Distributed Key Management in Microgrids

Micro sElf-orgaNiSed mAnagement (MENSA)

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Vaios Bolgouras, Christoforos Ntantogian, Emmanouil Panaousis, Christos Xenakis, " Distributed Key Management in Microgrids." *IEEE Transactions on Industrial Informatics, vol. 16, no. 3, pp. 2125-2133, March 2020.*

SealedGRID: Scalable, trusted, and interoperable platform for secured smart grid

European Commission | Horizon 2020 European Union funding for Research & Innovation

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SealedGRID: Scalable, trusted, and interoperable platform for secured smart grid

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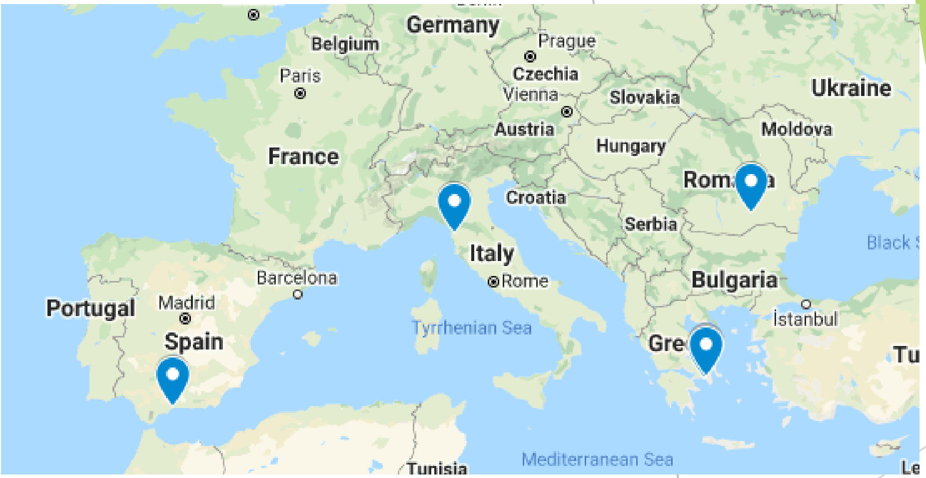

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Smart Grid and renewable energy sources

Environmental responsibility

Diversify energy mix

Increasing demand for energy power

Multiple energy producers

Microgrids

- A microgrid is formed by **a group** of electricity ***producers*** and ***consumers***
- Typically **connected** to a **Smart Grid**
- Can operate **autonomously** in an **“islanded”** mode
- Network of **interconnected smart devices**
- Bidirectional **M2M communication**
- **Power consumption**-oriented **smart applications**

