Blockchain-as-a-Service: The Effect of Cloud Computing and Vice-Versa

by

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M.S. Computer Science
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ABSTRACT

A Blockchain is a distributed database or ledger of validated and verified records of transactions and exchanges executed between shared parties participating in the chain. Blockchain is intrinsically the technology that enables decentralized cryptocurrencies like Bitcoin and Ethereum. Recently, Public Cloud providers like Microsoft (Azure), Amazon (AWS) and IBM have moved to provide service platforms to enable enterprises, governments and consumers to build and deploy secure Blockchain networks. From common themes like: cost, performance, scalability, identity, privacy and security, this thesis aims to qualitatively evaluate the effect of block chain technology on public cloud offerings, and vice-versa.

A Cloud environment is not necessarily needed to participate in a blockchain. However, the use of cloud computing makes participation much easier and seamless than conventional, on-premise solutions. A blockchain networks a large number of nodes, and is only as strong as its weakest link. Cloud computing helps to address potential issues of scalability, security consistency and performance. In evaluating the role of the Cloud in the ease of blockchain integration, this thesis would also address areas where concerns like cost could help drive more dynamic cloud offerings, and where the Cloud could play a part in driving blockchain adoption.

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LIST OF ABBREVIATIONS

AAD	Azure Active Directory
AI	Artificial Intelligence
API	Application Programming Interface
AWS	Amazon Web Services
CA	Certificate Authority
CDN	Content Delivery Network
FIM	Federated Identity Management
Fintech	Financial Technology
IaaS	Infrastructure as a Service
IBM	International Business Machines (Corporation)
I/O	Input and Output
NASDAQ	National Association of Securities Dealers Automated Quotation
P2P	Peer-to-Peer
PKI	Public Key Infrastructure
POC	Proof-of-Concept
POS	Proof-of-Stake
POW	Proof-of-Work
R&D	Research and Development
SaaS	Software as a Service
V1	Version One (Version Control)
VM	Virtual Machine

1. Introduction

The necessity for a shift in the reliance from a principal trusted authority to a next-generation financial, commercial and transactional technology in the current landscape of the digital economy has steadily been on the increase. Electronic and online transactional verifications and validations have always followed a central authoritative process as the source of truth. From the reliance on certificate authority (CAs) to endorse that a digital certificate is trustworthy, to banks verifying that a significant sum of money has been successfully transferred to an international recipient, the use of a centralized ledger has been the mainstay. The dependence on a third-party entity is not without identity, security and privacy concerns. Blockchain as a next-generation technology and revolutionary solution to address most of these concerns [1].

A Blockchain is a distributed ledger or public record that tracks and collates the execution of digital transactions. Every single executed transaction within the chain is verified and validated by the consensus of the members of the chain. In other words, Blockchain-based computing is implemented and integrated to eliminate the need for a middle-man [3]. As the data record of transactions continue to grow, a blockchain, as a distributed database is designed to restrict inadvertent or unwanted tampering. At its core, Blockchain has three main benefits: the distributed nature of its architecture allows for it to run on geo-located or global systems, meaning there is no centralized data store of records or database to hack. Secondly, it is encrypted, hence a higher level of security is enforced. Encryption of transactional records follows a specific rule that is adhered to for all computers and system that are participating as members of the blockchain. Finally, it

is open and publically available and can be viewed at any time and each transaction in this distributed ledger is cryptographically verified by consensus [2][3]. Once a transaction has been entered in a Blockchain record, that information is never erased or even temporarily deleted. Hence, a blockchain contains a "verifiable record of every single transaction ever made" [1].

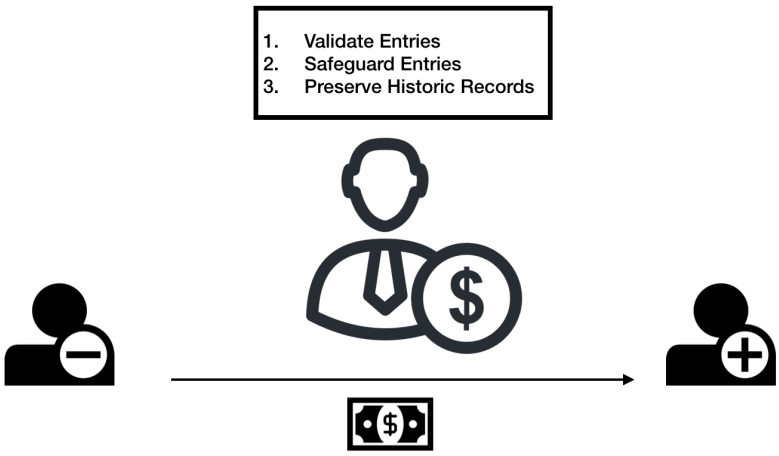

Figure 1: Traditional Digital Transactions using Trusted Third-Party (Source: [1])

The overarching potential of blockchain technology to transform the core of the digital world cannot be understated. This potential also stretches to the world of Cloud Computing. The possibility of Cloud Computing being revolutionized by the advent of Blockchain is much sooner than we think. We are slowly stemming away from the age of massive data centers to more distributed networks. Large enterprises, small and medium businesses and even individual consumers can host and store big data in distributed cloud platforms that are powered by highly secure blockchain networks. Cloud Computing itself has seen widespread adoption from SaaS applications to IaaS infrastructure implementations, due to increased efficiency, scalability and availability when compared

to On-Premise solutions [2]. However, Cloud providers continue to strive for lower computing costs, increased performance at high scale and more securing of identity and privacy in their offerings, and blockchain technology will continue to be front and center, as a core factor in these discussions.

This thesis would first investigate and describe Blockchain as a technology, history, its principles and its key frameworks for functionality. It then examines the various current applications of this technology over a wide range of spectrums, both financial and non-financial. Next, it would look into the Cloud and its correlation and potential relationship with Blockchain to form Cloud-based Blockchains. It explores the existing Blockchain market trend and landscape, its early adoption and what effect that could play in the consumer base, dynamics and evolving use cases and applications of existing Cloud offerings, provided by existing Cloud providers like Microsoft Azure, Amazon AWS and Google Cloud. Then, it evaluates and explores different risks of Blockchain Adoption including: performance, scalability, identity, privacy and security. This information serves as foundational data points for my industry interviews with engineering and product leads (across Cloud market leaders), where I probe for insights into underlying design decisions as well as real-world perceptions of the future of Cloud-based Blockchains. I validate use-case concepts by prototyping and set up a Blockchain in the cloud; including a step-by-step technical walkthrough and highlighting potential implementation challenges. Finally, I qualitatively analyze and collate, to provide recommendations based on research, thorough interviews and hands-on experimentation on the future of Blockchain technology in the Cloud.

2. Blockchain Technology and the Cloud

2.1 History of Bitcoin

In his paper "Bitcoin: A Peer-To-Peer Electronic Cash System", Satoshi Nakamoto introduced the idea of a "peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution" [4]. Nakamoto discussed an electronic payment system that relied on cryptographic proof as opposed to the use of a trusted third party [1][4]. Bitcoin as a form of payment was the initial implementation of this proposed concept. Bitcoin is known as a cryptocurrency – a term used to define all mediums of digital exchange that secure transactions cryptographically, independent of an overseeing trusted party. In January 2009, Bitcoin v0.1 was announced and released, and the first bitcoin transaction was initiated. Bitcoin has continued to see immense growth and increase in popularity since then as a form of payment, and the underlying Blockchain technology has continued to evolve into a myriad of new application areas beyond finance [1][4].

Figure 2: Bitcoin Value Growth since Inception (Graphed using: HighCharts.com)

2.2 Ethereum

The seismic growth in the value and adoption of bitcoin, led to the advent of new cryptocurrencies based on the underlying Blockchain technology. Ethereum, launched in July 2015, was designed to be more than a payment system and serve as a decentralized platform for the programming and development of applications. In other words, while Bitcoin is strictly a cryptocurrency, Ethereum is actually a platform [5]. The Ethereum foundation defines it as a "…decentralized platform that runs smart contracts: applications that run exactly as programmed without any possibility of downtime, censorship, fraud or third party interference" [5]. Furthermore, Ethereum is not just a platform, but a Turing complete programming language that enables developers to implement and publish distributed applications.

Ethereum is powered by its platform-specific cryptographic token, Ether. Ether serves two main purposes: as a digital currency for digital exchange and transactions and also as vehicle within Ethereum to run and develop applications. There are a few major differences between Bitcoin and Ethereum, as they both differ in purpose. From the block time of transaction confirmation (Ethereum in seconds and Bitcoin in minutes), to the differences in the hashing/encryption algorithms (Ethash vs. SHA-256), the architectural choices of the inventors highlight differing intentions [6]. Although just introduced in 2015, Ethereum has garnered widespread enterprise interest as a potential platform for the improvement of enterprise computing systems [7][8]. Tech giants like Microsoft, Cisco and IBM, both members of the recently formed Enterprise Ethereum Alliance, have shown significant interest in the integration of Ethereum into existing solutions and

applications. In 2016, Microsoft announced Project Bletchley, an infrastructural substrate that eases the deployment and configuration of a consortium Ethereum network within their Public Cloud offering, Azure [7].

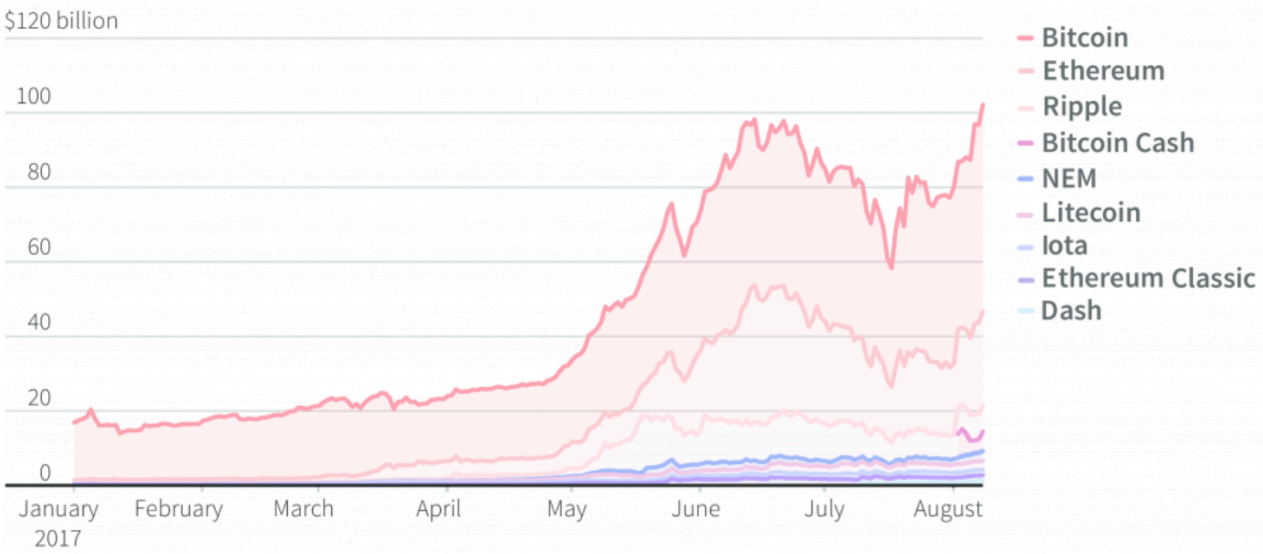

Figure 3: Relative Growth Rates of Cryptocurrencies, including Ethereum (Source: [9])

2.3 Principles of Blockchain

The Marco Iansiti's Harvard Business Review article details and breaks down five fundamental principles that are key to Blockchain's functionality [10]:

- Distributed Database
- Peer-to-Peer Transmission
- Transparency with Pseudonymity
- Immutability
- Computational Logic

Distributed Database: The entire blockchain of records and history of completed transactions is available to every single participant of the blockchain. There is no centralized entity that controls these records and there is no need for any intermediary party to verify or validate records or transactions.

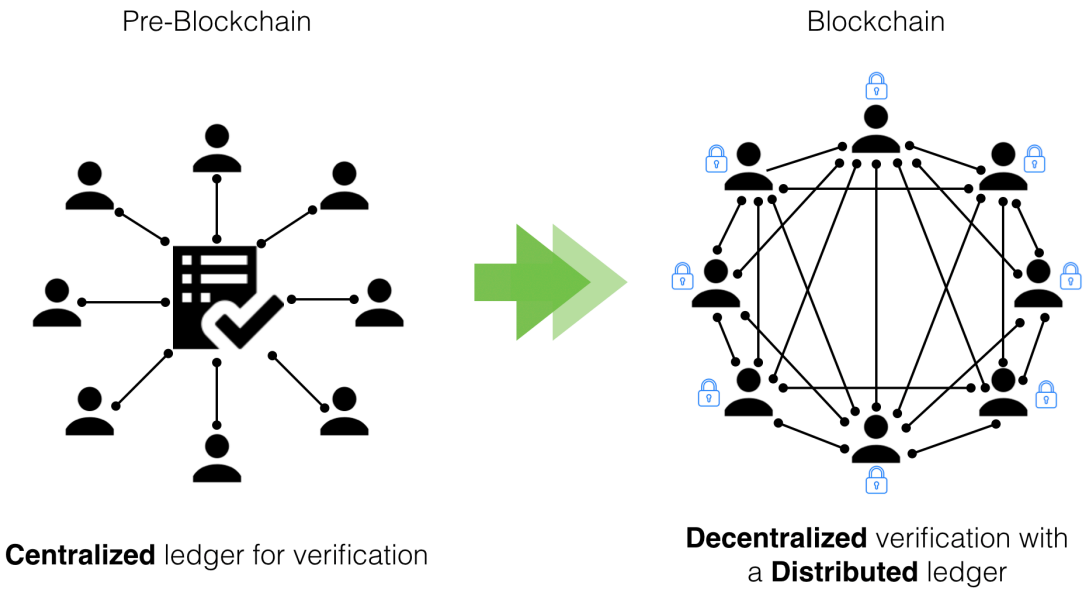

Figure 4: Centralized vs. Decentralized Ledger for Verification of Transactions

Peer-to-Peer Transmission: With a decentralized database in use, communication in the chain is occurs directly amongst peers within the network as opposed to a central node. The information stored on each node is forwarded to all other nodes in the network.

