Empowering the edge

Practical insights on a decentralized Internet of Things

IBM Institute for Business Value

Executive Report

Electronics Industry

Transforming businesses as the Internet of Things expands

As a global electronics company, we understand the issues facing the high-tech industry and the continuous transformation required to thrive. Across the industry, companies are turning their attention from smartphones and tablets to a new generation of connected devices that will transform not just the Electronics industry, but many others. The IBM Global Electronics practice uniquely combines IBM and partner services, hardware, software and research into integrated solutions that can help you deliver innovation, create differentiated customer experiences and optimize your global operations.

Testing the foundations of device democracy

Organizations, both private and public, must prepare to operate in the incomprehensibly immense Internet of Things (IoT) that lies ahead. Our first report in this IoT series, "Device democracy: Saving the future of the Internet of Things," proposes that decentralization can help address the challenges of cost, privacy and longevity in scaling the IoT to an inevitable hundreds of billions of devices.[1] In this subsequent report, we describe how we tested that concept using three goals:

- *Validate the future vision for decentralized systems to extensively augment today's centralized solutions;*
- *Demonstrate foundational IoT tasks without the use of centralized control; and*
- *Empower devices to engage autonomously in marketplace transactions.*

Executive summary

As the IoT scales exponentially, decentralized networks have the potential to reduce infrastructure and maintenance costs to manufacturers. Decentralization also promises increased robustness by removing single points of failure that could exist in traditional centralized networks. By shifting the power in the network from the center to the edges, devices gain greater autonomy and can become points of transaction and economic value creation for owners and users.

To validate the underlying technology vision, IBM jointly developed with Samsung Electronics the Autonomous Decentralized Peer-to-Peer Telemetry (ADEPT) proof-of-concept (PoC). This represented the second phase of the 2014 IBM Internet of Things Study.

The primary objective of the ADEPT PoC was to establish a foundation on which to demonstrate several capabilities that are fundamental to building a decentralized IoT. Though many commercial systems in the future will exist as hybrid centralized-decentralized models, ADEPT demonstrates a fully distributed proof.

While many commercialization challenges remain, our PoC validated the feasibility of both implementing the foundational functions of a decentralized IoT, and enabling device autonomy in IoT transactions and marketplaces. ADEPT opens the door for the electronics industry to further explore the challenges and opportunities of potential hybrid models that can address the complexity and variety of requirements posed by an Internet that continues to scale.

As we approach the era of hundreds of billions of devices, a hybrid IoT will evolve, and the "edge" will complement the center

Devices on the edge can be empowered to function autonomously in the IoT

The edge will become a frontier of new economic value, creating an Economy of Things

Through the partnership with Samsung Electronics and collaboration with the open source communities, ADEPT successfully demonstrated four use cases using functional Samsung products:

- A W9000 Samsung washer autonomously reordering detergent (B2C)
- A W9000 Samsung washer autonomously reordering service parts (B2C)
- A W9000 Samsung washer autonomously negotiating power usage (B2C)
- Samsung Large Format Displays (LFDs) autonomously displaying advertising content (B2B).

By empowering devices to engage autonomously in markets – both financial and non-financial – and react to changes in markets, the IoT will create an "Economy of Things." Virtually every device and system can potentially become a point of transaction and economic value creation for owners and users. These capabilities will be crucial to everything from enabling sharing economies to energy efficiency and distributed storage.

