ons
NORTH AMERICA
OPEN NETWORKING //
Enabling Collaborative
Development & Innovation

Extending Blockchains For Risk Management and Their Application to Network Security

Raj Jain
Barbara J. and Jerome R. Cox, Jr. Professor
Washington University in St. Louis
jain@wustl.edu

Open Networking Summit, San Jose, CA, April 4, 2019

Slides and Video Recording at:
http://www.cse.wustl.edu/~jain/talks/pbc_ons.htm

Hosted By
THE LINUX FOUNDATION | LF NETWORKING

Overview

1. What is a Blockchain?
2. Applications to Networking
3. Strengths and weaknesses of the current blockchains
4. Extending Blockchains: Converting data to knowledge
5. Applications of Probabilistic Blockchains to Network Security

What is a Blockchain?

- Blockchain is the technology that allows **two complete strangers** to complete a transaction/contract **without a trusted third party**
- Blockchain was invented by the inventor of Bitcoin
  - After Bitcoin became successful, people started looking into the technology behind Bitcoin and found:
    - Blockchain is the key for its success

Example of a Contract: Wedding

Example of a Contract: Wedding

- Centralized registry
- Single point of failure
- Easier to hacked

- Decentralized
- No single point of failure
- Very difficult to hack

Trend: Decentralized – No Central Point of Trust

- Decentralized systems are:
  1. More secure: Attack tolerant
  2. No single bottleneck
  3. More reliable: Fault tolerant
  4. No single point of control ⇒ No monopoly

- Blockchain is one way to do this among untrusted multi-domain systems.

Time is a cycle: Decentralized vs. Centralized debate

Examples of Centralized Systems

- **Banks**: Allow money transfer between two accounts
- **City Records**: Wedding registers, Property ownership
- **Networks**: Certificate Authorities, DNS

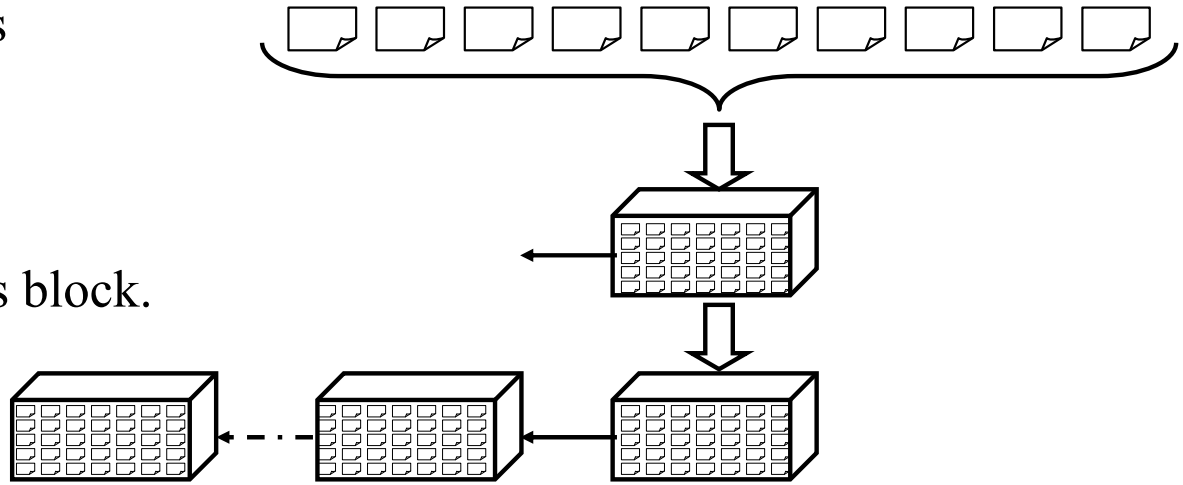
- In all cases:
  - There is a central third party to be trusted
  - Central party maintains a large database ⇒ Attracts Hackers
  - Central party may be hacked ⇒ affects millions
  - Central party is a single point of failure. Can malfunction or be bribed.