Transparency with Pseudonymity: The transparent nature of records in a blockchain is key to driving its decentralization. Each transaction must be visible to all participants in the network. A distinct alphanumeric address is assigned to every node or user in the blockchain, and this is used for identification of every user. Anonymity is also an option within the network, in the sense that proof of identity can be provided as needed or users

can choose to remain anonymous. The distinct alphanumeric address of each user or node is used to execute and identify during transactions between blockchain addresses.

Immutability: Very vital to the functionality of blockchain is the irreversibility of records. Transaction and validated records that are entered in the distributed database cannot be deleted, altered or abased in any shape or form once they are entered. This is due to the fact that records are linked and once entered, they are tied to the transaction records that preceded them. Complex computational algorithms ensure that ensure the persistence and chronological order of the database as well as the availability of all records across the network.

Computational Logic: The ledger is digital and hence algorithms and rules can be programmed via computational logic. These algorithms can be programmed to automatically initiate transactions within the network.

2.4 How Blockchain Works

In the simplest of breakdowns, a 'blockchain' is comprised of a chain of blocks. Data in a blockchain is stored in structures referred to as "blocks". Each of these blocks consist of a header and a body (its content). The header of each block includes metadata like a unique block reference number and the hash values of current and previous (linked) blocks. Successive blocks need the hash value of the previous block as this is needed for linking all the blocks together (see Figure 5). The body of each block consists of a validated list of instruction statements and transaction records and other relevant transactional information like the transaction amount, timestamp recorded, and unique addresses of

parties involved [2][16]. With each block having a link to the preceding block, it is possible to access every single preceding block in the chain, so a blockchain database preserves a comprehensive history of all assets and executed transactions – making its records verifiable and immutably auditable. As the number of users in the network grows, it becomes much more difficult for malicious attackers to overcome the verification capabilities of the majority, therefore, increasing the robustness and security of the network [16].

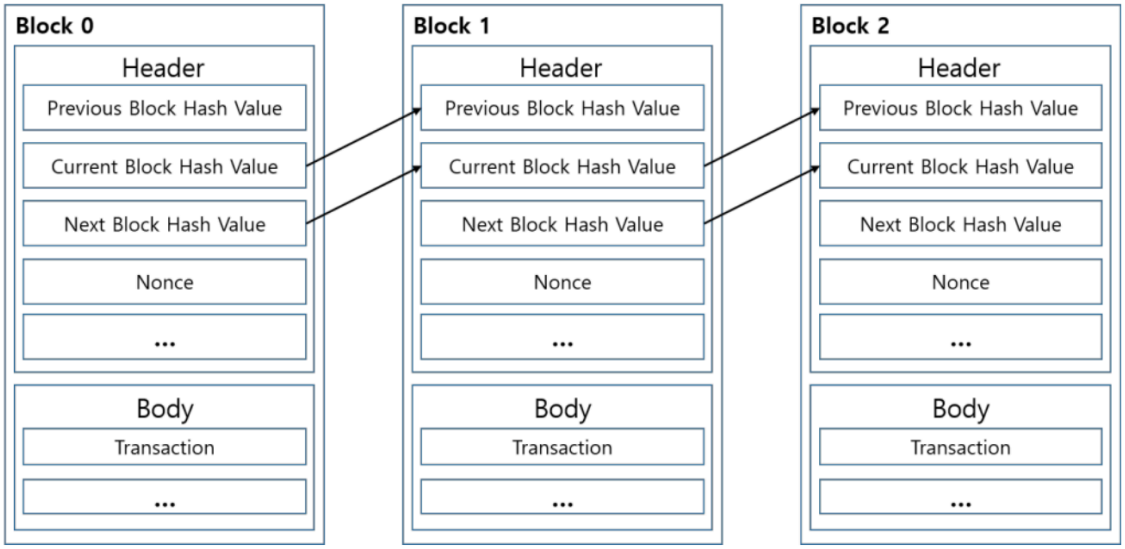

Figure 5: Connection of Blocks in a Blockchain (Source: [2])

In order to add a new block to the chain, the new block has to be 'mined'. Transactions in a blockchain are validated by a subset of users called 'miners' that compete (via lottery) to donate their computing power to aid in the complex computing algorithms, using a shared database and distributed processing. The chances of a miner winning the lottery are higher if the miner dedicates more computing power to the process and is able to find a valid new block first and propagate it across the rest of the network. There is a reward

for committing a new block to the chain and for the work and contribution of the miner. A crypto-token reward (e.g. Bitcoin) tied to the block chain is usually awarded to the miner. The transaction fees that are also included in transaction execution also play a part in incentivizing miners to prioritize them over other participants in the construction of new blocks. Furthermore, as the chain grows in size, more blocks are added, and more computing power is contributed, it becomes increasingly difficult to reverse or alter a past transaction. Therefore, in these sort of "Proof-of-Work" systems, a blockchain is only as secure as the amount of compute power and resources dedicated to carry out and execute tasks [16].

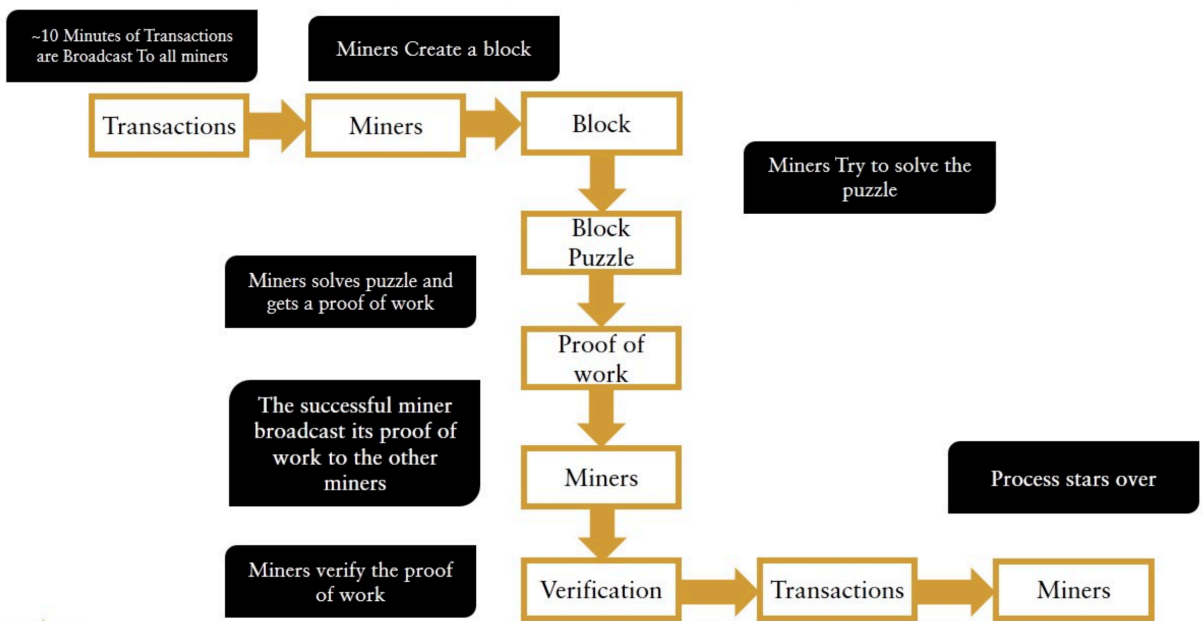

Figure 6: Blockchain Mining Process (Source: [18])

2.5 The Thin Cloud

When we look at the architecture of Blockchain, we need to view it not just as a programmable system of transactional and verifiable records, but as a networked infrastructure of systems. Cloud computing infrastructure in its current state is not as lightweight or "thin" when compared to the blockchain cloud. The thin nature of the blockchain cloud makes it more ideal for running the new array of thin programs known as "Smart Contracts" [3][11]. Smart Contracts are "business logic that execute on a blockchain's Virtual Machinery (VM)". The term Virtual Machines (VM) is a familiar term in the traditional cloud computing space, and it in this case, describes a virtual network of computers that are tethered together by a set of consensus rules and run smart business logic in a decentralized way [3].

Applications and services that run on current Public Cloud offerings like Microsoft Azure, Amazon Web Services (AWS) and Google Cloud Platform are charged based on application uptime, storage utilization, processing and computing power. When comparing the cost of running virtual machines (for example, on Ethereum) to Cloud-based computing costs, the uniqueness is that you pay for running the business logic of an application on the blockchain that is run on physical servers, but there is no hassle of setting up the servers, as they are managed by "miners" that "benefit from a crowdsourced-like metering of their part of the infrastructure" [11]. In other words, the thin blockchain cloud bears similarities to standard cloud computing offerings with its form of computing-use-based pricing, but with a new layer. In his paper, "Reinventing the Cloud with Blockchain", Hitesh Malviya describes it as not just a "physical

unbundling of the cloud, but a new layering of cryptography-based transaction validation and state transition recordings on a parallel, but thinner cloud" [3].

2.6 Economics of Blockchain and the Cloud

Catalini and Gans [16] address the two key cost factors that blockchain can help to reduce – the cost of verification and the cost of networking. When a transaction between parties occur, there is need for intermediary verification of the key elements of the exchange. Intermediaries usually charge fees for verification of transactions across parties. As more and more participant and parties are involved in multiple markets, the need for an intermediary verification at scale, grows as well. Without scalability in verification to be able to handle market growth, verification costs increase, leading to fewer parties finding it profitable to transact [16]. In addition, to requiring a third-party for verification, pertinent information needs to be disclosed in order for a transaction to be verified. This may include information like addresses to social security data, leading to the increased risk of data compromise and privacy in the case of a leakage or hack. With the secure transactional attributes of blockchain the cost of verification and networking can be effectively eliminated by securely storing updatable, verifiable and reusable transactional attributes in a ledger that can be retrieved or accessed at any time without any additional verification cost. For example, "Bitcoin can mimic the core functionality of the SWIFT or ACH financial networks without using banks or vetted institutions as trusted nodes." [16] However, as a blockchain grows and more blocks are added, more and more transactions need to be accommodated, the infrastructure that supports the verification and consensus must scale to meet the growing needs. In other words, a

"…blockchain is only as secure as the amount of computing power dedicated to mining it" [16]. This is where cloud computing comes in as a solution for infrastructure scalability, compute, storage, networking and privacy. Section 2.7 addresses some of the areas where blockchain and cloud computing could work hand to deliver enterprise grade blockchain applications at large scale.

2.7 Cloud-Based Blockchains

Enterprise technology giants like IBM and Microsoft have taken considerable lunges into the integration of Blockchain technology, offering what is called "Blockchain-as-a-Service" (BaaS). IBM is the market leader in hosting Blockchain applications in their cloud offering [13]. With IBM's offering, customers can construct secure blockchains based on Hyperledger Fabric. Hyperledger is an open source collaborative effort by the Linux Foundation for the advancement of cross-industry blockchain applications and is a platform for distributed ledger solutions. IBM blockchain customers can develop and implement secure blockchain applications in IBM cloud that meets financial regulatory and industry compliance requirements [13].

In late 2015, Microsoft added a Blockchain-as-a-Service (BaaS) offering to it Cloud (Azure) Marketplace, as a result of the project codenamed Project Bletchley [7] [14]. With Project Bletchley, Microsoft Azure provides its customers with the fabric for blockchain to be able to develop, deploy and test distributed blockchain applications. With pre-defined service templates, customers can provision a fully configured blockchain network topology with a simple single-click deployment, in a matter of minutes. This allows for a wide range of end user personas, from blockchain experts and

heavy users to consumers with minimal blockchain knowledge. As opposed to spending hours or days building and configuring blockchain infrastructure, the geo-location and computing capacity of Azure's networking, storage and compute services allow for significant automation in blockchain application build-out scenarios. Microsoft is touting that its "availability in 24 regions across the globe, hybrid cloud capabilities, extensive compliance certification portfolio, and enterprise-grade security would [drive to] enable blockchain adoption, especially in highly regulated industries like financial services, healthcare and government" [13] [14]. Since the inception of Microsoft's BaaS offering, Microsoft has garnered partnerships with a consortium of over 50 large multinational banks who have been granted access to Azure to build and implement their Blockchain applications. Microsoft's partnerships have also stretched to cryptographic ledger software vendors and startups like *Ripple* as they venture into this new push for seamless integration of blockchain applications [13].