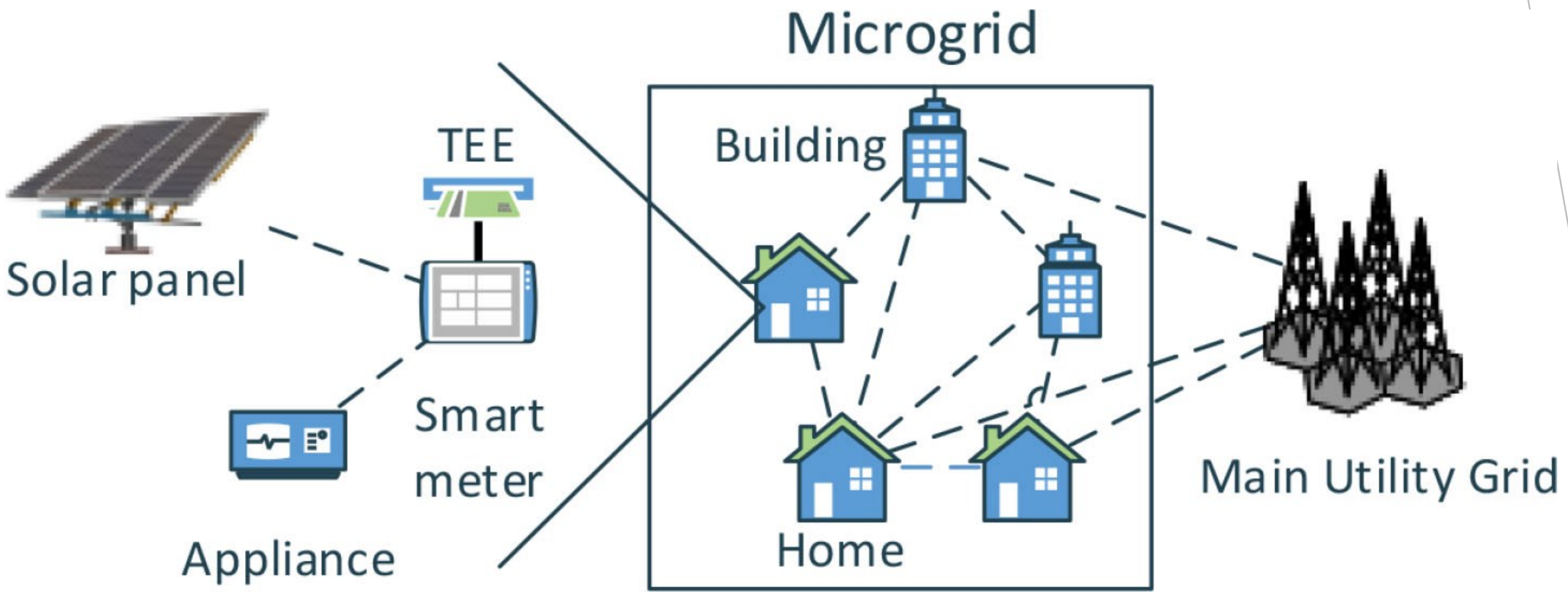
Challenges for Key Management in Microgrids

- **C1:** High **churn rate** (frequent **join** & **leave** of nodes), causes **overhead** to centralized structures & solutions
- **C2: Compromised** Certification Authority (CA)
  - **Revocation** of all issued certificates
  - **Impairment** of information exchange
- **C3: Dependability** to the CA
  - **Unable** to validate certificates if **connectivity** with the **CA is lost**
- C4: The **CA** constitutes a **single point of failure**

MENSA: Micro sElf-orgaNiSed mAnagement

- Distributed & scalable **key management** and **authentication scheme** for microgrids
- Hybrid solution utilizing **Public Key Infrastructure** and **Web of Trust** concepts
- Allows **frequent** actions of **“Join”** and/or **“Leave”** without impacting on the network’s efficiency
- **Compromised CA** does not necessarily result in performing **certificate revocation**
- Network’s operational continuity **does not depend** on the **CA’s availability**
- No **single point of failure** due to decentralized nature