Blockchain Process

1. **Users** broadcast signed transactions or smart contracts

2. **Mining nodes** validate transactions and create blocks. Point to previous block.

3. **Blockchain nodes** validate blocks and construct a chain



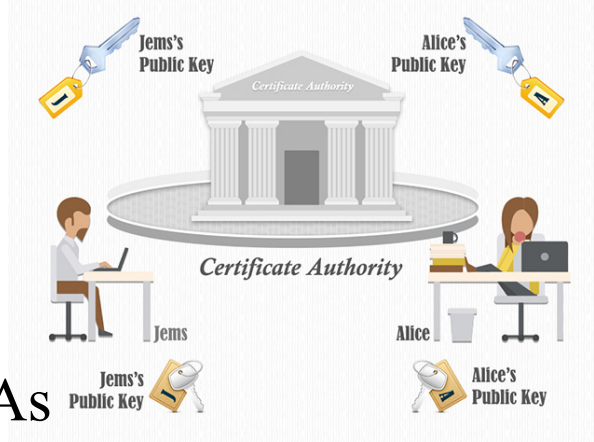
- There are many users, many mining nodes, and many blockchain nodes. More nodes ⇒ Better. Less ⇒ Blockchain not required/useful.

Key Strengths of Blockchains

1. **Distributed**: No single point of failure
2. **Decentralized Consensus**: Transactions valid only if agreed by majority
3. **Trustless**: Transacting or processing parties do not need to trust
4. **Cryptographic Security**: Elliptic Curve Cryptography
5. **Non-Repudiation Guarantee**: All transactions are signed

Networking Application 1: PKI

- **Certificate Authorities**: Issue certificates – Heart of SSL
- If a CA is hacked, all certificates issued by it are invalid
- March 2011: A hacker tricked Comodo to issue certificates for Google, Yahoo, Microsoft, …
- Sep 2011: Dutch CA DigiNotar was hacked
  - Several fraudulent certificates were issued
  - DigiNotar declared bankruptcy
  - The hacker claimed he had infiltrated 4 other CAs



PKI Using Blockchains

1. **Instant Karma PKI**: CA behavior is recorded on a blockchain
2. **Pemcor**: Hashed value of each certificate is stored in a blockchain
3. **IoT**: Public Keys of IoT devices are stored on a blockchain
4. **Blockstack**: Open-source software to store public keys using "Namecoin"
5. **Certcoin**: Register, update, lookup, verify, revoke public keys w Namecoin

Ref: Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "**Security Services Using Blockchains: A State of the Art Survey**" IEEE Communications Surveys and Tutorials, First Quarter 2019, Volume 21, Issue 1, 858-880 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

Other Network Security Applications

1. **Data Privacy**: Private user data accessible iff his/her access policy is satisfied
   - Medical records in a cloud
2. **Data and Resource Provenance**: Metadata to track the operations on data
   - Who originated or manipulated the data?
3. **Integrity Assurance**: Data has not been changed.

Ref: Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "**Security Services Using Blockchains: A State of the Art Survey**" IEEE Communications Surveys and Tutorials, First Quarter 2019, Volume 21, Issue 1, 858-880 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

Key Strengths of Blockchains

1. **Distributed**: No single point of failure
2. **Decentralized Consensus**: Transactions valid only if agreed by majority
3. **Trustless**: Transacting or processing parties do not need to trust
4. **Cryptographic Security**: Elliptic Curve Cryptography
5. **Non-Repudiation Guarantee**: All transactions are signed

Can the Blockchains be Enhanced?

Limitation 1: Only facts are recorded

- Alice is married to Bob
- Alice gave 20 coins to Bob
- Alice signed a contract with Bob to pay 10 coins for 1 kg of xx.