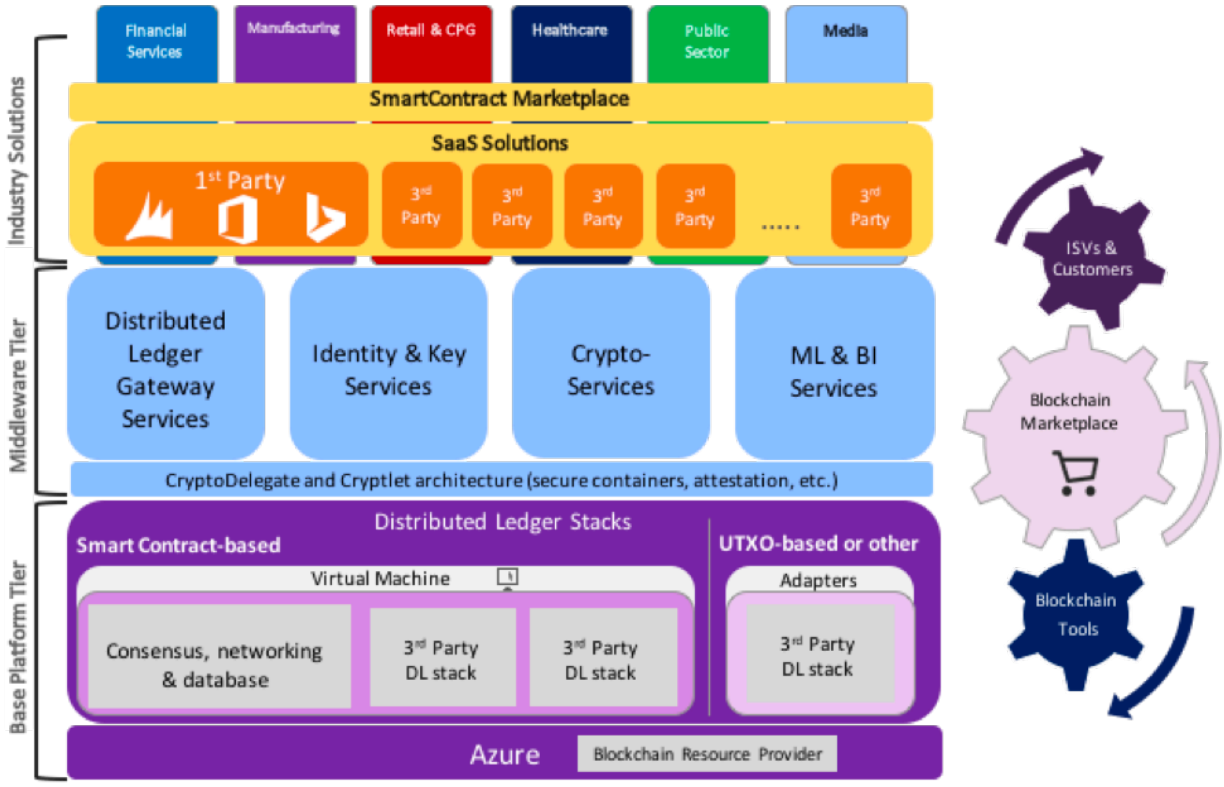

Figure 7: Microsoft Azure Blockchain-as-a-Service Fabric (Source: [14])

Amazon (AWS) has not fully delved into this area in comparison to IBM and Microsoft's efforts. However, in 2016, they announced a partnership with investment firm Digital Currency Group (DCG) to offer Blockchain-as-a-Service in an experimentation ecosystem, specifically for enterprises [13]. The goal of this partnership was to enable blockchain providers within DCG's portfolio to implement and deploy in a secure environment with clients that ranged from financial institutions and insurance to enterprise technology. As the blockchain market continues to grow and invade more digital service areas, so will the interest from more major tech giants across multiple industries (storage, security, infrastructure etc.).

The combination of containerized mining nodes (see Section 2.4) and Public Cloud would provide an easy and cost-effective way for enterprises, consumers and individuals to participate in peer-to-peer borderless commerce networks, while enhancing the resilience and integrity of those networks [15].

Here is how Blockchain and the Cloud can work hand-in-hand [3] [15]:

- There are high computing, I/O operations and resource requirements required for a secure, robust and functional blockchain. With the flexibility of current Public Cloud offerings, you can allocate and deallocate resources and virtual machines (VMs) as needed. Cloud Computing has a term referred to as "elasticity". The elastic nature of current cloud offering allows for scaling up or down of instances, to support secure blockchain transactions.
- The ubiquity of public cloud computing allows for nodes in a blockchain network to be supported by a neutral third-party, in this case the cloud provider without the worry of infrastructure maintenance and operations costs. This makes the costs of moving to Blockchain affordable, and thus slightly reduces the outlook of monetary barriers to entry.
- Identity and role-management are significant pieces of access control for blockchain enabled applications. Azure and AWS have perfected the craft of delivering identity and access-based management protocols in their offerings. As the services are already baked-in, there is no need for end-user integration, or any additional implementation required for access control functionality.

- The ability to spin up new instances in real time with cloud computing, is very ideal for blockchain logging and I/O operations. When intensive operations for transaction logging are triggered that have new VM instances can also be automatically launched and provisioned to handle the required compute and storage load. These instances can then be decommissioned after serving their purpose.

Blockchain technology and Cloud Computing “are forces that could converge to become a “perfect storm” of computing innovations, bringing creative destructions that would reshape businesses and societies profoundly and fundamentally.” [15]

3. Current Market and Evolving Use Cases

3.1 Existing Market

Industries with reliance of third party trusted entities for validation, security and verification in both financial and non-financial areas are usually areas where Blockchain technology is looked at as a potential proposition for process advancement. With the need to track, record and verify transactions from healthcare, energy, legal, agricultural and manufacturing sectors to supply chain, Blockchain is not solely tied to financial applications. In 1996, Nick Szabo introduced the idea of "Smart Contracts". The idea was to automate the execution of agreed contracts between two or more parties. He defined the term Smart Contract as a "set of promises, specified in digital form, including protocols within which the parties perform on these promises" [19]. At that time, the technological advent of cryptocurrencies and blockchain was not in place. Once the concept of crypto currencies like Bitcoin and programmable payments came into place, Smart Contracts began to emerge. Now, with the underlying Blockchain technology, Smart Contracts can trigger payments based on a pre-agreed and pre-programmed condition in a mutual contract. These contracts are self-executing, self-verifying and tamper proof. Furthermore, Smart Contracts have developed to become one of the mainstay applications of Blockchain in the world of cryptocurrency [1] [19].

With blockchain technology, the hassle and delays in paperwork needed to register and verify contracts is effectively eliminated. For example, Ethereum as a platform (see Section 2.2), with its underlying technology is able to enable and trigger Smart Contracts using blockchain. Applications that leverage cryptocurrencies like Bitcoin, Litecoin and

Ripple are also able to support Smart Contracts. In other words, situations where assets, goods and/or services are transferred or exchanged only on meeting a set of stipulated mutually agreed conditions that require a legal intermediary to draft and oversee a contract, can be replaced with the use of Smart Contracts.

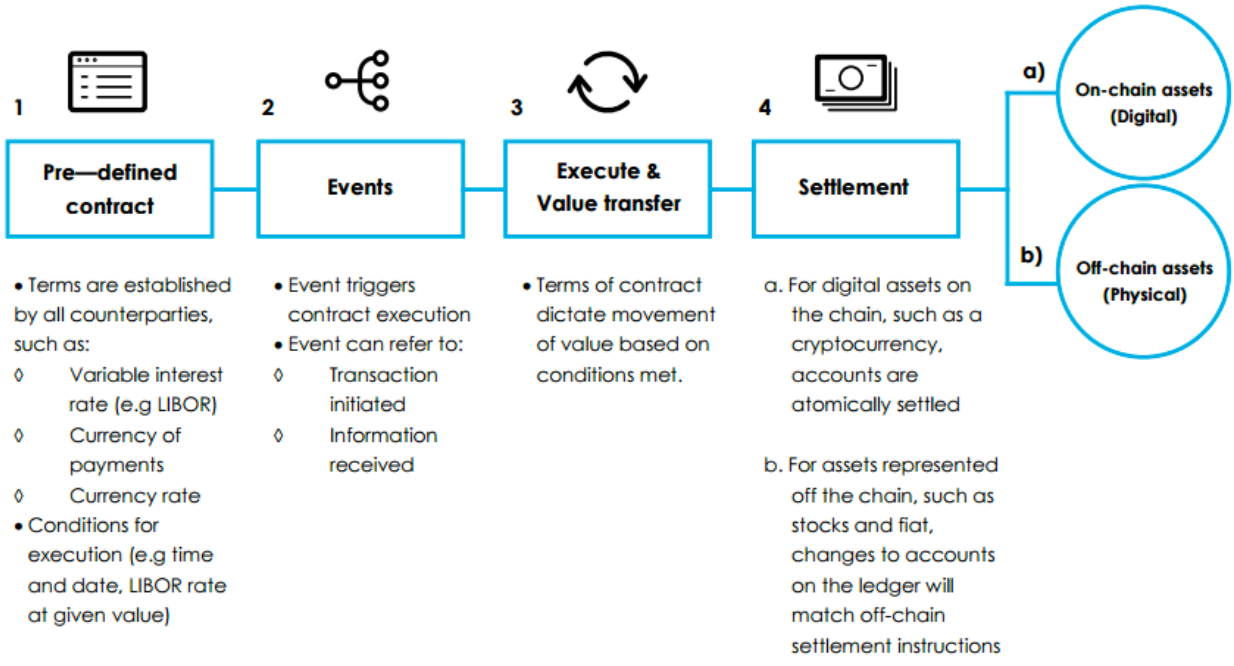

Figure 8: Smart Contract Process Powered by Blockchain (Source: [20])

Companies such as Samsung (Hardware, Semiconductor), Overstock, Amazon, EBay (Online Retail), UBS, Citi (Financial), Verizon (Telecommunications) and Maersk (Supply Chain) have begun to explore alternative and novel uses cases of the blockchain chain technology that integrate into their existing applications [1] [14]. Since 2014, major multinational banks and institutions (including Bank of America, JPMorgan, Bank of Scotland, BNP Paribas, BNY Mellon and Deutsche Bank) have joined 'R3', a financial technology firm that leads the consortium of over 60 financial institutions in and

initiative to increase the research and growth of blockchain distributed database adoption in finance.

3.2 Financial Applications

3.2.1 Private Securities

In recent times, some of the world's most prominent stock exchanges have been evaluating areas to leverage the use of distributed ledgers and blockchain technology to significantly improve on existing mechanisms. Stock exchange operations can involve a lot of replicated and complex procedures that are time inefficient, cost ineffective, flawed and prone to risks or fraud. The "multi-layered processes – pre-trade, trade, post-trade and custody, and securities servicing – is extraordinarily complex" [21]. Blockchain is beginning to see experimentation in this space with the potential ability to streamline the functionality of this process and bring in a more seamless mechanism.

NASDAQ has led the efforts in this space in blockchain experimentation. NASDAQ recently partnered with startup Chain.com to improve the inefficiencies in the stock trading process due to multiple third parties. Chain.com as a startup has been experimenting with a released version of NASDAQ's *Linq* Blockchain Ledger to implement smart contracts for exchange functionality. In 2015, the Australian Stock exchange (ASX) began evaluating options to replace the outdated Clearing House electronic system and have invested over to $15 million to date in developing distributed ledger based solutions for clearing, validating and settling trades. The forays in this area

also stretch to the Japan Exchange Group (working with IBM), India National Stock Exchange, Korea Exchange and Deutsche Bundesbank, to name a few [21].

3.2.2 Insurance

With blockchain technology assets under insurance that can be uniquely identified can be registered in a blockchain with the assurance that the records would be difficult to destroy, replicate or be tampered with. With these immutable records in place, verification of asset ownership and transaction history would be easily traceable and validated. Ownership of physical or digital insurable properties like: real estate, vehicles, boats, electronic devices and systems, jewelry can be registered and traced in a blockchain. Smart contracts as a concept can also see some use here in the automation of insurance claims and its ensuing processes during an incident. The amount of paperwork required and delays in an insurance claims process can be reduced by the efficiency and implementation of Smart Contracts. For example, in conjunction with budding IoT technology, equipping physical and digital assets with smart sensors can help the processing of insurance policy details and the assessing of damage in the event of an incident or accident. Since records and policy details can be easily verified and validated, there is reduction in the duplication of work and improved time and cost savings from the insurer to insured as well as across third parties like towing companies and vehicle repair shops.

3.2.3 General Fintech and Accounting

Outside the use of smart contract and streamlining the settlement of stock transactions between parties, there are general financial technology applications like the use of blockchain to store and trace financial information and serve as a source of truth with the use of an immutable accounting ledger than can be validate across banking institutions. For example, a consumer at Bank A would not need to enter information and be proceed again at Bank B when setting up a second account, if Bank A and B are part of a consensus verifiable chain [1] [21].

3.3 Non-Financial Applications

3.3.1 Identity Management

With recent publicized hacks, personal information is highly vulnerable in online databases in their current form. When consumers are required to identify themselves for a service to be provided, a good variety of information is required or retrieved. From date of birth, residence location to social security and credit score, these vulnerabilities would always exist with traditional methods. With blockchain able to securely store data and information that uniquely identifies a participant, the individual can have full control over what information is retrieved and present the minimum amount of information required to identify them. In other words, the ability to have "self-sovereign identity" through the use of decentralized networks [22]. Combining a decentralized network on blockchain with identity verification allows applications to create a digital unique identifier that can serve as a digital watermark associated with every digital transaction of any asset. This could

go long ways in helping to reduce fraud, leaks in personal information, identity theft and compromised information.

3.3.2 Supply Chain

Traditional supply chain methods are process-heavy and convoluted. Utilizing blockchain technology, the origin, transfer, location and transportation of goods can be registered in a transaction ledger for identification; as well as, parties involved, price of transactions, time of transactions, quality and product state, in the management and visibility of a supply chain. With the integration of Block chain, IoT and smart devices tracking the location of goods, it would be "possible to trace back every product to the very origin of the raw material used" [23].

IBM has recently partnered with Walmart, Unilever and Nestlé to evaluate the use of a distributed ledger in the tracking and traceability of their food supply chains. These food giants are looking to blockchain technology as a means of revamping a complex network of supply from origin to destination, that include, farm locations, farmers, traders, distributors, suppliers, retailers, and end consumers. One of the major areas of potential benefit is the detection of the source of food-borne illnesses like Salmonella and E. Coli. Investigation into a contaminated batch could currently take anywhere from weeks to months. However, with the use of a distributed, immutable and publically available ledger, that investigation can be reduced to a matter of seconds [23], [24]. Walmart has done two widely publicized experiments on IBM's Hyperledger: one to track the food supply of Chinese Pork, and the other, tracing Mexican mangoes [23]. Outside direct use

for food supply chain, suppliers can also utilize blockchain to handle source of defects and incident recalls in goods and quickly handle any disruptions.