Three foundational functions

To perform the functions of traditional IoT solutions without a centralized broker, any decentralized approach must support three foundational functions (see Figure 1):

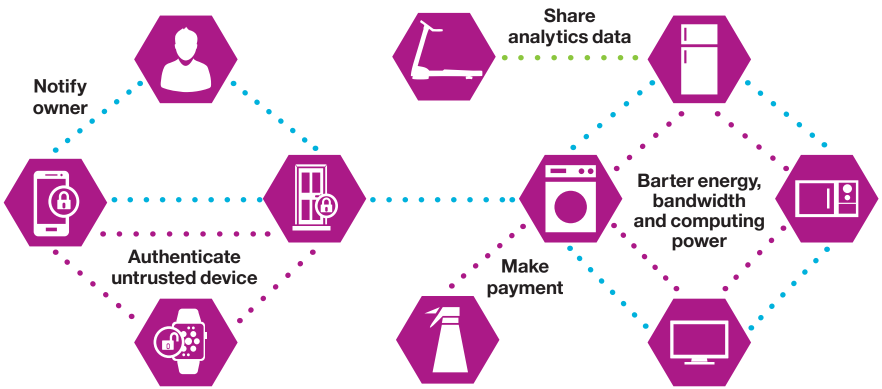
- Peer-to-peer messaging
- Distributed file sharing
- Autonomous device coordination.

The ADEPT PoC implemented these functions using three open source protocols: Telehash for messaging, BitTorrent for file sharing and Ethereum, a blockchain protocol for autonomous device coordination functions such as device registration, authentication, proximity-based and consensus-based rules of engagement, contracts and checklists.

Figure 1

In the ADEPT PoC, devices are empowered to perform three foundational functions

- Peer-to-peer messaging
- Distributed file sharing
- Autonomous device coordination



Peer-to-peer messaging in a decentralized IoT must support: trustless, encrypted messaging and transport; low latency with guaranteed delivery; and storage and forwarding of messages with "hop-on" to other connected devices.

Peer-to-peer messaging

Peer-to-peer networks are capturing much emerging interest because they provide a good platform for distributed computing. Today, such networks support a rich list of features, including selection of nearby peers, redundant storage, efficient search/location of data, data permanence or guarantee, hierarchical naming, trust and authentication, and anonymity.[2]

Peers can share computing resources without dependency on a central cloud or server, thereby optimizing resource utilization and cost involved in subscribing to a central service. A network of peers with diverse capabilities and resources could further strengthen the overall stability and performance of the system without dependency on a third party.

Peer-to-peer messaging in a decentralized IoT must support:

- Trustless, encrypted messaging and transport
- Low latency with guaranteed delivery
- Storage and forwarding of messages with "hop-on" to other connected devices.

Distributed Hash Tables (DHTs) can meet such messaging requirements, enabling peers to search for other peers on the network using a hash table with *(key, value)* pairs stored in the DHT.[3] Each device can generate its own unique public key-based address (a hashname) to send and receive encrypted messages with other endpoints.

For ADEPT, of the many messaging protocols considered, an emerging open source messaging protocol, Telehash, best matched our goals for peer-to-peer messaging. Telehash is an open source DHT implementation of the Kademlia protocol.[4] Our protocol choices were made based on their current capabilities and our ability to implement them in a PoC. In our demonstration of a decentralized IoT, Telehash is used primarily for notifications among devices without using a centralized server.

Distributed file sharing

In a decentralized IoT, distributed file sharing enables content distribution such as propagating software/firmware updates, transfer of device analytics reporting and media content for files of large orders of magnitude. Such distributed file sharing can also be achieved securely via distributed peer-to-peer networks using DHT. BitTorrent, a well-known DHT file sharing protocol was chosen for ADEPT file sharing. In our demonstration of a decentralized IoT, BitTorrent is used primarily for content distribution without using a centralized server.