Limitation 2: Binary Validity

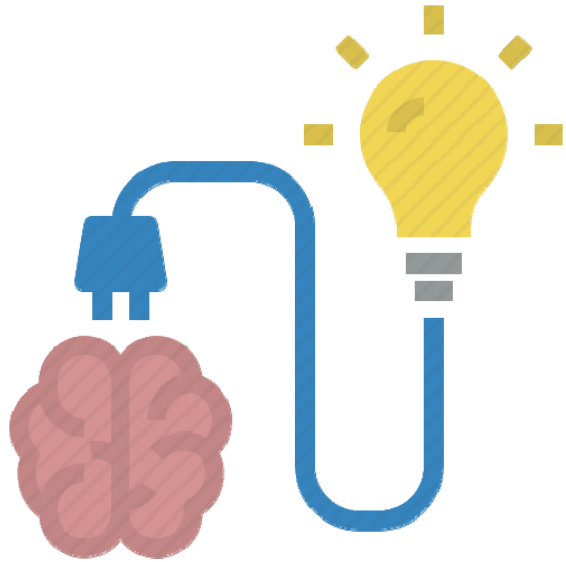
- All transactions recorded on the blocks that are committed are valid
- Those not on the committed blocks and old are invalid
- So the recording is binary: only 0 or 1.

Limitation 3: Deterministic Events only

- Can not record that I am only 90% sure that Alice gave 20 coins to Bob.

Ideas to Enhance Blockchains

- Blockchain is just a distributed **data storage** of valid transactions
- All transactions are ***deterministic***
- What's Wrong?
  - Need to convert data to knowledge
  - We are in big data and machine learning age
  - Real life is probabilistic
  - Most to the decisions we make are probabilistic
    ⇒ All decisions have some risk



Risk Propels Progress

- Banks take money from risk-averse savers and give them interest
- Banks invest the money in corporations ⇒ Takes the country forward
- Venture capitalists take risk by investing in half-cooked ideas
- Startups take risk by working in unchartered territories

Decisions with Risk

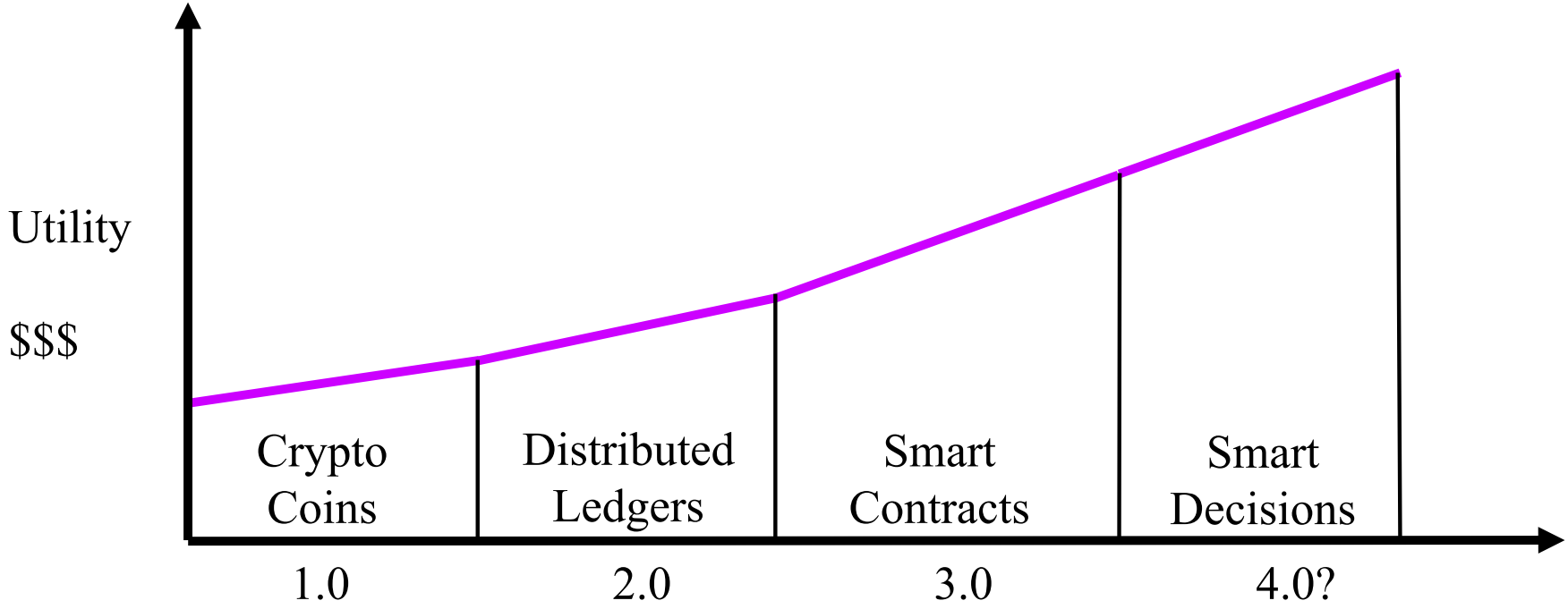
- Sell insurance
- Buy insurance
- Sell a stock
- Buy a stock
- Download a software application on your computer
- Update Windows
- Marry someone