3.3.3 Medical Records

Patient data and records are always, more often than not, sensitive and highly classified. More medical data can be shared with blockchain as an underlying platform for more purposes, with the guarantee that patient data is secure and data integrity and patient privacy is ensured and protected. This goes a long way in streamlining clinical examinations and the sharing of record across multiple health institutions (with patient consent). For example, if an open-source cross-institution wide trusted ledger receives updates on patients' health history, records, results, prescriptions and medications, additions and or subtractions to medical records are clearly understood and easily auditable across health institutions. Instead of a health institution pulling records from their internal single database instance, they can reference data from every database that is documented and verified in the ledger. This would result in the assurance of untampered data that can be easily reconciled, with the assurance of integrity without manual human manipulation [25].

3.3.4 Decentralized Internet of Things (IoT)

IoT is another budding technology that has seen concurrent rise and wave of interest like blockchain. The majority of IoT ecosystems are based on centralized models with brokered communication, following the traditional client/server architectural model. This brokered communication that requires IoT smart devices to exchange data between

themselves autonomously, has become impractical for a lot of evolving IoT scenarios. Although this client-server model has been the mainstay in the internet computing architecture of systems for years and would continue to be feasible for smaller scale IoT solutions, it would not be able to adapt to the increasing needs of much larger scale IoT systems going forward. Decentralizing IoT using blockchain technology and P2P communication helps facilitate the implementation of platforms for secured and trusted data exchange, communication and record keeping between smart devices.

3.3.5 Proof of Existence and Notary

Proving the validity and existence of signed documents and contracts can be carried out using blockchain technology, as there is no need for a centralized overarching authority. This have very concrete applications in the legal field. Current methods require a centralized authority to store, verify and validate the existence of documents and contents, and this comes with potential security challenges, like risks of alteration and fraud. Maintaining this traditional model of validation becomes even more cumbersome and difficult, as documents get older and more documents are added that a centralized authority must maintain and keep track of. Blockchain technology allows for an "alternative model to proof-of-existence and possession of legal documents" [1] [26]. Leveraging the mechanisms of blockchain, signatures of legal documents and their corresponding timestamps can be stored and validated at any time [26].

3.3.6 Other Use Cases

In addition to some of the non-financial use cases listed in the section above, blockchain can span a myriad of other use cases like: decentralized storage, alternative Public Key Infrastructure (PKI) solutions, anti-counterfeit applications, smart contracts for music royalties, and so on.

4. Blockchain Adoption and the Cloud: Factors, Concerns and Risks

For every budding technology, there are always risk factors and potential concerns and use-case challenges. Given the vast array of potential applications, both financial and non-financial (see Section 3.2), from private equities to music royalties, blockchain has the potential to radically change the norm of a good number of industries. With the adoption of drastic innovation that changes the fundamental core of the way things have been done for decades, in certain areas, there are always significant risks of adoption and concerns that need to be addressed and evaluated. Some key risk factors and concerns are:

- **Behavioral Changes**: The resistance to drastic changes in the standard methodology of the way things are done across industries, is a significant factor that could blockchain's adoption and growth. The intricacies of setting up a blockchain and integrating it across existing applications is something that could potentially take enterprise customers some time to fully embrace. Despite the ability of cloud computing to make the deployment of blockchain applications seamless, the "process of adoption will be gradual and steady, not sudden, as waves of technological and institutional change gain momentum" [10]. Blockchain technology will see that networked growth effect where the continuous momentum and increase in adoption will be driven by the value derived from new early adopters [17]. This is a crucial factor that would play a major part in the advancement and adoption of blockchain across financial and non-financial institutions.

- **Scalability and Performance**: Time taken to put a transaction in the block, and the time taken to reach consensus on a transaction are fundamental to the functionality and performance of blockchain. The larger the blockchain grows, the more the requirements for compute, storage and network resources grows. The symbiosis between Cloud computing and blockchain helps to allay some of these concerns. With blockchain applications on the cloud, developers can implement and integrate without the worry of infrastructure performance, scalability cost and operational processes. Nevertheless, utilizing the cloud as a low-risk, low-cost, fail fast option as opposed to individually maintained physical systems, or on-premise infrastructure, will play a critical role in the growth and adoption of blockchain for enterprises.
- **Holistic Integration**: Migrating all existing documents like financial contracts or business frameworks into a new blockchain integration would require a substantial amount of migration tasks to be executed, depending on the scale. For example, there is the consideration of time and cost when it comes to migrating documents like real estate liens that are maintained by county or escrow to its equivalent form on a blockchain platform. Furthermore, enterprise companies do not readily embrace partial integration of production critical systems. The time it would take for experimentation and holistic integration is an important factor in the readiness of institutions to readily implement blockchain applications.
- **Regulatory and Compliance**: In the regulation of industries, there are governmental rules that monitor and control with specific set of compliance policies that must be adhered to. Evaluation with administrative rulings and the

need for interpretive guidance on blockchain as a technology from agencies like the Federal Trade Commission (FTC), Securities and Exchange Commission (SEC) and FinCEN could play a part in its adoption across certain financial institutions. Regulatory and Compliance also stretches to data handling and integrity, where compliance audit like ISO 27001, SOC 2 and PCI would be important to comply with when it comes to the way information of participants of a blockchain are handled and processed [28].

- **Security**: In the experimentation and assessment of blockchain as a replacement for existing methodology, some users are usually tentative about diving right in, due to uncertainties around security. With the decentralized nature of the system, "a permission-less database with an ever-growing list of data records could leave back doors open for unauthorized access" [27]. Cloud computing helps to provide that extra layer of security with services like secure container technology and key vault (for securely storing secrets and keys). However, security continues to be fundamental to the discussions and decisions that could lead to hesitancy in the widespread adoption across larger-scale enterprises.

5. Blockchain Industry Interviews

In collating information on real-world exposure to the customer experiences and adoption of Blockchain technology across enterprise leaders in this space, this thesis probes into the fundamental cloud computing factors that propel and/or affect blockchain currently, and vice versa. Via interviews with industry experts across Blockchain enterprise innovators at IBM and Microsoft, this thesis qualitatively evaluates the underlying hypothesis of blockchain's effect on the cloud. These interview transcripts are verbatim and only proprietary and non-public information have been abstracted for legal reasons.

5.1 Richard Melzer, Associate Partner at IBM

Title and current role?

Associate Partner at IBM working with the US Rail Industry for IBM Global Business Services. I am assigned to our travel and transportation vertical, and I work mostly with railroads and IBMs partnerships with global logistics companies and trucking companies.

Background before blockchain and how did you get interested/start working on blockchain?

I have been in the supply chain world since the mid-90s and worked with several leading supply chain and global transportation management companies before my stint at IBM. As soon as I heard about Blockchain and what IBM was doing in the Blockchain world, I quickly figured out that this was going to potentially have a significant impact on the railroad industry. One of IBM's major blockchain initiatives is with Maersk, a global

container shipping company and I saw areas where my background in global logistics was going to fit in with initiatives in this space.

Overall view of the current market and adoption?

I do think that it is still early days for blockchain. Most of our customers are still in the POC (Proof-of-Concept) stage as opposed to having solutions fulling integrated into a production system. However, that is not surprising for a good number of reasons. Blockchain like other network-driven technologies needs volume in order to drive adoption. For example, if I am a global shipper and only one of my container lines uses blockchain, then I still need to maintain all my systems to deal with the standard methods in place. So, I am not as compelled to jump on blockchain until all my systems are fully integrated. There is that network effect, and as more and more enterprise customers adopt blockchain, the pull is going to get stronger and stronger, almost like a gravitational pull. There are companies that like to be early adopters and like to have that first-to-market advantage and although these railroad and supply companies are confident that blockchain is going to be a big play, they are still not sure what percentage of their own customer base is going to have the level of sophistication and/or technology to be able to jump on the blockchain. That leads to thing stalling down a bit during the POC stage, as some companies in this space are still skeptical about how quickly they should jump into this. However, this varies widely across our customers and the pull from their own customers. We have big shipping companies that move goods for Walmart that have started to feel the pressure to start evaluating blockchain solutions in their supply chain.

Personal engagement with blockchain customers/partners, describe the form of engagement?

Most of our customers come to us and want us to implement proof-of-concepts and experimentation of applications that are tied to their industries. We determine the viable customers, and I engage with those customers directly by educating, consulting and working on potential blockchain applications in their industries.

In what ways are your enterprise customers utilizing blockchain. In other words what are the current market use-cases?

My vertical is currently focused on the railroad, supply chain and trucking industries, however, various departments at IBM are evaluating areas like trusted identity and secure key, as well as private equities and financial technology.

Any evolving use-cases that you envision?

Food traceability is the one area that I have seen blockchain technology currently evolve as a use-case. The ability to solve food safety challenges with blockchain is an intriguing evolving area for application.

What key things do customers or partners look for in decision process of adopting blockchain technology in the cloud?

From my engagement with our customers in the supply chain industry, many of our customers don't even know what questions to even ask yet, at this point. With a lot of our customers, the first couple of meetings are very educational. A small percentage of these

customers come into these meetings with a lot of background research already done on blockchain, and how it could be potentially utilized in their applications and use cases. However, the rest of these customers like us to connect the dots for them and show them how IBM Blockchain Hyperledger running on IBM Cloud can accelerate development and governance in their markets. When it comes to key decisions, they assume that with the cloud and blockchain, that the high security of data and transactions is in place. They have a lot of questions and concerns around how to integrate different parties and how Blockchain can be implemented across all their existing systems. Another key concern is with networking and infrastructure, and the amount of transactions that their systems and applications would be trying to execute over given periods of time. This is where the power of the cloud – scalability, auto deployment, compute, resource and networking, comes into play to quell those concerns.

How has the blockchain market and adoption affected cloud computing and vice versa?

Let me illustrate something for you. When I am engaging with our customers through sessions, I draw three intersecting circles below:

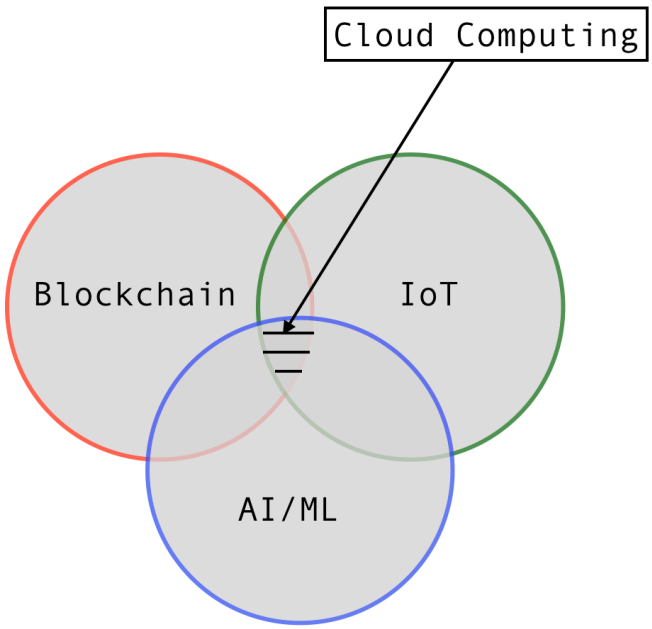

Figure 9: Richard Melzer's Illustration on Blockchain, Cloud Computing and IoT

First of all, our blockchain solutions at IBM run on the cloud, period. IoT systems themselves are entirely cloud-based. Blockchain applications could be run on Public Cloud, but it could also run on Private Cloud, as some of our customers, in some cases, like to retain all the proprietary data behind their firewalls. These are highly secure cases where these customers request direct control over their environment. This is the main difference between the Public and Private Cloud offerings. In both cases, however, the scalability, compute and resource benefits are still the same. Nevertheless, what I have seen is that the intersection of this technologies has driven cloud adoption, and has raised interest in our cloud-based applications.

However, one thing to note is that, in current rail road and supply chain companies there are huge existing IT departments that currently maintain all IT service and application infrastructure. For example, *Union Pacific* has over 1200 professionals in its IT

department, and a lot of these employees are paid to maintain non-cloud, on-premise infrastructure. So, one caveat is that when IBM goes in and engages these IT departments about running blockchain applications and integrating it with the cloud, there is a bit of skepticism, as they interpret it as the possibility of losing their jobs. From my experience, there is some tension in the world between the professional IT people and the technology professionals who are pushing the cloud. This would resolve itself over time as companies start to see the huge amount of benefits they obtain from running blockchain in the cloud. It's a matter of when, not if we would start seeing increased growth in cloud adoption as blockchain becomes more widely adopted. For enterprise applications, the growth of blockchain and cloud computing are directly proportional.

How would blockchain and the Cloud as a symbiosis, mutually help to address the concerns of cost, performance, scalability, identity, privacy and security in each space?

Most of our potential customers evaluate the cost of running their blockchain applications on the cloud, with any of our cloud variants. The benefits of not having to maintain their own infrastructure on-premise, and the operations cost advantages of running in the cloud, has been huge in the discussions with IBM. The cloud also provides that extra layer of security and network topology that eases the whole process of implementing blockchain solutions.

Potential race from other cloud providers late to this space, any beneficial reasons to be first to market in certain industries?

