Data integrity protection for data spaces

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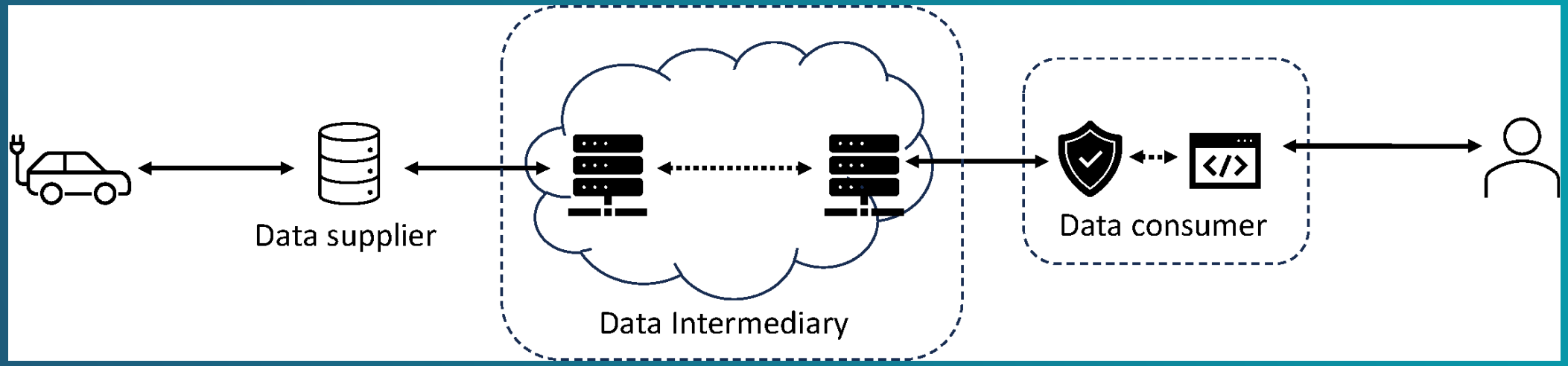
https://mm.aueb.gr/projects/snds

What is a data space?



- A way to liberate data from silos
  - Data supplier shares data with data consumers
  - An intermediary facilitates the exchange
  - Standardized storage & retrieval API at intermediary
    - Example: ETSI's NGSI-LD API

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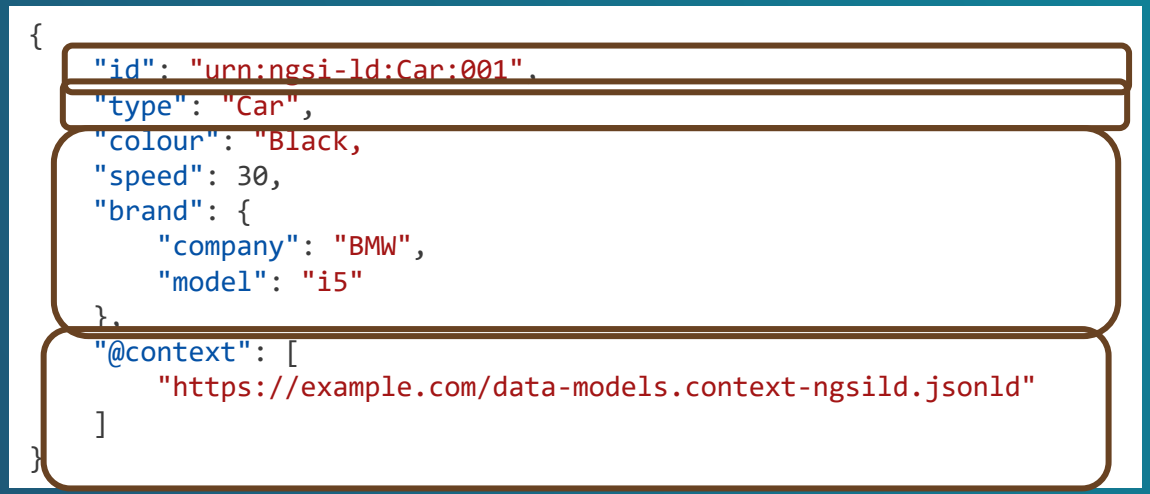
NGSI-LD Objects



```
{
    "id": "urn:ngsi-ld:Car:001",
    "type": "Car",
    "colour": "Black,
    "speed": 30,
    "brand": {
        "company": "BMW",
        "model": "i5"
    },
    "@context": [
        "https://example.com/data-models.context-ngsild.jsonld"
    ]
}
```

- Each entity is a uniquely identified JSON-LD encoded object
- Each entity has a "type"
- Each entity consists of name-value "attributes"
  - Which may be JSON-LD objects themselves
- The attributes of a type are defined in a "context"

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NGSI-LD Queries - Retrieve Item

GET https://broker.com/ngsi-ld/v1/entities/urn:ngsi-ld:Car:001

```
{
    "id": "urn:ngsi-ld:Car:001",
    "type": "Car",
    "colour": "Black,
    "speed": 30,
    "brand": {
        "company": "BMW",
        "model": "i5"
    },
    "@context": [
        "https://example.com/data-models.context-ngsild.jsonld"
    ]
}
```

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NGSI-LD Queries - Retrieve Attributes

GET https://broker.com/ngsi-ld/v1/entities/urn:ngsi-ld:Car:001?**attrs=brand%speed**


```
{
    "id": "urn:ngsi-ld:Car:001",
    "type": "Car",
    "speed": 30,
    "brand": {
        "company": "BMW",
        "model": "i5"
    },
    "@context": [
        "https://example.com/data-models.context-ngsild.jsonld"
    ]
}
```


Colour is hidden!