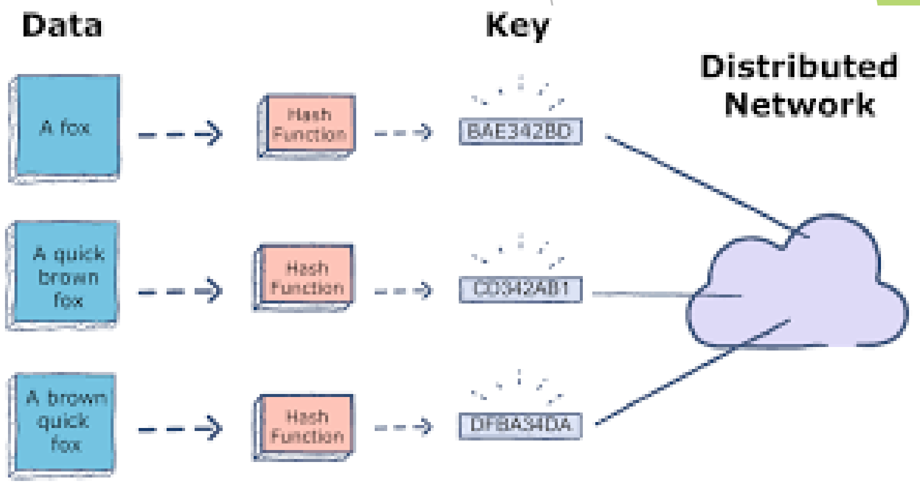
Functional Components

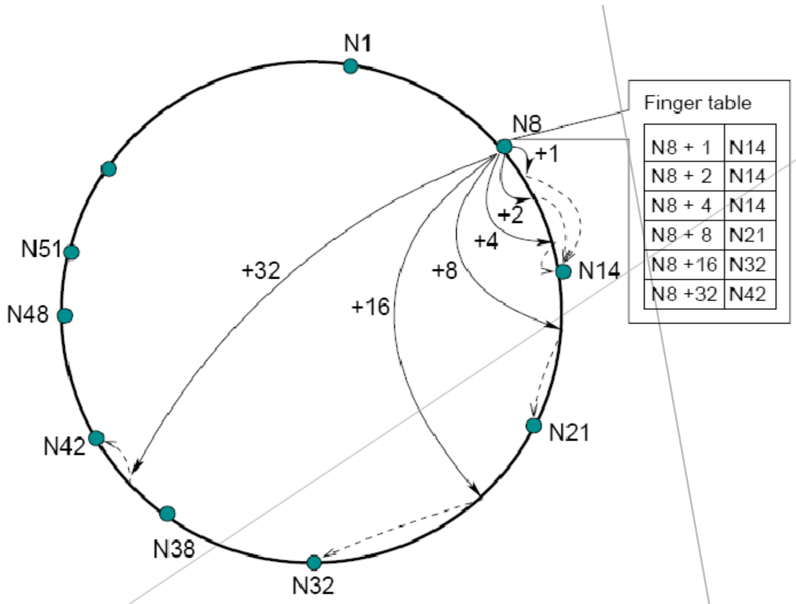


**Trusted Execution Environment resides in the smart meters*

Technical Background

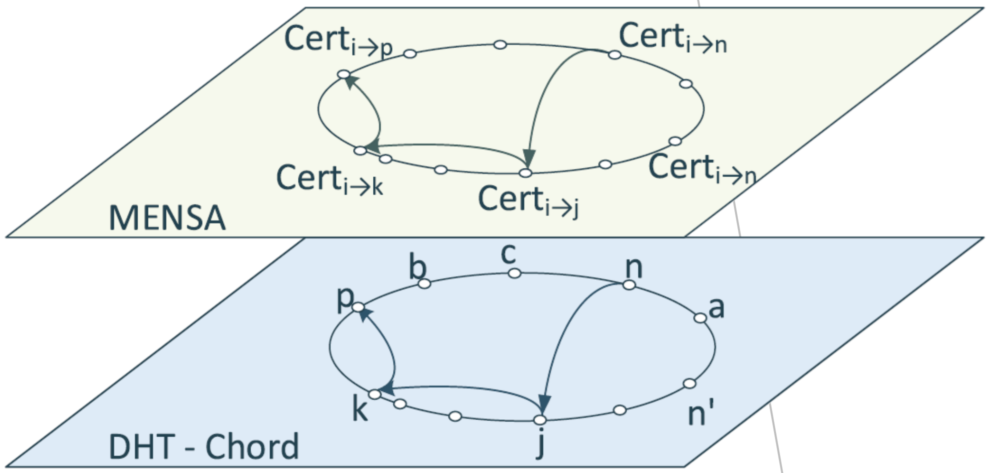
- **Distributed Hash Tables - DHT**
  - **key, value pairs** are stored in a **distributed manner** among the network participants
  - **Value** is retrieved based on its **paired key**
- **Chord Protocol**
  - Defines **key assignment** to the network
  - Provides queries to **locate the value** of a corresponding **key**
  - **“Finger Table”** defines nodes that can be communicated with