Autonomous device coordination

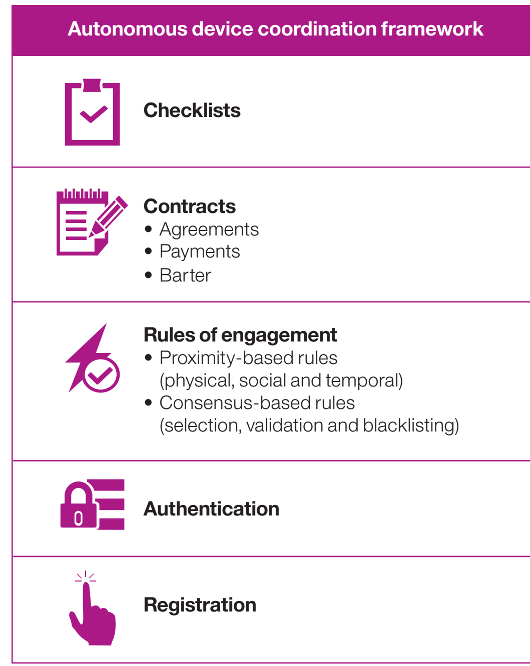
By not requiring a third-party arbiter of roles and permissions, an autonomous device coordination approach empowers owners of devices to define and manage their own interactions. Simple device coordination functions include registration and authentication. More complex interactions require the owner or user to define rules of engagement. These rules could be proximity-based (physical, social or temporal), consensus-based (selection, validation or blacklisting), or triggered by other device stimuli.

Another form of device coordination is contracts – simple agreements about actions or control, more complex financial contracts involving payments or barter contracts that allow devices to exchange their resources for a service. Digital checklists allow devices to maintain themselves to prevent failure.

To implement such an autonomous device coordination framework across a network of devices in our PoC, we chose the blockchain technology platform (see Figure 2).[5]

Figure 2

An autonomous device coordination framework enables transactions among devices, from simple registration to complex checklists



Applying the blockchain concept to the IoT offers fascinating possibilities that include maintaining product information, history, product revisions, warranty details and end-of-life so that the blockchain itself can become the trusted product database.

Building a blockchain-based IoT

A blockchain – the technology platform underlying the decentralized financial system Bitcoin – is a long ledger of transactions shared by participants of the network. A full copy of the blockchain holds a record of every transaction ever completed in the network. Every blockchain participant can maintain its own copy of the ledger, although the amount of data stored will vary based on capability, need and preference. Every block on the ledger contains a "hash" of the previous block.

This enables blocks to be traced back even to the first ("genesis") block. It is computationally prohibitively difficult and impractical to modify a block once it is created, especially as the chain of subsequent blocks get generated. Blocks in shorter chains are automatically invalidated by virtue of there being a longer chain – all participants adopt the longest available chain.

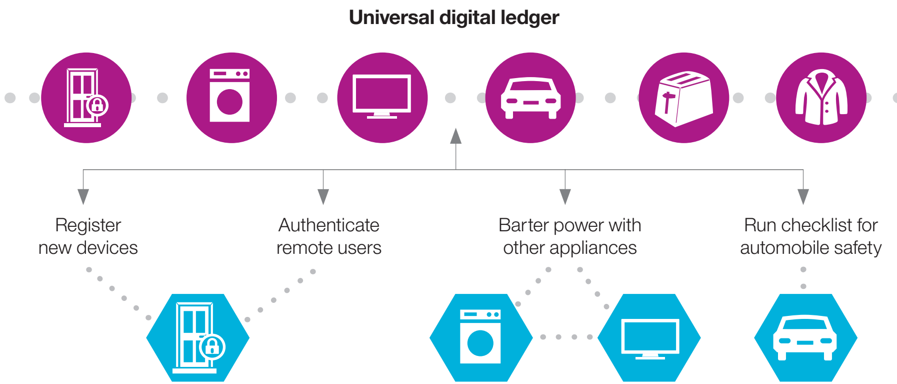
Applying the blockchain concept to the world of IoT offers fascinating possibilities. As soon as a product completes final assembly, it can be registered by the manufacturer into a universal blockchain representing its beginning of life. Once sold, a dealer or end customer can register it to a regional blockchain (a community, city or state). When registered, the product remains a unique entity within the blockchain throughout its life. The possibility of maintaining product information, history, product revisions, warranty details and end-of-life in the blockchain means the blockchain itself can become the trusted product database.

