryption of content using a symmetric key

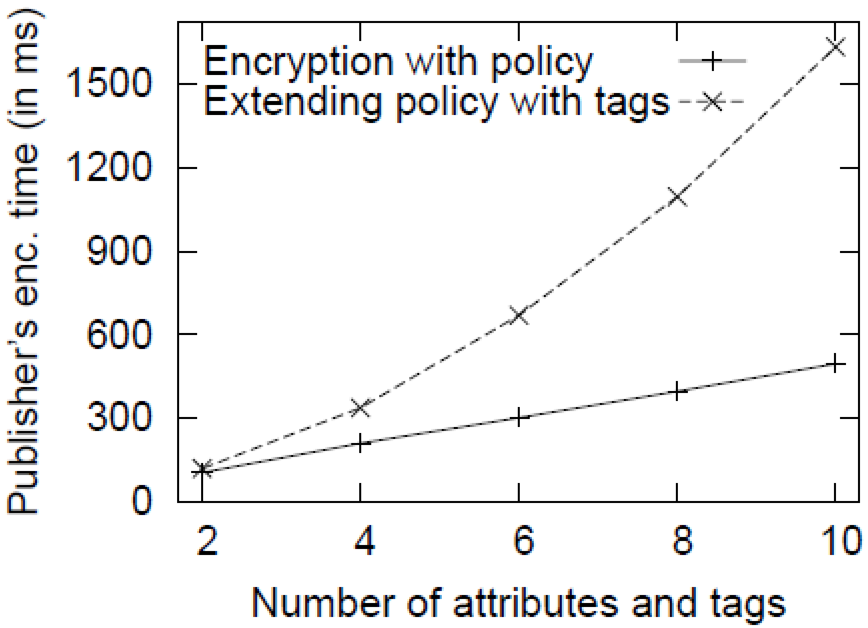
- Complexity
  - **Linear**
  - **O (|Content|)**



Performance Analysis: Publisher's Encryption

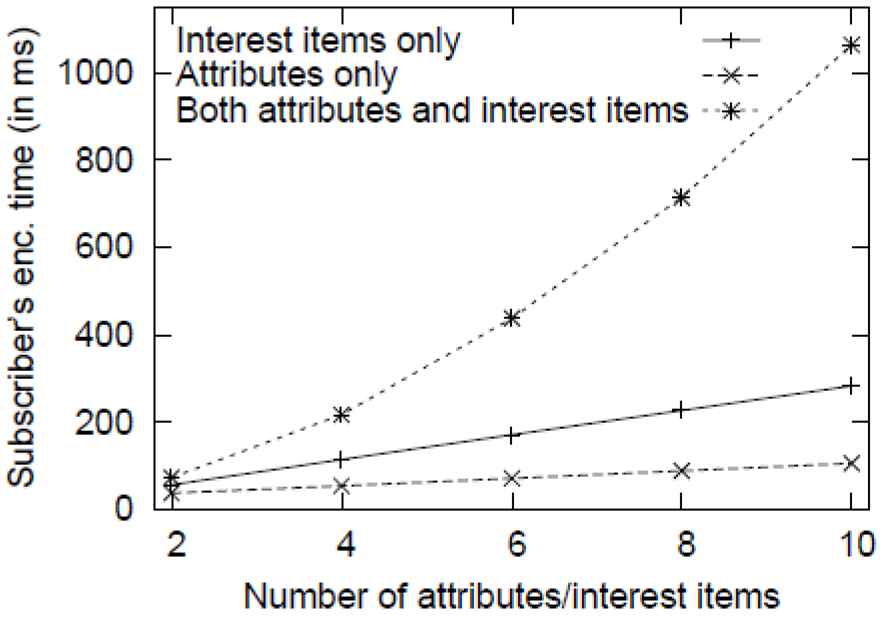
- Encrypting symmetric key with policy and then extending policy with tags
  - Each Etag is of 256 bytes

- Complexity
  - **Quadratic**
  - **O (|Tags| * |Attributes-Pub|)**



Performance Analysis: Subscriber's Encryption

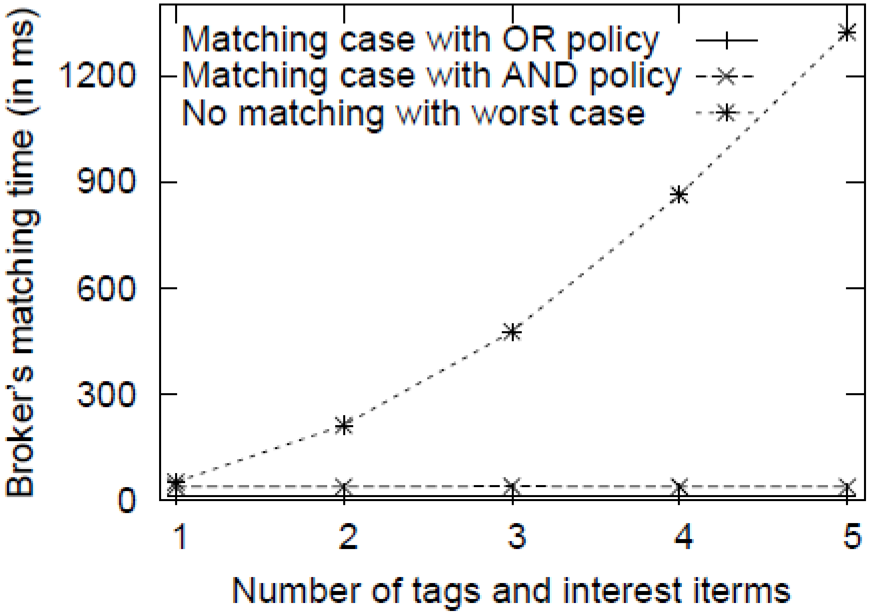
- Effect of number of interest items and attributes on subscriber's encryption time
  - Each Trapdoor of interest item/attribute is of 128 Bytes
- Complexity
  - **Quadratic**
  - **O (|Interest-Items| * |Attributes-Sub|)**



Performance Analysis: Broker’s Matching

- Effect of number of interest items and tags on broker’s matching time

- Complexity
  - **O (|Tags| * |Interest-Items| * |Attributes-Pub| * |Attributes-Sub|)**



Related Work

- Search on encrypted data
  - **Symmetric** encryption schemes are **not suitable** in opportunistic environments
  - Public-key encryption schemes do **not** support **expressive** policies
- Attribute-Based Encryption (**ABE**) support expressive access control polices
  - CP-ABE and KP-ABE **reveal** policies and attributes, respectively
- Predicate encryption and hidden vector schemes assume end-to-end communication
- Shikfa *et al.* propose content dissemination in opportunistic networks
  - Only **uni-directional** communication from publishers

Discussion

- Optimisation
  - Short-circuit evaluation
- Scalability
  - Time to live
  - Content creation time
  - Content received time
- Key management
  - Deployment in practical scenarios
  - Distributed authorities

Summary

- We proposed **PIDGIN** that regulates access to content
- In PIDGIN, brokers **enforce sensitive policies** without compromising privacy of subscribers
- Publishers and subscribers **do not share** keys
- We **implemented** a prototype and measured performance by running on Samsung **Galaxy SIII**
- It can be applied to a number of other application scenarios, e.g.,
  - Reporting and controlling crimes
  - Offloading content delivery networks

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