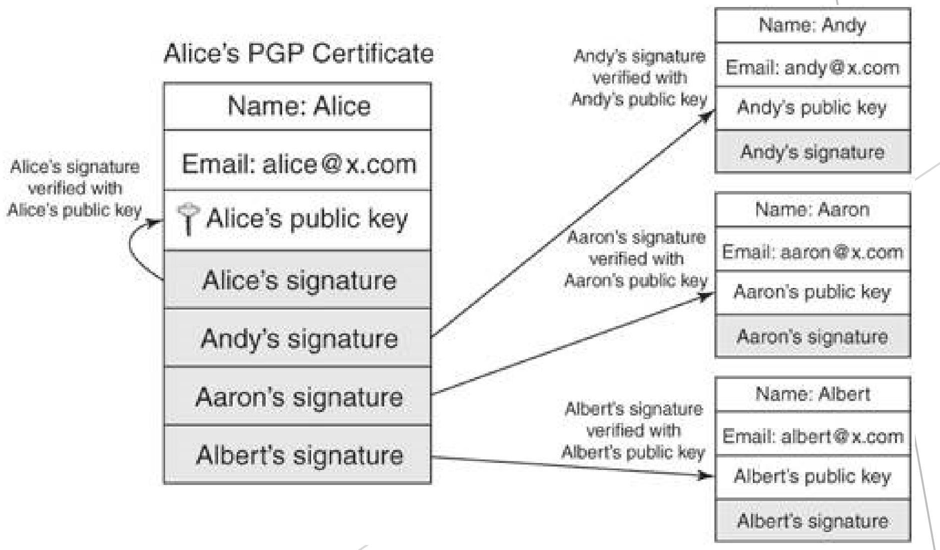




MENSA Architecture

- Each node ***n*** possesses **key pair *Pk_n/Sk_n***
- ***Pk_n/Sk_n*** follows the self-generated approach
- Overlay pair → **(*K_n* , *$Cert_n$*) as (key, value)**
  - ***$K_n = h(Pk_n + ID_{device})$***
  - ***$Cert_n$*** follows the **OpenPGP** format
- **Finger tables** contain nodes that:
  - Hold **position** defined by Chord protocol
  - Possess a **valid certificate**
- If ***a*** wants to communicate with ***b***
  - ***a*** retrieves ***b's* certificate**
  - if ***a*** trusts it or its trust path
  - ***a*** communicates with ***b***