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Challenge

- Given that:
  - The data space stores complete items
  - Attribute hiding is implemented by the intermediary
  - Consumer may not be authorized to access hidden attributes
  - Consumers trust suppliers

➞ How can consumers verify the integrity of partially retrieved items?

✓ We propose two signing solutions that support selective disclosure

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Approach

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A "disclosures" construction mechanism

- A common construction shared by both solutions
- Step 1: Decompose an item into a list of "disclosures"
- Step 2: Reconstruct a "partial" item by selecting which "disclosures" to reveal

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Step 1: Decomposition

- Turn each attribute into a "disclosure"
  - The disclosure name is the attribute's "JSON Pointer"
  - The disclosure value is the attribute's value
- For each composite attribute repeat the process for all inner objects

```
{
    "id":"urn:ngsi-ld:Car:001",
    "type":"car",
    "colour":"black",
    "speed": 30,
    "brand":{
        "company":"bmw",
        "model": "i5"
    }
}
```

/id	urn:ngsi-ld:Car:001
/type	car
/colour	black
/speed	30
/brand	{'company': 'bmw', 'model': 'i5'}
/brand/company	bmw
/brand/model	i5

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Step 2: Reconstruction

- Select the disclosures to reveal
- Perform the reverse process
  - E.g., reveal 1st, 4th and 6th disclosures

/id	urn:ngsi-ld:Car:001
/type	car
/colour	black
/speed	30
/brand	{'company': 'bmw', 'model': 'i5'}
/brand/company	bmw
/brand/model	i5

```
{
    "id":"urn:ngsi-ld:Car:001",
    "speed": 30,
    "brand":{
        "company":"bmw",
    }
}
```

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Two non-solutions

- Sign the entire item
  - Cannot split it at the intermediary
  - Need to sign each and every possible attribute combination
- Sign each attribute separately
  - Does not preserve objects
  - No way to know if attributes belong to the same object

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Hash signature-based approach - Sign

Performed by the supplier

1. Generate a random salt value for each disclosure
2. Hash each disclosure + salt value
3. Digitally sign concatenation of all hashes
4. Store signature, hashes, disclosures and salt values at intermediary

H(	/id	urn:ngsi-ld:Car:001	<Salt>	)
H(	/type	car	<Salt>	)
H(	/colour	black	<Salt>	)
H(	/speed	30	<Salt>	)
H(	/brand	{'company': 'bmw', 'model': 'i5'}	<Salt>	)
H(	/brand/company	bmw	<Salt>	)
H(	/brand/model	i5	<Salt>	)

Sign()

Hash signature-based approach - Reveal

Performed by the intermediary

1. For each revealed attribute also reveal the salt
2. For the hidden attributes only return the hash
3. Reveal the signature
   - E.g., reveal 1st, 4th and 6th disclosures

	/id	urn:ngsi-ld:Car:001	<Salt>
H(	~~/type~~	~~car~~	~~<Salt>~~)
H(	~~/colour~~	~~black~~	~~<Salt>~~)
	/speed	30	<Salt>
H(	~~/brand~~	~~{'company': 'bmw', 'model': 'i5'}~~	~~<Salt>~~)
	/brand/company	bmw	<Salt>
H(	~~/brand/model~~	~~i5~~	~~<Salt>~~)

Hash signature-based approach - Verify

Performed by the consumer

1. For each revealed attribute calculate the hash
2. Concatenate the hashes
3. Verify the signature

H(	/id	urn:ngsi-ld:Car:001	<Salt>	)
H(	~~/type~~	~~car~~	~~<Salt>~~	)
H(	~~/colour~~	~~black~~	~~<Salt>~~	)
H(	/speed	30	<Salt>	)
H(	~~/brand~~	~~{'company': 'bmw', 'model': 'i5'}~~	~~<Salt>~~	)
H(	/brand/company	bmw	<Salt>	)
H(	~~/brand/model~~	~~i5~~	~~<Salt>~~	)

Verify()

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BBS+ signature-based approach

- BBS+ signatures allow:
  - A signer to sign a "group" of messages
  - A third party to select a subset of the messages and calculate a ZKP to prove that "this subset of the messages is part of the set that matches the provided signature"
  - Size of the ZKP linear on hidden disclosures
- Straightforward application to the list of disclosures ➞ Treat each disclosure as a separate message

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Implementation*

- Part of Secure Named Data Sharing (SNDS) project
  - Data supplier stores disclosures & signatures at intermediary
  - Intermediary accessed via NGSI-LD API gateway
  - Gateway trusted (and operated) by consumer
- Gateway operation
  - Receives NGSI-LD API request from consumer
  - Retrieves disclosures from intermediary
  - Validates signatures and proofs
  - Responds with reconstructed partial item