Cloud providers are driving to create that network-effect that is going to be critical to growing blockchain adoption and in-turn, growing their network of enterprise cloud customers. For example, if I have Maersk (a $36bn multinational transportation and logistics company) on my blockchain cloud platform, and Maersk represents 15% of global GDP (moving on Maersk container lines), I have the draw to attract third party players and others in this space, with proven functionality of my blockchain solution and cloud infrastructure. Winning over the big players who are not already utilizing the cloud in their applications via the provision of excellent blockchain solutions that would reduce inefficiencies, would be very important in cornering certain market and bringing huge on-premise customers to the cloud.

How do you see blockchain evolving from its current state in the near future, and going forward?

Blockchain will evolve through maturity, and I don't think its evolution as a technology is going to be directly correlated with any effects from the cloud, but just with open source contributions.

Any other valuable insights you would like to share?

My summary here is that, with my expertise in this space (railroads, trucking and supply chain), I envision customers who are not already on the cloud and using on-premise solutions being pushed to the cloud in their evaluation of a seamless enterprise blockchain integration or solution. A potential win for cloud providers who move fast with engagement and experimentation.

5.2 Zeyad Rajabi, Principal Product Manager at Microsoft

Title and current role?

I am a Principal Product Manager on the Blockchain team at Microsoft. I have been on the blockchain team since inception for over a year now.

Background before blockchain and how did you get interested/start working on blockchain?

For the last 6-7 years, I have been working on V1 projects for Microsoft, most specifically with Microsoft Office core products. When I was looking to move into our cloud division (Azure), I was looking for an incubation project where I could build something from the ground up. It was then I heard about Blockchain and started doing research and considering that as my next option. Prior to hearing about Blockchain, my knowledge was very scarce, all I had heard about was Bitcoin and its incredible growth. After a few weeks of evaluating my options, I decided to join the blockchain team in 2016, and start my next journey.

Overall view of the current market and adoption?

From an enterprise perspective, the reason why blockchain is so interesting, is that is spans across multiple industries, and it has a very profound potential for impact across the board. However, blockchain is so nascent as a technology, and enterprises have not really realized its full potential. Unfortunately, you also get a lot of hype associated with blockchain, where customers want to get started with experimentation and evaluation, but

do not even know the underlying aspects of blockchain, as a technology. Some of these customers want to get on the hype train, just to advertise that they are experimenting with blockchain, while some others are concretely focused on being first-to-market. Gartner has a hype cycle on emerging technologies, and blockchain is close to the top of the curve when it comes to inflated expectations and hype, at the current moment.

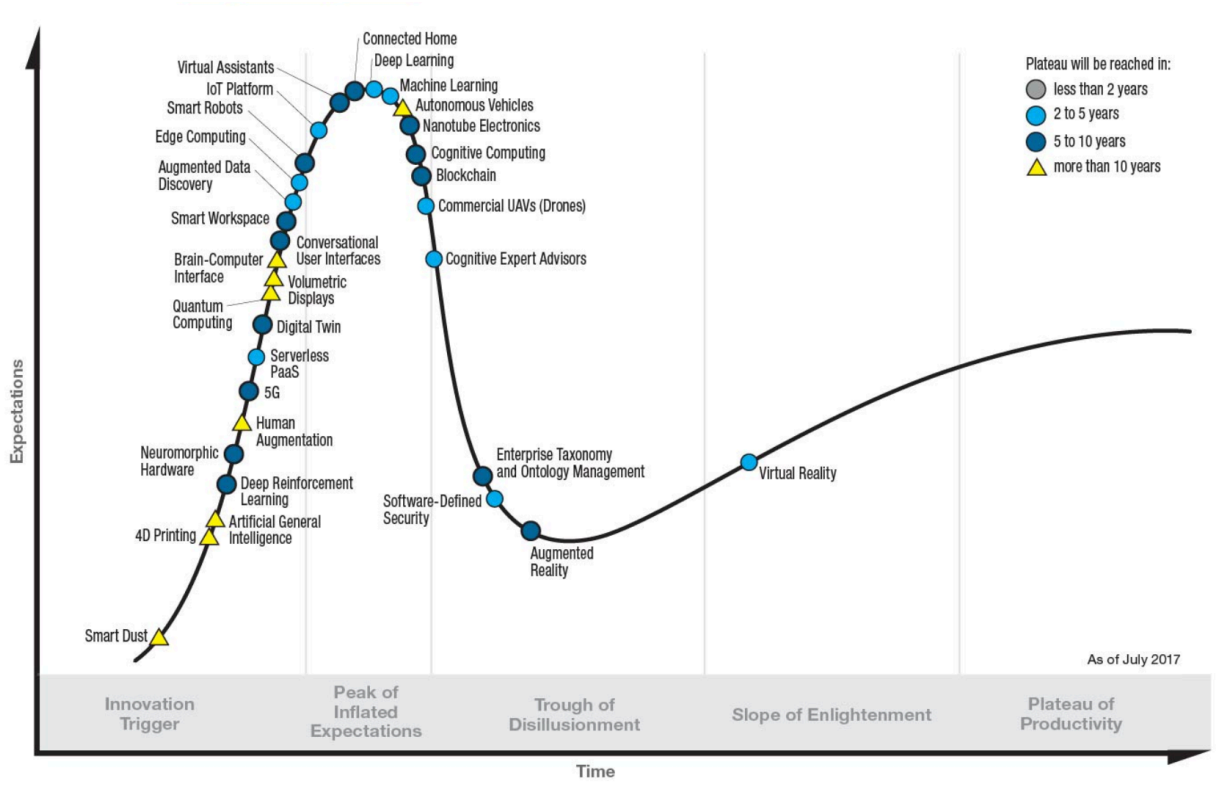

Figure 10: Gartner Hype Cycle of Emerging Technologies (Source: [29])

Personal engagement with blockchain customers/partners, describe the form of engagement?

We are incredibly customer focused on the blockchain team here at Microsoft. Due to the fact that the technology is so nascent and most of our customers are still in the

experimentation stage, there is a desire and need to interact with customers early on, so we can be as agile as possible in delivering the set of functionalities that they truly need. We leverage our partners to help us scale and empower and help accelerate customer work, adoption and satisfaction. In terms of engagement, blockchain has raised so much hype that we literarily have a line of customers (across all segments, financial and non-financial), that are seriously eager to come talk to our blockchain team about possible solutions. As an experience Product Manager, this is the first incubation product that I have worked on, where we don't have to necessarily reach out to our customers. The potential of blockchain is very evident, and most of our customers are aware of the solutions that we can enable for them with the cloud.

In what ways are your enterprise customers utilizing blockchain. In other words what are the current market use-cases?

The two most common segments that I have engaged with are trade finance and cross-border payment solutions and supply chain and manufacturing supply. These are the areas of blockchain application that I have seen pop-up most frequently, in my opinion.

Any evolving use-cases that you envision?

Provenance in food supply, from farm to fork, and the traceability of goods and produce.

What key things do customers or partners look for in decision process of adopting blockchain technology in the cloud?

This is simple. One key word – Efficiency. In simple terms, our customers have one goal in mind, and that is, for them to adopt blockchain technology, there must be a considerable efficiency increase in their current methodologies and processes.

How has the blockchain market and adoption affected cloud computing and vice versa?

This goes back to the question, why are many customers still in the prototyping or POC stage? The problem is, the manual implementation is hard. Working on blockchain is like being thrown on a deserted island. In the sense, that it is not reasonable to just take one piece of your application and put it on blockchain. To have full end-to-end integration and a seamless experience with blockchain, you are going to have to connect it with everything else you care about – be it machine learning models, analytics systems, identity systems, IoT etc. That is where Microsoft is leveraging the cloud (Azure) as a platform, to really build those bridges to enable customers to make those seamless integrations and enable end-to-end experiences across their applications.

How would blockchain and the Cloud as a symbiosis, mutually help to address the concerns of cost, performance, scalability, identity, privacy and security in each space?

Customers look at the cost factors of experimenting, testing and integrating blockchain solutions into their existing applications, and our focus at Microsoft is to deliver the set of services and tools that make it easier and more efficient, at a cost model that is better than the competition. By providing a seamless integration process, that allows our customers to stand up blockchain applications in minutes, and at a cost that is practical to them.

From an overall cloud computing perspective, cloud providers would continue to strive to provide the better solution and win the most customers, in order to increase revenue. Blockchain as a new technology is going to drive the improvement in the quality and efficiency of deployments across cloud providers. In other words, as cloud providers race to win the biggest customers into blockchain-integrated solutions, there is a faster pace and cycle of development when it comes to building more features than enhance the enterprise cloud experience.

Furthermore, we have a huge list of customers who do not even have existing cloud subscriptions, eager to talk to us and engage about blockchain in the cloud. This list would only continue to expand going forward, and the draw is going to lead to a surge in cloud adoption as blockchain solutions become more prominent.

Potential race from other cloud providers late to this space, any beneficial reasons to be first to market in certain industries?

We have a very interesting state of things across cloud providers working on blockchain. For Azure, I will illustrate it as running a race, as fast as you can, and being in front of the pack, but no one told you where to go. However, there is an advantage of being a first mover, as you get to dictate to some degree, where things [market and third-party] would go.

How do you see blockchain evolving from its current state in the near future, and going forward?

The intersection between Blockchain, IoT, AI and the Cloud is significant. As the these "third-party" enabling technologies see evolution and growth, integrate solutions based on blockchain will continue to evolve as well. As of now, things are so nascent, it would be naïve to make any educated predictions.

5.3 Ramya Pradhan, Engineering Enterprise Smart Contract at Microsoft

Title and current role?

I am currently in Software Engineering, working on enterprise smart contracts within the blockchain team at Microsoft.

Background before blockchain and how did you get interested/start working on blockchain?

I finished my Ph.D. in Computer Science, with a focus on fault tolerant distributed systems, and I have extensive experience in cryptography, both hardware and software. When I interviewed with the Azure product group after my Ph.D. program, I had not heard much about blockchain or what Microsoft was doing with blockchain technology. All I heard about was the popularity of bitcoin and how much its value was increasing. However, I had some of the key fundamental cryptographic skillsets from my research, that the Blockchain team was looking for, so after a successful interview and discussing with the General Manager of Blockchain services at Microsoft, I decided and was excited to join.

Overall view of the current market and adoption?

From my engagement with our Customer Council, which includes multinational financial and non-financial corporations from various industries like Boeing, Bank of America and BNP Paribas, one commonality is that these customers understand that Blockchain is this hot new thing that everyone wants, but they do not have any concrete idea how it will integrate or what specifically they would be doing with it in the short term. I think this stretches wide around the current market of blockchain, where most enterprise use cases are still at the experimentation stage and not fully in production yet. With our customers, if I draw the number line [see Figure 10 below] of blockchain readiness, this is where I our current customers lie (within the gray box area):

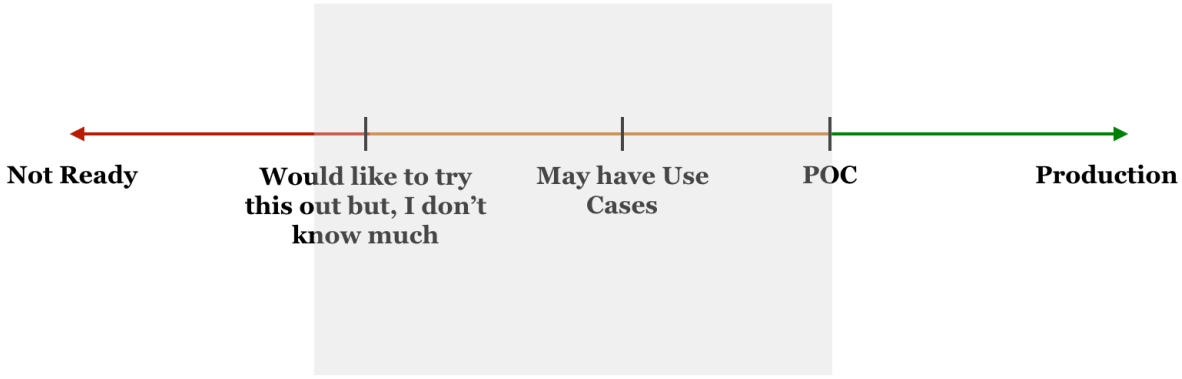

Figure 11: Ramya Pradhan's Illustration of Blockchain Readiness

Personal engagement with blockchain customers/partners, describe the form of engagement?

Most of the customers we engage with, come to us, instead of the other way around. We have a huge line of customers interested in evaluating potential blockchain solutions and

applications for their industries. Personally, I engage mostly via our conferences and discussions we have quarterly with our Customer Council and well known enterprise partners who are interested in blockchain. I have specifically been assigned to work with Boeing and BNP Paribas over the past few months.

In what ways are your enterprise customers utilizing blockchain. In other words what are the current market use-cases?

My engagement has been with customers looking to experiment in areas of supply chain management, trade finance, integration with IoT and smart devices and anywhere tracking is needed (for example, farm-to-fork). Supply chain management has been the most reoccurring use case we have seen.

Any evolving use-cases that you envision?

Charity donation tracking is an interesting evolving use case that I see when it comes to allowing givers to understand how their donations are used and increase transparency in charitable organizations.

What key things do customers or partners look for in decision process of adopting blockchain technology in the cloud?

One of the things that usually pops up from my interactions this year with our customers is the fact that some customers do not know if they just want a secure database or a blockchain solution. However, the most important decision maker is the ease of integration and implementation and how seamless it is to stand up a POC. This is where

the cloud has a huge advantage, most specifically with customers standing up blockchain applications on Azure (Microsoft Cloud). With Azure, customers do not have to worry about the underlying technology nitty-gritty of blockchain or worry about setting up or maintaining any on-premise infrastructure to power their blockchain. Azure allows for easy set-up of smart contracts in only a matter of minutes with a pay-as-you-use model. This is huge for our current partners and potential customers.