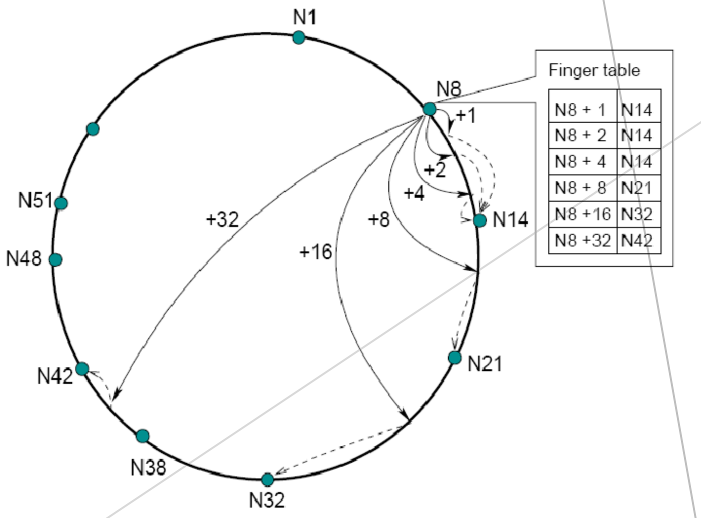




Node Join – node n

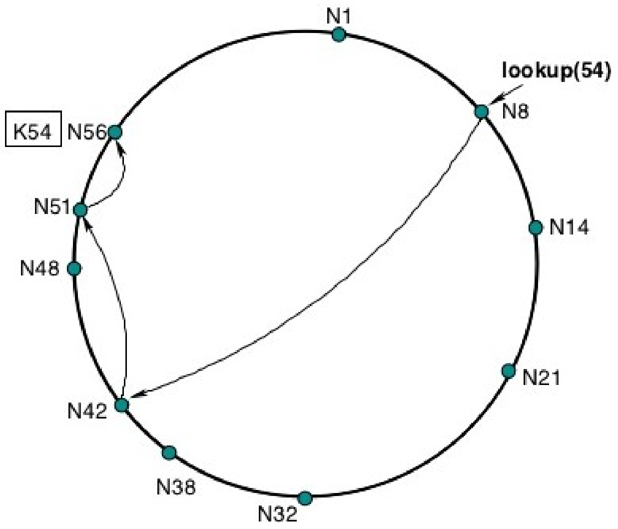
- ***n's Cert$_n$*** should be signed by <u>at least one</u> **"Introducer"** (trusted members of the structure)
- If the ***Cert$_I$*** of the **introducer is invalid**, the process **stops**
- ***n*** verifies the **validity** of the ***Certs*** assigned to the nodes ***n's* finger table** by chord
- Each node in ***n's* figure table** also checks the validity of the node ***n's Cert$_n$***
- Validation can be also performed using **remote attestation**

Function *nodeJoin(k)*
- **if** $Cert_i$ *is valid* **then**
  - **while** *next* (IP_k) *to be stored in* $fingerTable_n$ **do**
    - **if** $Cert_k$ *is signed by introducer i* **then**
      - // $Cert_k$ is trusted
      - n stores IP_k in $fingerTable_n$
    - **end**
  - **end**
- **end**



Normal Operation

- **n** accumulates signatures from **multiple endorsers**
- Operations **not affected** if an **Introducer gets compromised**, other endorsements are utilized
- Searches are executed as defined by the **Chord protocol**



Function $n.find(n')$

if n' *resides in* $n.fingerTable$ **then**

`// n' is trusted`

return success

else

send request to the next trusted node p closest to n' from node n

if n' *resides in* $p.fingerTable$ **then**

`// n' is trusted`

return success

else

send request to the next trusted node k closest to n' from node p

.

.

.

end

end

`// No trust chain was found`

return failure

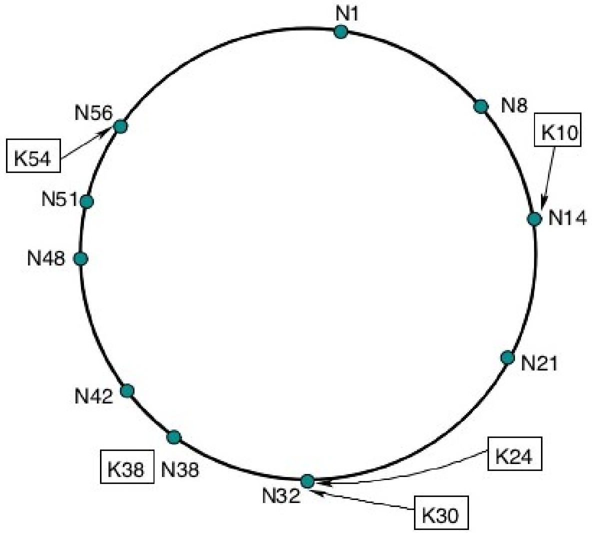
Algorithm 2: Searching for another network node.

Certificate Revocation

- There are **three ways** to revoke a **Cert** in **MENSA**
- 1st **Implicitly,** when a **Cert expires**
  - Nodes with expired **Certs** will have to get through the **verification process** again
- 2nd **Explicitly,** by the owner using a revocation Cert, ***RevC****n* (created together with *Cert**n*)
  - ***n*** sends its ***RevC****n* to the nodes that are included in **its figure table**
- 3rd **An empowered node** is able to revoke ***n's*** Cert using ***RevC****n*
  - Misbehavior can be detected using **specification-based methods + remote attestation**
  - The ***RevC****n* is sent only to the nodes that have **the leaving node** in their **finger tables**
- **Trusted Execution Environment** is used to avoid **abuse** of revocation certificates

Node Leave

- **Implicit** or **explicit** certificate revocation
- **Re-organization** of finger tables
- Affected nodes will need to check the **certificates** of the **newly** assigned nodes