Our Goal

- Moving the chain from deterministic to **probabilistic**
- Moving the chain from storage to **computation**
- Moving the chain from data to **knowledge**
- Moving the chain from information to **decision making**

- Google is moving from "Search" to "Suggest" using AI
- A blockchain that provides knowledge
  - A **knowledge chain** would be more useful

Blockchain Generations

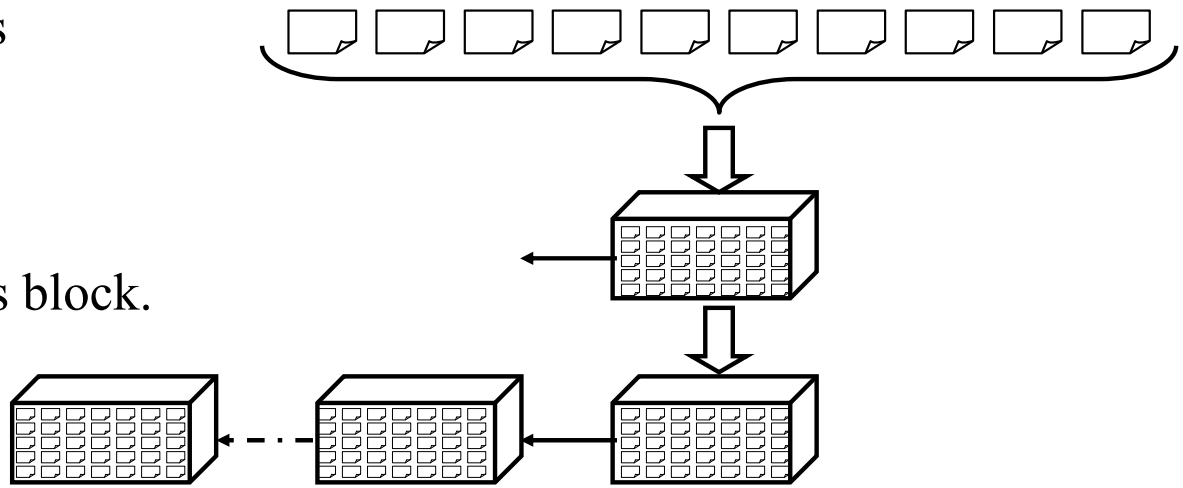


Blockchain Process

1. **Users** broadcast signed transactions or smart contracts

2. **Mining nodes** validate transactions and create blocks. Point to previous block.