How has the blockchain market and adoption affected cloud computing and vice versa?

Blockchain by design has to run on distributed systems. Cloud computing is a collection of distributed systems. They fit is almost perfect here. We have seen customers who do not run on Azure evaluate Blockchain solutions and that spikes their interest in onboarding their services and applications to our Cloud. Blockchain is bringing in a new wave of financial and non-financial customers that are going to drive the growth in usage and adoption of the cloud.

How would blockchain and the Cloud as a symbiosis, mutually help to address the concerns of cost, performance, scalability, identity, privacy and security in each space?

Consensus in the public blockchain is a key to its fundamental structure. Participants in a blockchain must reach consensus whenever transactions take place. In a growing blockchain, we are talking about a good amount of transactions per second. This brings into questions of latency and performance with complexity of the algorithms taken place. Outside performance, enterprises focus intensely on infrastructure costs in their

assessments and with flexibility of our pay models for storage and compute usage, as well as the elasticity and scalable power of Azure, we can provide that backbone for which any blockchain application can run almost effortlessly.

Potential race from other cloud providers late to this space, any beneficial reasons to be first to market in certain industries?

Yes, the brand-new wave of blockchain customers that are not utilizing existing cloud solutions are going to be a chunk of users that cloud providers would like to corner. Being first to market with enterprise blockchain and pulling in these customers is going to influence cloud market shares in the long-term future, in my opinion.

How do you see blockchain evolving from its current state in the near future, and going forward?

We have seen blockchain technology slowly evolve from Proof-of-Work (PoW) to Proof-of-Stake (PoS), and with more contributions to the cryptocurrency and blockchain forums, it will continue to evolve as a technology. This evolution however, should not have a direct impact on the current integration with the cloud and the contributions of cloud computing in this area.

5.4 Ramesh Gopinath, Vice President of Blockchain Solutions, IBM

Title and current role?

I am the Vice President of Blockchain Solutions at IBM. Responsible for all the solutions that are evaluated and implemented on blockchain with IBM.

Background before blockchain and how did you get interested/start working on blockchain?

I had spent a couple of years as the Research Director at IBM Research and Cloud Services, and when our research lab started to evaluate the revolutionary potential of blockchain technology, it immediately sparked my interest. I decided to move in as the VP of Blockchain early in 2016, and start this journey of enabling our customers build blockchain solutions powered by IBM Cloud.

Overall view of the current market and adoption?

There is no denying that these are early days, however, I would say that the year 2016 was the year or blockchain tourism. A lot of customers tried to "kick the tires" and experiment multiple areas, without any good clarity on what they specifically wanted to do. It gradually started changing as we entered the year 2017, and would continue as we head into 2018. Now, there are clients that now seriously talking about moving from the experimentation and POC stage into mission critical production systems. In other words, we are starting to see the turn from tourism into the start of real deployments, and this has been stimulated by the ease of integration enabled by our cloud infrastructure.

Personal engagement with blockchain customers/partners, describe the form of engagement?

There is so much interest in this space, that we get a lot of inbound engagement. In the sense that, a lot of enterprise companies (over hundreds) come to us and engage with us when they hear about our forays in the areas of food safety, trade digitization, trade finance etc. In 2016, when things started off, we accepted almost every inbound request, because things were new and we (IBM) were just getting into this space ourselves. More recently, we qualify the leads and inbound request much more carefully, and that is due to the fact that the demand for POCs and experimentation of blockchain on our platform is so much, that we want to make sure that the customers we select have a clear path to production, and are fully invested. In other words, we quantify if we believe that the client in question will be taking our implement solution into production, and that determines if we agree to engage or not. Apart from inbound requests, we have also picked a few significant industries of interest that we think are going to be transformative in the near term, and gone ahead and basically created the market. For example, early last year (2016), we engaged with senior executives at Walmart on how blockchain can transform their food distribution lines, and now (18 months later), we have a limited availability version of an integrated solution that Walmart is now using, along with several their ecosystem partners.

In what ways are your enterprise customers utilizing blockchain. In other words what are the current market use-cases?

This is a tough question, because, in every good emerging use cases that we have evaluated, as well as some established use cases. I view it as more of the characteristics of the use-case. There are some common themes that we see however when it comes to our inbound requests from most of our enterprise customers. The first theme is around blockchain solutions that deliver a shared and trusted system of records across transactions. The second is, managing the lifecycle of records. Basically, tracking the start and completion of transactions, purchases and asset ownership. The third is provenance, and the origin of produce and goods. These are three of the most common cases that we see and have evaluated over the past two years.

What key things do customers or partners look for in decision process of adopting blockchain technology in the cloud?

The most important thing for our enterprise customers is tackling inefficiencies and improving holistic processes with blockchain, as well as using blockchain in the cloud as a means of cost reduction. When we break down the time and cost efficiency benefits of running with our cloud platform, as opposed to implementing through and on-premise managed infrastructure, our customers are usually bought in. With the operational advantages of not having to maintain infrastructure, and with cloud computing speeding up the deployment of blockchain applications, we see more and more enterprise customers across various industries being drawn to our cloud offerings.

How has the blockchain market and adoption affected cloud computing and vice versa?

Given the state of blockchain as a technology, and given that there are not too many experts in this field yet, at these industries, the customers see it as a huge advantage to run and experiment their blockchain solutions in the cloud and they are easily able to manage and scale their applications with the power of cloud computing, without worrying about the intricacies of blockchain's underlying technology. As stated previously, I have many years of experience in the cloud space, and the push is undeniably there with newer customers developing on our cloud platform due to the blockchain hype.

How would blockchain and the Cloud as a symbiosis, mutually help to address the concerns of cost, performance, scalability, identity, privacy and security in each space?

The cloud essentially eliminates the concerns of scalability when it comes to blockchain operations as more blocks are added to the chain. Applications that are powered by blockchain technology already have that baseline of security due to its functionality, and that is only enhanced by a secure cloud (most cloud providers have to meet intensive security and data handling requirements). The most important factor here is compute and storage, and with the symbiosis of the cloud and blockchain, developers across these industries can integrate and scale applications that are highly performant due to the compute power of cloud computing.

Potential race from other cloud providers late to this space, any beneficial reasons to be first to market in certain industries?

I will keep this short, the biggest winners in this early adoption cycle will be the cloud providers that can garner the biggest consumers across the financial and non-financial industries, as well as the ecosystem of third party users that these consumers bring along with them (e.g. Walmart, Bank of America etc.)

5.5 Michael Glaros, Senior Product Manager Blockchain at Microsoft

Title and current role?

I am currently a Senior Product Manager on the blockchain team within our cloud offering at Microsoft. My specific function on the blockchain team is customer success and enabling our enterprise customers effectively implement and experiment their solutions on Azure (Microsoft Cloud).

Background before blockchain and how did you get interested/start working on blockchain?

I was in the Cybersecurity space for over 20 years, specifically focused on Risk and Vulnerability management or data, data handling and protection, as well as, information security. My core focus prior to blockchain was designing solutions for risk mitigation and cyber security, and helping enterprises protect their data in a secure and seamless way. As I started looking into the world of blockchain and seeing what Microsoft was doing in this space, I felt that this closely aligned with my future interests. My background in cyber security was the right Segway, into the world of blockchain.

Overall view of the current market and adoption?

I would say it is all over the place. There are certain industries like finance and supply chain that are coming on really fast and are investing in R&D [Research and Development] into blockchain, although there still very few scenarios and networks that are poised for production at this moment. However, things are starting to really speed up, as more and more enterprises are starting to hone in their focus on moving from the experimentation and POC stages into production as soon as early 2018.

Personal engagement with blockchain customers/partners, describe the form of engagement?

This is interesting, as our engagement model has changed over the past year, and Microsoft is doing things more differently now. When we started the blockchain incubation project here at Microsoft, we initiated a lot of our customer engagement, and talked to as many customers as were interested. In recent months, we now have a huge line-up of customers who are waiting to engage with our blockchain engineering team and evaluate solutions in their industries. With the announcement of Project Bletchley, and with customers now being aware of how fast they can stand up blockchain applications in the cloud, we have seen a significantly increased wave of interest.

In what ways are your enterprise customers utilizing blockchain. In other words what are the current market use-cases?

Most of my engagements as a PM have been enterprise application that could utilize reform with the use of an immutable system of records. However, we have multiple product professionals across Microsoft Azure with different areas of blockchain focus.

Although I have focused on customer success and blockchain adoption in the financial sector, I have seen a repetitive pattern of interest for utilizing blockchain as a technology for an immutable system of recording, tracking and provenance.

What key things do customers or partners look for in decision process of adopting blockchain technology in the cloud?

Ensuring that the underlying infrastructure is secure is key to the decision making when enterprise customers are looking to adopt. From a Federated Identity Management (FIM) perspective, enterprise users and administrators of enterprise systems are able to manage keys and manage access control with features like Azure Active Directory (AAD) and Azure Key Vault, that ways participant on a blockchain can be effectively managed. This key pieces of identity, access control and security that is made easy with the use of our cloud is a key decision factor. Another main decision factor is performance and how our compute and storage infrastructure can help power the speed up the deployment of their blockchain applications.

How has the blockchain market and adoption affected cloud computing and vice versa?

As mentioned earlier, the networking and sheer compute capability of our cloud infrastructure and offering, as well as the other features that Azure provides that reduce the hassle of standing up and experimenting enterprise grade, real-time blockchain applications has led to a huge wave of customers that are now interested in deploying on our cloud platform. Cloud computing has effectively eliminated the worry that enterprise

customers have on service integration and evaluating the cost of implementation. In other words, the hype around blockchain has driven more serious customers to the cloud and the value derived from the power of cloud computing has garnered even more interested parties, so almost a multiplier effect. Over the next 6-12 months, our number of engagements are expected to increase, which would bring more customers and other third party users in their ecosystem into our cloud space. This has the potential to be a big win for Public Cloud providers who are fully invested in this blockchain.

How would blockchain and the Cloud as a symbiosis, mutually help to address the concerns of cost, performance, scalability, identity, privacy and security in each space?

In my unbiased opinion, Cloud is the only way that enterprises can reasonably do blockchain work successfully. As a baseline, when you look at this as P2P technology, where there are an array of endpoints that have to replicated to build a ledger, then you can think about the firewall strengthening requirements, from a security standpoint. Cloud computing as a secure offering helps to allay some of those security concerns. Cloud computing is also critical to blockchain integration because when you have web micro-services and API style design patterns that can be easily implemented via the cloud, that make most of the complicated bits of the ledger somewhat more manageable. The ledger is complicated for enterprises with existing mission critical applications because it is a storage technology, a network technology, a security technology, and a runtime for application technology all in one. So by utilizing cloud services and web micro-services running in the cloud, then you reduce most of the development and

deployment workload, and developers in these industries are able to more easily create and design their customized blockchain solutions.

Potential race from other cloud providers late to this space, any beneficial reasons to be first to market in certain industries?

When we sell our technology sales professionals sell our cloud solutions now, they integrate a blockchain story to relevant parties. As a cloud provider, Microsoft Azure is committed to allowing our enterprise customers evaluate the full potential of our cloud offering and the capabilities it provides. This is an added benefit to us when you look at the competition. In this digital transformation age, getting in early and getting it right is crucial. With the potential that I believe blockchain has, the cloud providers than can garner the most market now, would have a significant stake in market share, going forward.

6. Deploying Blockchain Applications in the Cloud

A general consensus across the interviews with industry experts was that the cloud wholly takes out the abstraction and time concerns, in the deployment of blockchain applications and setting up of a blockchain network. In validating these claims, this section walks through the deployment of VMs and network resources based on pre-configured blockchain cloud templates required to stand up an Ethereum multi-member network. This walkthrough was done using Microsoft Cloud (Azure) Blockchain service.

6.1 Step-by-Step Technical Walkthrough

Step 1: An enterprise cloud user can easily pull down an Ethereum Consortium Blockchain provided by Microsoft from the Azure Marketplace and begin the deployment process.

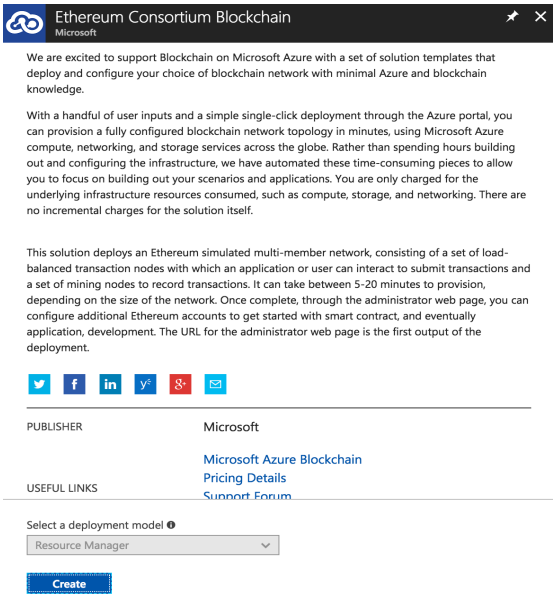

Figure 12: Setting up an Ethereum Multi-Member Network

Step 2: In other to administer resources in a multi-member blockchain network in Azure, the resource identifiers as well as configuration passwords (encrypted) a required. Infrastructure and network resources and also be geo-located using CDNs by specifying where they should be deployed. This allows for enterprise users to locate resources appropriately for faster speeds, blockchain performance and minimal latency.