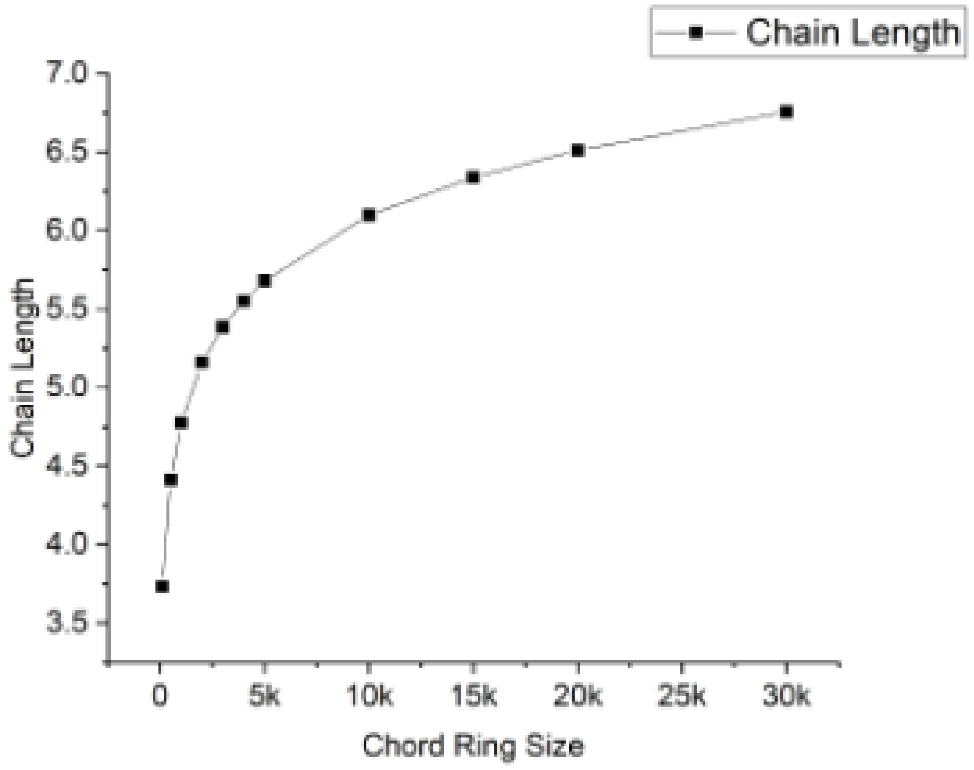
Evaluation – Node Join delay

- Scenario 1: Node **Join time delay** (0 – 30.000 nodes)
  - For 0 – 5.000 nodes the **delay is 1.55 sec**
  - While from 20.000 – 30.000 the **delay is 2.2 sec**
- The **slight decline in performance** is the byproduct of the overall **increased requests**
- **Negligible impact** of **signing** and **validation delays**
- Minimal increase in nodes saved at **finger tables** ***O(log N)***
- **MENSA is scalable**