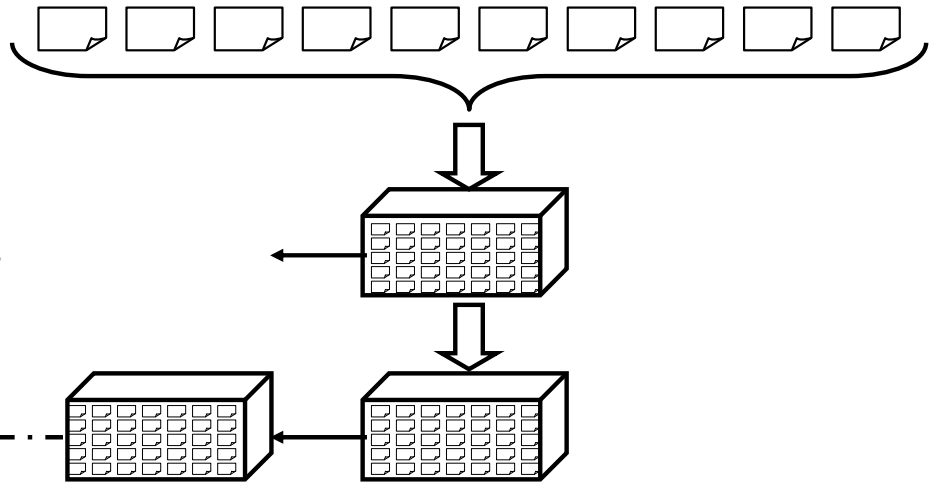
3. **Blockchain nodes** validate blocks and construct a chain



- There are many users, many mining nodes, and many blockchain nodes. More nodes ⇒ Better. Less ⇒ Blockchain not required/useful.

Probabilistic Blockchain Process

1. **Agents** broadcast transactions,
   Transactions = Opinions/decisions



2. **Mining nodes** validate transactions,
   create a knowledge summary and create blocks

3. **Blockchain nodes** validate blocks
   and construct a chain

- Two types of users:
  - **Agent nodes** provide their probabilistic opinions/decisions
  - **Management nodes** that inquire the blockchain and use it for group decisions

Probabilistic Blockchain Example

- **Issue**: Whether Cisco stock will go up tomorrow?
- i^{th} Agent says that the probability that it will go up is p_i
- Summary of all opinions related to this issue is:

$$P[\text{Stock will rise}] = G(\{p_1, p_2, \ldots, p_n\})$$

Here, G is the summarizing function

- For Example: Group decision is the first moment of individual decisions

$$P = \frac{1}{n}\sum p_i$$

Ref: T. Salman, R. Jain, and L. Gupta, "**Probabilistic Blockchains: A Blockchain Paradigm for Collaborative Decision-Making**," 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON 2018), New York, NY, Nov. 8-10, 2018, 9 pp., http://www.cse.wustl.edu/~jain/papers/pbc_uem.htm