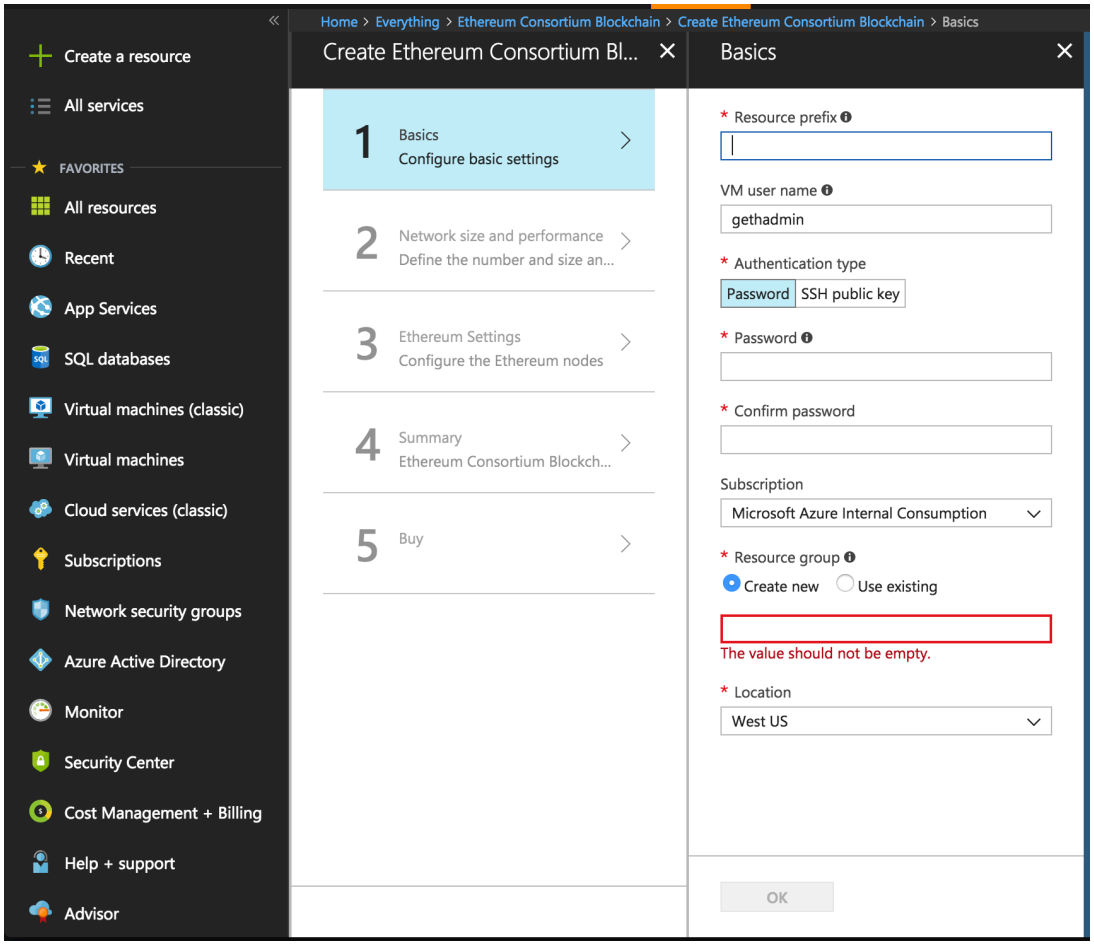

Figure 13: Configuring Basic Settings

Step 3: The customizability of mining nodes to optimize for cost and performance is key to scalability, as more blocks are added to the network. Cloud users can select the number of initial members of the network, number of nodes, storage performance and replication as well as load balancers.

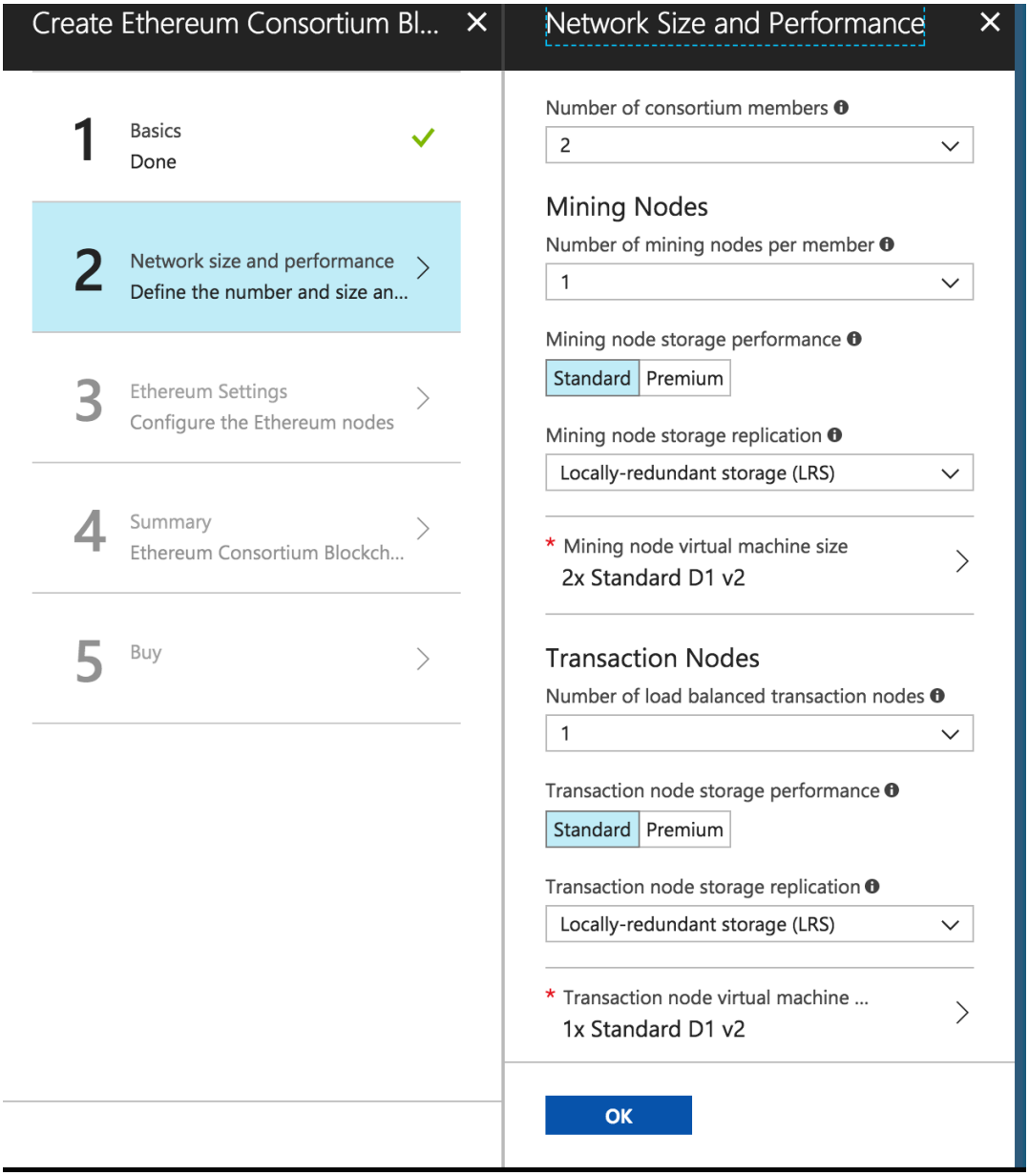

Figure 14: Customizing Network and Storage for Blockchain Network

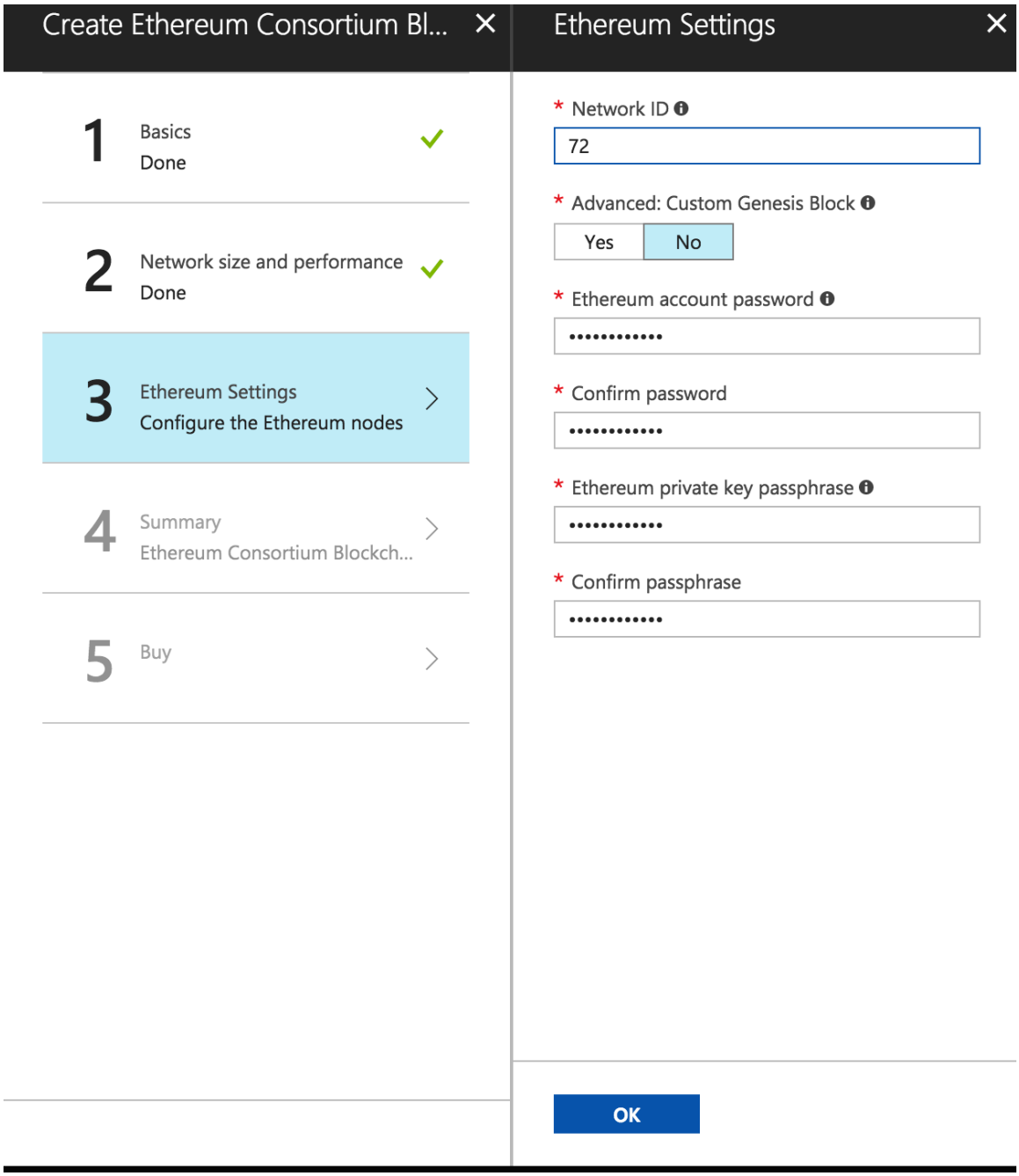

Figure 15: Ethereum Node Settings

Step 4: The configuration and node settings specified by the user, is verified and validated before the nodes are built and the blockchain network is deployed in the cloud.

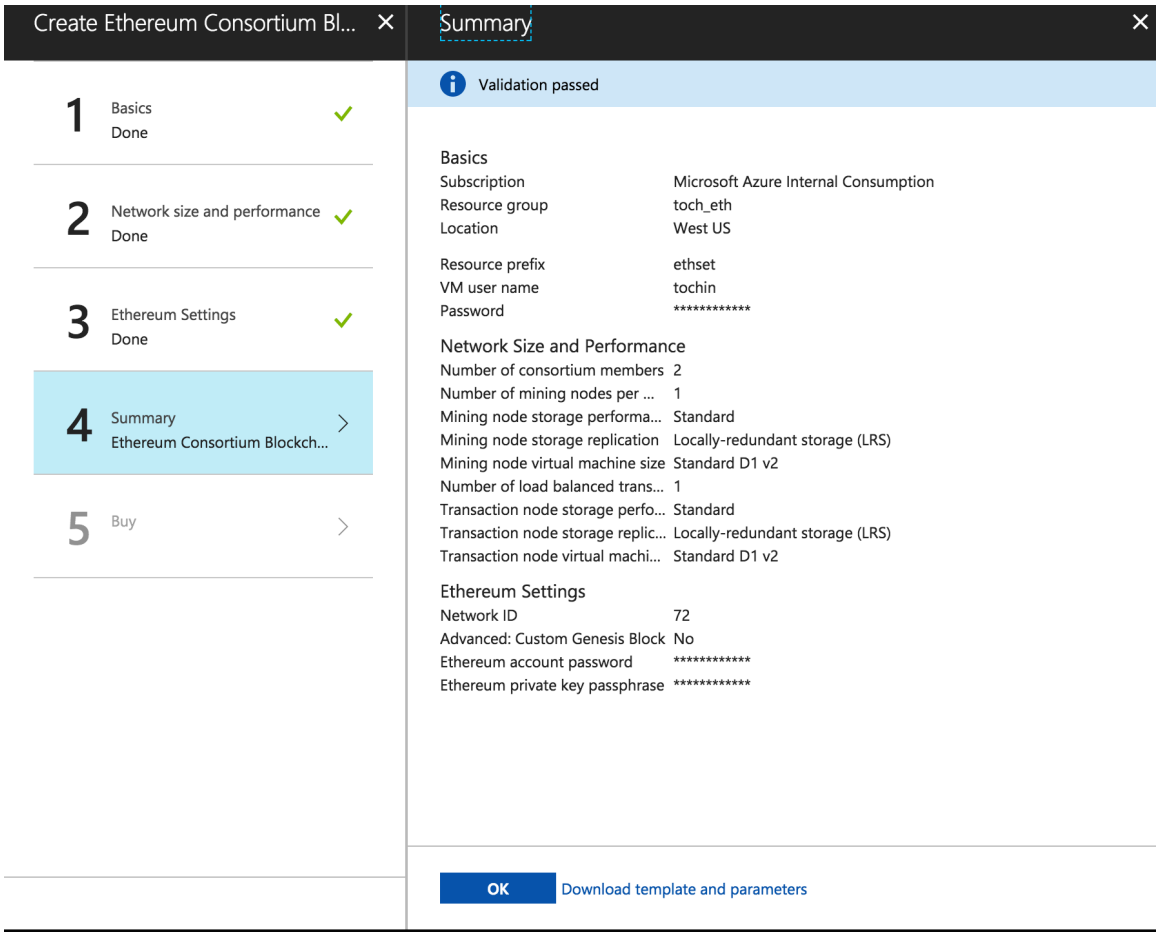

Figure 16: Validating Network and Resource Configuration

Step 5: This deployment experimentation was run *10 times* over the period of 30 days, with an average total completion time of slightly over 8 minutes. In this final scenario, the deployment took approximately 7 minutes to provision a fully configured blockchain network topology.