N	fingerTable size
500	8
5,000	12
15,000	13
30,000	14
.	
.	
5,000,000	22

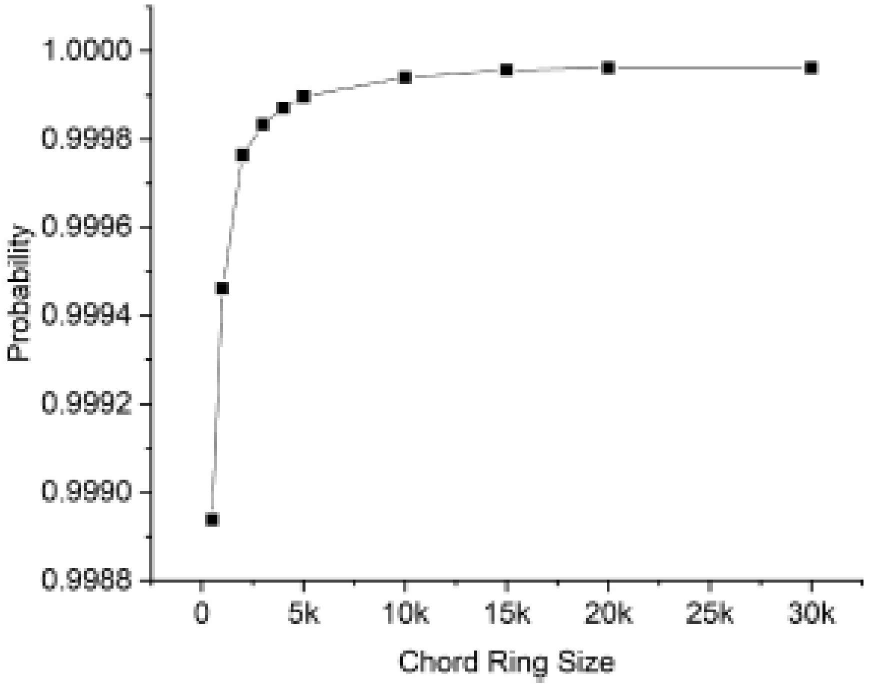
Evaluation – Chain Length

- **Scenario 2:** Ordered **list of certificates** starting from the **node initiating a look-up** operation up to the **target node**
- Mean length of the **chain of trust**
- It includes the **initiator** & the **target** node
- Chain length varies from **1 - 5 nodes**
- No **significant changes** are perceived in MENSA as the **size of the grid increases**



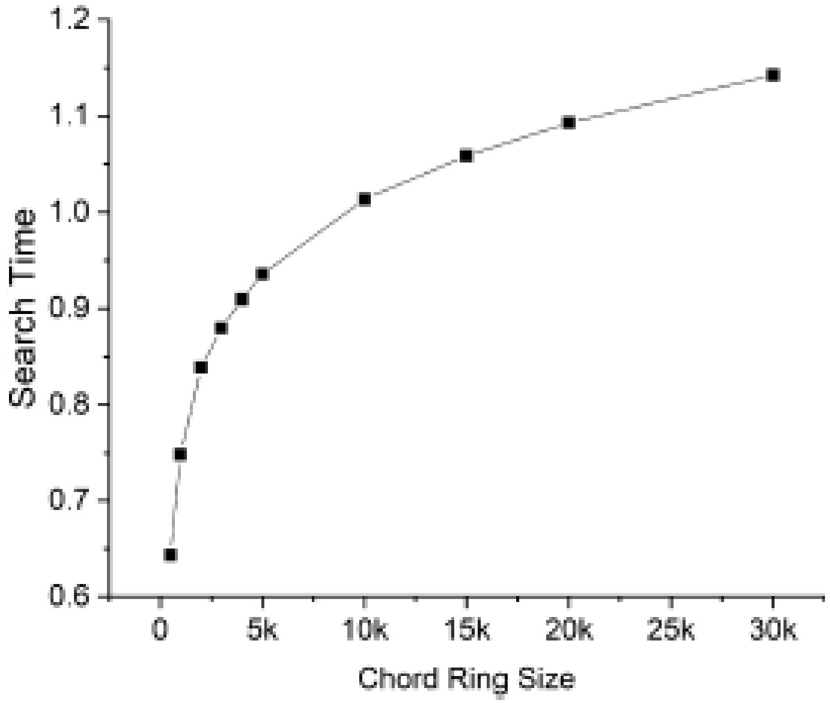
Evaluation - Probability of finding trust

- The **probability** that **two random nodes** will be able to **establish trust relationship** between them



Evaluation - Search time

- **Average time needed** for a random node to establish **trust relationships** with another random node



Conclusions

- MENSA is the **first distributed hybrid key management** and **authentication system** for microgrids
- It **eliminates** the need for **a TTP**, while ensures **high availability**
- DHT is used for **efficient discovery of trust relationships** among the microgrid nodes
- It is a **decentralized** and **flexible** solution that promotes **scalability** and **resilience**
- Paves the way toward **developing microgrids** further and it will help **realizing their full potential** in terms of scalability and performance efficiency

Thank you!

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