For example, imagine a world where a smart device is able to detect a component failure, check warranty status on the blockchain, place a service order with a contracted service provider and have the service provider independently verify the warranty claim – again from the blockchain – all autonomously. In such a world, we would redesign and simplify how we design our master data management systems, after-sales systems, and order processing and management. A blockchain-based, decentralized IoT can become a truly revolutionary approach to transaction processing among devices (see Figure 3).

It is important to note that while Bitcoin contains an escalating difficulty in the blockchain mining process to restrict the issuance of currency, no such restriction is necessary in our vision of blockchains for the IoT. For the ADEPT implementation of a blockchain-based IoT, we chose the Ethereum protocol in its alpha version.[6] Ethereum's improvements to the traditional blockchain approach of Bitcoin, the Turing complete scripting languages it introduced and its ability to create binding contracts were extremely compelling for our PoC.

Figure 3

The blockchain functions as a distributed transaction ledger for various IoT transactions

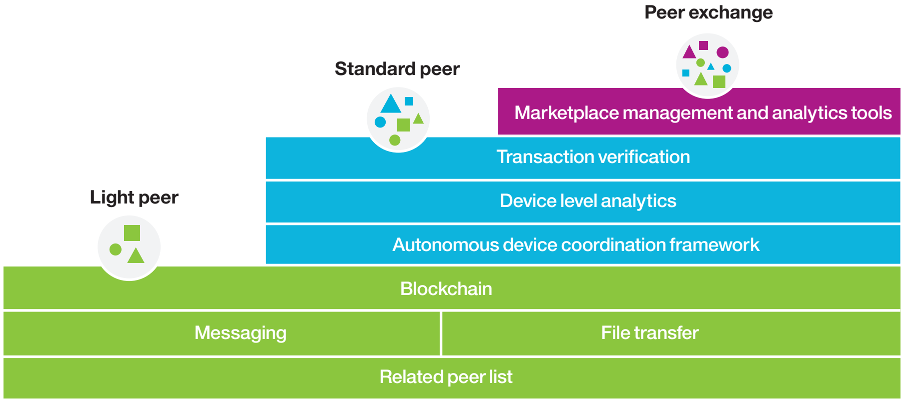


Three device types

Devices in the IoT vary widely by computing power, networking capability, storage space, whether they are AC or battery powered, and stationary or mobile, to mention a few. Devices will be part of ecosystems that can also require continuously evolving levels of trust. As more transactions occur between peer devices, trust will evolve between them. What starts as an interaction between two trustless peers can over time become a semi-trusted or even a trusted relationship.

So the extent of transaction verification required between devices depends on many factors: the kind of device, nature of the interaction, kind of relationship between the devices and also the constraints imposed by device owners on what the devices can and cannot do in specific circumstances. Based on these considerations, we identified three broad categories of devices and defined the decentralized IoT capabilities of each (see Figure 4).

Figure 4. *Device capabilities get increasingly sophisticated in moving from light peers to standard peers to peer exchanges*



Different devices in the IoT support different degrees of ADEPT functionality, depending on their performance and storage capabilities. At the lowest end are *light peers:* devices such as wearables and light switches that perform basic IoT functions like messaging. At the other end of the device spectrum, *peer exchanges* on servers or clouds enable more complex marketplace transactions as peer services.

As these devices become peers of a decentralized network, it is essential that each can identify itself uniquely to peers in a verifiable manner, retain details on its relationship with different peers and identify peers unambiguously across protocols. These actions are achieved by means of a secure peer list.

Light peers

Light peers are devices with low memory and storage capabilities, such as sensors and devices supporting light applications. Current representatives of light peers include Raspberry Pi, Beaglebone and Arduino boards.