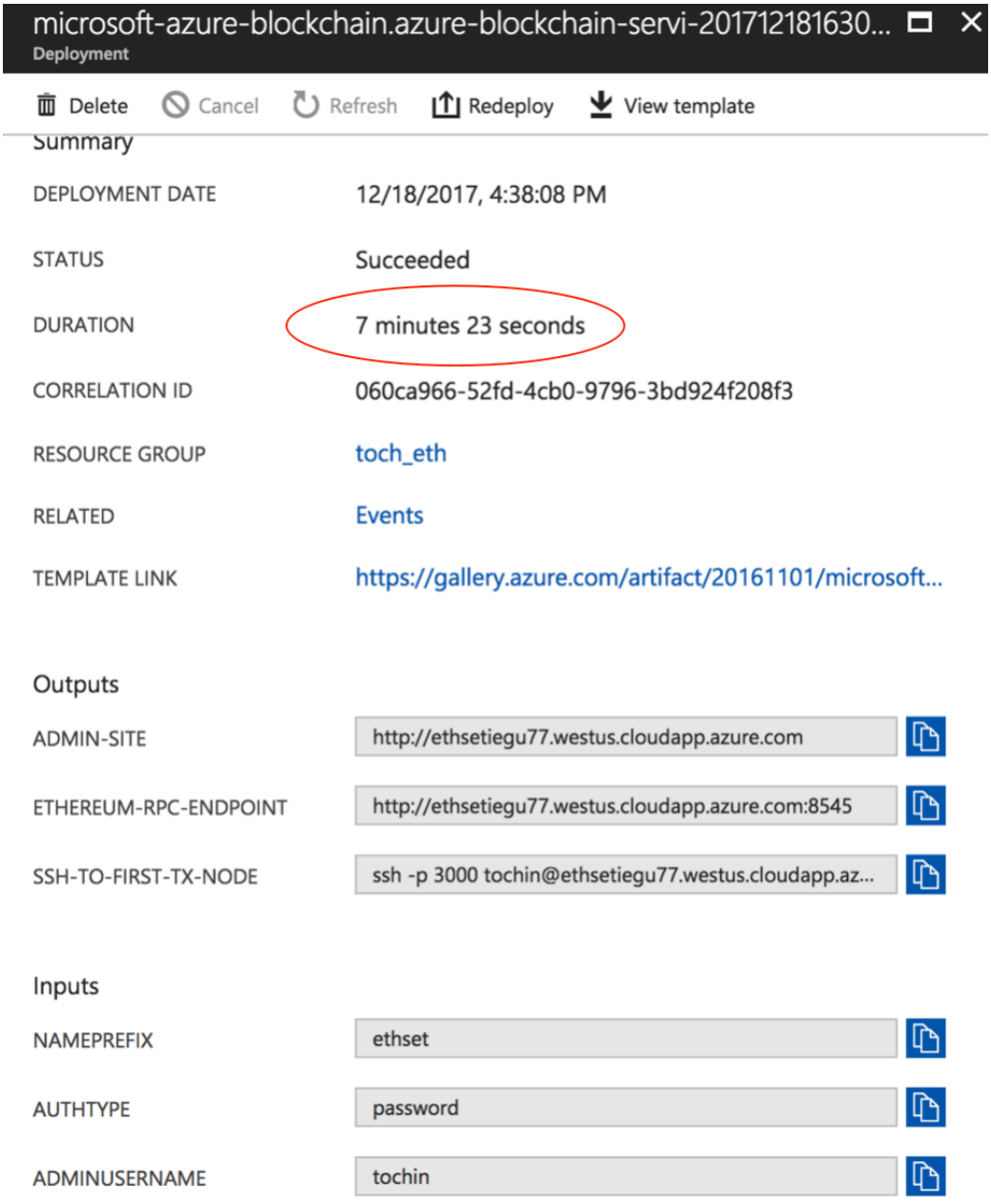

Figure 17: Blockchain Deployment Validation showing Completion Time

Step 6: Post Deployment, enterprise administrators can allocate and deallocate resources as more infrastructure is needed, or more blocks are added to the network. With the cloud, resource costs and metrics and be easily monitored, alert rules triggered (for example when a block is added), policies can be strictly set and most importantly, identity can be easily managed using Access Control mechanisms.

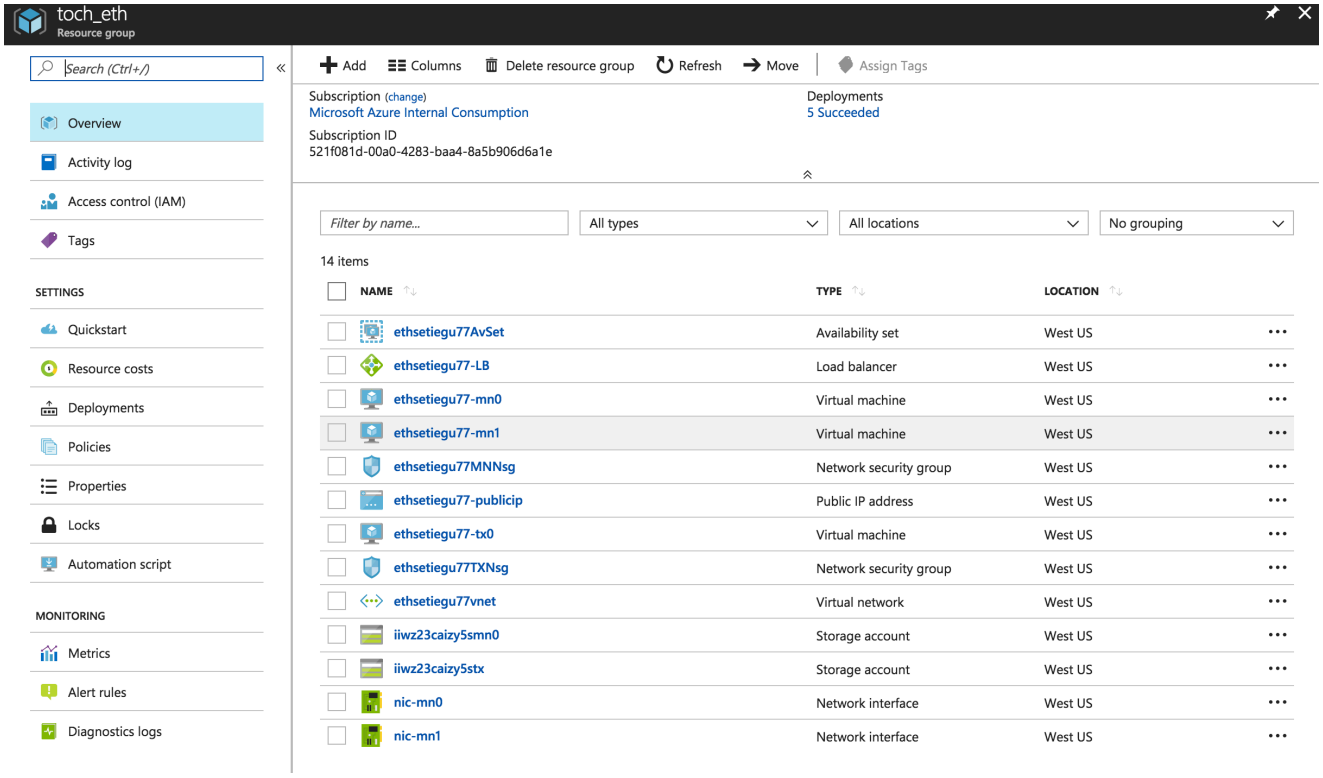

Figure 18: Complete Blockchain Resource Scope View (Post-Deployment)

6.2 Blockchain Deployment Runs & Results

A deployment experimentation was configured 10 times in multiple availability zones over a period of 30 days and the run time results are listed in Table 1 below. The start times denote the local time that the deployment was triggered at the specified deployment region/availability zone. Peak classifications are identified as period of times when there are significant cloud workloads (indicating potential effect on performance). The average time taken to set up the network resources for a multi-member blockchain network was slightly over 8 minutes – validating the postulation that the cloud can ease the blockchain integration and implementation process for application developers.

Runs	Date & Start Time	Peak?	Deployed Location	Run Time
1	11/02/2017 1:14pm	Yes	West US	9 mins 28 secs
2	11/06/2017 7:21pm	No	East US	5 mins 19 secs
3	11/12/2017 8:55pm	No	East US	8 mins 22 secs
4	11/15/2017 10:19am	Yes	East Asia	8 mins 35 secs
5	11/23/2017 7:33pm	No	West Europe	7 mins 41 secs
6	11/24/2017 9:34pm	No	East US	6 mins 57 secs
7	12/03/2017 1:55am	No	Canada East	7 mins 08 secs
8	12/05/2017 1:32pm	Yes	North Europe	8 mins 11 secs
9	12/11/2017 10:12am	Yes	Australia East	8 mins 43 secs
10	12/18/2017 4:38pm	Yes	West US	7 mins 23 secs

Table 1: Blockchain Multi-member Cloud Deployment Runtime

7. Conclusions

Despite still considered a nascent technology, blockchain has seen immense growth in interest and acclaim since its introduction in 2008. Recent publicity around cryptocurrencies and the growth of Bitcoin have been key contributors to this growth in interest and evaluation of Blockchain as a technology. As financial and non-financial applications of blockchain start to evolve and continue to grow, these applications must be able to handle increasing scale and the clamor for holistic integration. In addition to scalability, enterprise companies continue to factor in performance, security, privacy, identity and ease of implementation, as significant dynamics to wide spread adoption. This is where Cloud Computing as a supporting platform, comes into the picture. Since the start of 2016, the degree of enterprise interest for blockchain applications powered by the cloud has progressed from "kicking the tires" and early proof-of-concept, to late-stage experimentation and production ready solutions (heading into late 2017 and early 2018).

Looking at all angles, the future is promising for blockchain technology. As more enterprises dedicate resources and expertise in the exploration of blockchain in the reduction of inefficiencies and improving processes in existing industry methodologies, the potential impact that blockchain could have as an underlying technology to widespread applications is significant. However, looking outside all the hysteria, there are adoption challenges (see Section 4) that must be addressed for blockchain to see continued growth in the road to enterprise ubiquity. Integrating blockchain applications in the cloud, could potential play a part in alleviating most of these adoption concerns. Cloud providers that have explored and started to provide blockchain offerings (IBM and

Microsoft) have touted infrastructure scalability, raw compute and networking power (for blockchain algorithmic tasks), identity management, cost of operations and most importantly, ease of integration and deployment as significant benefits of implementing blockchain applications in the cloud. To validate these notions extrapolated from literary research as well as blockchain industry expert interviews, a proof-of-concept cloud VM environment was created to test the run time of multiple deployment cycles of a multi-member Ethereum network infrastructure in the cloud (results in Section 6). Research, in-depth industry interviews and experimentation have led to the following key conclusions:

- Cloud Computing has started to, and would continue to play a significant part in the early growth and prevalence of blockchain applications across enterprise industries. The unification of blockchain, IoT, AI and the Cloud would be the centerpiece of numerous blockchain applications.
- Interest and hype across blockchain would drive an initial push of non-cloud enterprise customers to the cloud. Public Cloud providers have provided means by which the deployment of underlying infrastructure for blockchain applications have been made trivial, and have abstracted any complex intricacies of blockchain by enabling intuitive and easy-to-use deployment templates and mechanisms. A good number of enterprise customers who were initially resistant to standing up applications and services in the cloud, are starting to "buy-in", in the blockchain exploration process.
- In terms of cost and operations, enterprises exploring blockchain as an underlying platform, can avoid the concerns of implementing on-premise infrastructure to run

and support their blockchain applications or IT operations to maintain and scale with growth.

- The seamless integration across all other applications and services in an enterprise application needs to continue to be a focus for Cloud providers to draw in these customers, and is one of the areas where Cloud providers continue to see room for improvement in luring more early adopters.
- With the way blockchain functions, as more block are added to the network and as the network grows, transaction and verification tasks become increasingly computationally difficult. Cloud providers must maintain the reliability of performance and scalability to see big wins in this space.
- Security and privacy in data handling, identity management and access control of network resources and members are other provisions of cloud computing that would drive the adoption of blockchain in enterprise applications and concrete interest in moving experimentation solutions to production.

Over the next two years, we will see a significant shift from experimentation efforts to real-time and mission critical applications running in production using blockchain as an underlying technology, and powered by the Cloud. This increase in blockchain adoption would drive a substantial increase in cloud subscriptions. The cloud providers who can assure intuitive and dynamic offerings, and win over the big players (including ecosystem) early, would be confident of significant market shares over the next decade.

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