*https://github.com/mmlab-aueb/selective-disclosure

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Evaluation

- Baseline scenario
  - Intermediary is fully trusted
  - Constructs partial content item
  - Signed with ECDSA with the P-256 curve
- Hash-based scenario
  - 128-bit random salts
  - Hashes calculated using SHA-256
  - Signed with ECDSA with the P-256 curve
- BBS+-based scenario
  - MATTR's BBS+ implementation
  - Group signatures using the BLS12-381 pairing-friendly elliptic curve
  - Must also create/send ZKP based on revealed disclosures

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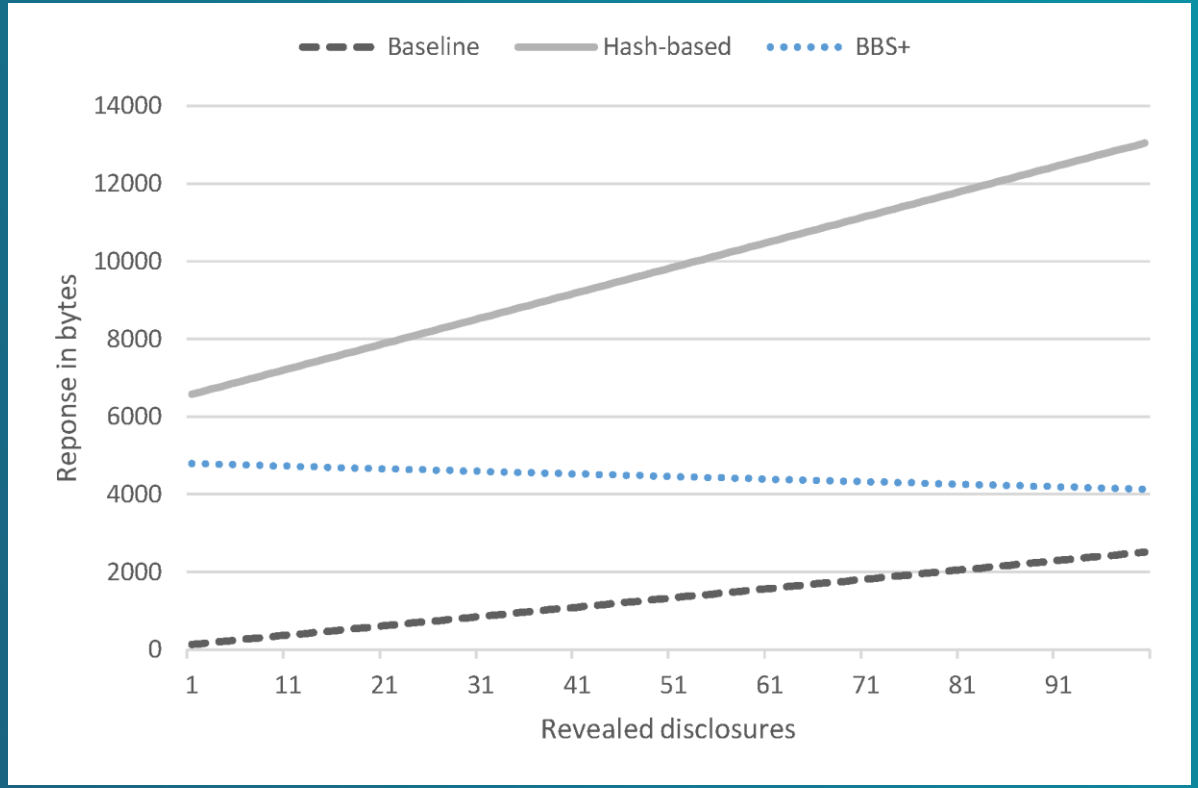
Communication overhead



- Size of responses returned
  - Against disclosures revealed

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Computing overhead

	Supplier (sign original items)	Intermediary (sign disclosed items)	Consumer (verify signatures)
Baseline	None	<0.1ms	<0.1ms
Hash	<0.1ms	None	<0.1ms
BBS+	22ms	70ms	60ms

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Security properties

	Hash-based	BBS+
Integrity protection	✅	✅
Indistinguishability of hidden disclosures (Let D1 and D2 be the same attribute for two items, if D1 and/or D2 is hidden, the gateway should not be able to say if D1==D2)	✅	✅
Untraceability of disclosures (Let D1 be a hidden attribute of an item and D1' the same attribute after some time, the gateway should not be able to say if D1==D1')	❌	✅
Hide the total number of disclosures	❌	❌

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Summary

- Selective revelation in data spaces
  - Data integrity protection
  - Content only signed by supplier
  - Content selectively revealed by intermediary
  - Hash based solution: higher communication overhead
  - BBS+ based solution: higher computing overhead
- Future work
  - Disallow hiding of some attributes (e.g. object ID)
  - Integrate with FIWARE Orion context broker
  - Integrate proofs directly into NGSI-LD objects

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Thank you

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