Generalizing the Summary Function

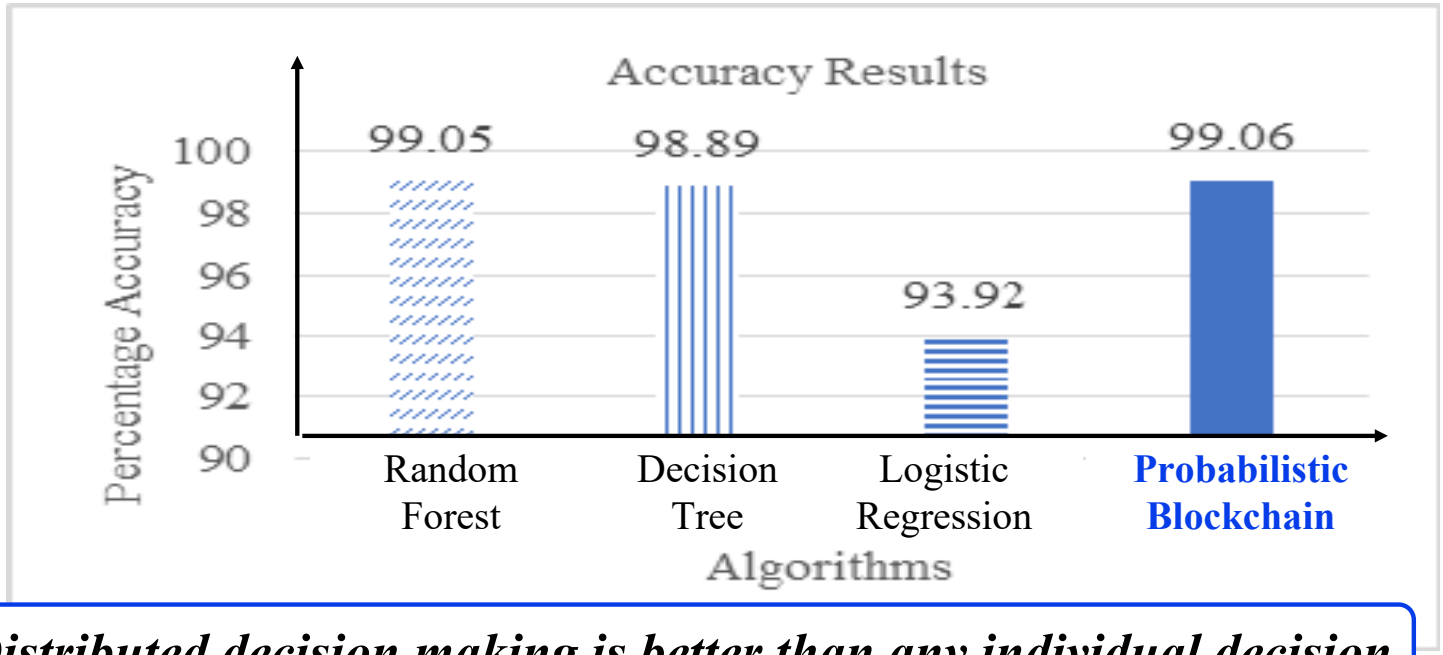
- Summary can be any other reasonable function of individual decisions:
  - 90-percentile
  - Median
  - Mode
  - 2nd Moment
- Summary can be a vector: {1st moment, 2nd moment, …, n^{th} moment}
- Summary can be the result of any **statistical** algorithm
- Summary can be the result of a **data mining** algorithm
- Summary can be the result of a **machine learning algorithm**

Empirical Validation

- Issue: Whether a network traffic pattern represents intrusion
- 1000 Agents using different machine learning algorithms give their decisions: Yes or No
  - Agents randomly pick one of the 3 algorithms:
    - Random Forest, Decision Tree, Logistic Regression
- Mining nodes summarize these decisions using the majority function

Results

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Overall Samples}} \times 100\%$$



Distributed decision making is better than any individual decision

Blockchain 4.0: Database to Knowledge Base

- Blockchain = Distributed database of smart contracts
- Probabilistic blockchain = Knowledge + database
- **Database**: Who bought, who sold, what quantity, what price, what time
- **Knowledge**:
  - Where the market is going?
  - Whether we should buy, sell, or hold?

Knowledge Chain

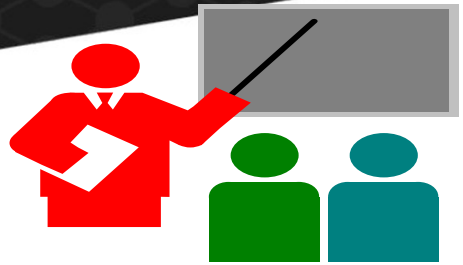
- Customer query to blockchain network:
  How is the Cisco stock doing today?
- Blockchain to Customer: With 60% confidence, the probability of stock rising is 90%, …
- Ideal for **large** distributed systems with **no national boundaries**, no exchange limitations, no brokers in between
- Crowd-sourced knowledge, crowd source decisions

Application Examples

1. Spam from Email/IP Addresses/Cloud providers/source/public IP
2. Intrusions/attacks from IP Addresses. Anonymously share attack information.
3. Gray domains: Share gray list among agents.
4. Reliability/Issues with recent software updates
5. Error/reliability statistics of network/IoT devices
6. Virus in software

Issues

1. **Summary functions**
2. **Overhead of consensus mechanisms**: Proof of Work, Proof of Stake, …
3. **Reputation of Experts and Bad Actors**:
   - Some agents are better than others
   - Group decisions should give more weight to them
   - How to incentivise better agents
   - How to penalize bad actors



Summary

1. Blockchains provide an immutable, secure, distributed database
2. Three generations: Crypto currency, Assets, Smart contract
3. All three generations are deterministic and **only provide storage**
4. The next generation needs to **connect computation and AI** to make knowledge/decisions in addition to data storage
5. Consensus can be probabilistic result of any statistical algorithm, data mining, or machine learning ⇒ **Knowledge Chain**

Related Papers

- Tara Salman, Raj Jain, and Lav Gupta, "**Probabilistic Blockchains: A Blockchain Paradigm for Collaborative Decision-Making**," 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON 2018), New York, NY, November 8-10, 2018, 9 pp., http://www.cse.wustl.edu/~jain/papers/pbc_uem.htm
- Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "**Security Services Using Blockchains:A State of the Art Survey**" IEEE Communications Surveys and Tutorials, Accepted September 2018, 28 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

Related Talks

- Raj Jain, "**Blockchains: Networking Applications**," An invited talk at the 38th IEEE Sarnoff Symposium, Newark, NJ, Sep 19, 2017, http://www.cse.wustl.edu/~jain/talks/blc_srnf.htm
- Raj Jain, "**Blockchains: The Distributed Trust Technology**," Keynote at The 2017 International Conference on Computer, Information and Telecommunication Systems (CITS 2017), Dalian, China, July 21, 2017, http://www.cse.wustl.edu/~jain/talks/cits17.htm
- Raj Jain, "**Blockchains: The Revolutionary Trust Protocol**," BEL Keynote at 22nd Annual International Conference on Advanced Computing and Communications (ADCOM 2016), Bangaluru, India, Sep 10, 2016, http://www.cse.wustl.edu/~jain/talks/blc_ad16.htm Grand Tara

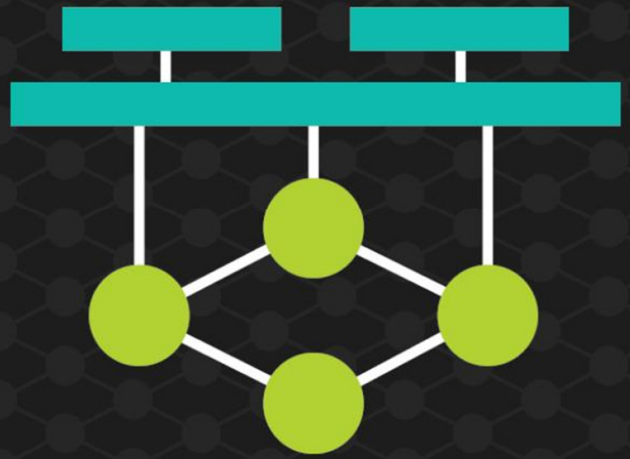
List of Acronyms

- AI Artificial Intelligence
- DNS Domain Name Service
- IEEE Institution of Electrical and Electronics Engineers
- IoT Internet of Things
- IP Internet Protocol
- PKI Public Key Infrastructure
- SSL Secure Socket Layer

Scan This to Download These Slides

Raj Jain
Jain@wustl.edu

Slides and Video Recording at:
http://www.cse.wustl.edu/~jain/talks/pbc_ons.htm



ons

NORTH AMERICA

OPEN NETWORKING //
Enabling Collaborative
Development & Innovation

Hosted By
THE LINUX FOUNDATION | LF NETWORKING