Light peers perform messaging, retain a light wallet with their blockchain addresses and balances, and perform minimal file sharing: for example, receiving firmware updates or sending a transaction summary file to another peer based on a business or functional need. To obtain its blockchain transactions, a light peer will turn to a trusted peer.

Devices on the edge perform different roles in a decentralized IoT based on their capabilities.

The peer exchange not only supports transaction verification, but also functions like a financial exchange by providing liquidity for transactions between devices in the marketplace.

Standard peers
In the next few years, we expect processing power and storage capabilities of most products to increase as the cost of general-purpose computing declines. The incremental cost to manufacturers or end consumers for increased computing power and storage will be insignificant.

So washers and refrigerators of the future, for example, will be equipped with higher storage and processing capabilities that make it possible to meet blockchain requirements for a specified period of time – not only of themselves but also of light peers in their trusted environment. We expect such products to become the standard in the years to come.

At the core level, a standard peer is very similar to a light peer, but it retains a part of the blockchain, based on its capabilities. This could include its own recent transactions, but also those of other lighter devices in the ecosystem that it holds contracts with. Standard peers can also support light peers in performing file transfers. They will have capabilities to store and forward messages to peers and to perform light analytics for themselves and peers.

Peer exchanges
Peer exchanges are high-end devices with vast computing and storage capabilities. In a decentralized IoT, they are also peers, owned and operated by organizations or commercial entities and capable of hosting marketplaces. Marketplace components such as analytical solutions, payment exchanges, fraud detection, trade and legal compliance packages, and demand-supply matching solutions are supported by peer exchanges, as well as the integration capabilities required to support and interoperate with other business solutions.

Peer exchanges are also potential repositories for a complete copy of the blockchain and provide blockchain analytical services. The size of blockchains can rapidly increase in scenarios where a city or community may have millions of IoT devices. Even standard peers with advanced processors and storage may not be able to hold blockchain information for themselves and the peers they service for more than a few days. However, with the blockchain being the trusted source of information holding all product transactions, it is important to be able to access it at a regional or community level going back in time, in some cases back to the start of a product's life.

For example, a solar micro-grid may be commissioned for a decade or a smart street light may have been registered a few years back. When servicing or support is needed, blockchain access may verify the first registration or installation details.

The peer exchange, somewhat akin to the role performed by current-day financial exchanges, performs supply and demand balancing across the marketplace. So resources offered by a set of assets in one community might turn to a peer exchange for buyers in another. Peer exchanges then become more than a large server or cloud offering memory and technical support They become the lifeline for new economic opportunities – the new "silk roads" – making possible the liquification of assets described in "Device democracy" (see Figure 5).[7]

Figure 5

Marketplaces hosted by peer exchanges provide liquidity for transactions between devices

Transforming the IoT into an Economy of Things

By enabling devices to engage autonomously in marketplaces and supporting complex marketplace transactions, the IoT is expected to improve the utilization and profitability of physical assets and devices. By transforming every device into a point of transaction and economic value creation for owners and users, the IoT will create new real time digital economies and new sources of value. We call this transformation the "Economy of Things."

To demonstrate the feasibility of a decentralized IoT and its role in creating new digital economies, the ADEPT PoC use case scenarios spanned a spectrum of devices and marketplace transactions. A set of B2C and B2B use cases was implemented on functional Samsung products in close collaboration between IBM and Samsung.

The B2C ADEPT use cases demonstrated how a washer can become an autonomous device capable of managing its own consumables supply, perform self-service and maintenance, and even negotiate with other devices – both in the home and outside – to optimize energy consumption. These use cases can be extended to scenarios where micro-commerce solutions can be built using a set of ordinary home appliances.

All of these functions were achieved without a central controller orchestrating or mediating between the devices (see Figure 6). The B2B ADEPT use case demonstrated a decentralized advertising marketplace using LFDs to share and publish content, all without a centralized controller (see Figure 7).

Figure 6

The ADEPT washer participated autonomously in the consumables, energy and service marketplaces

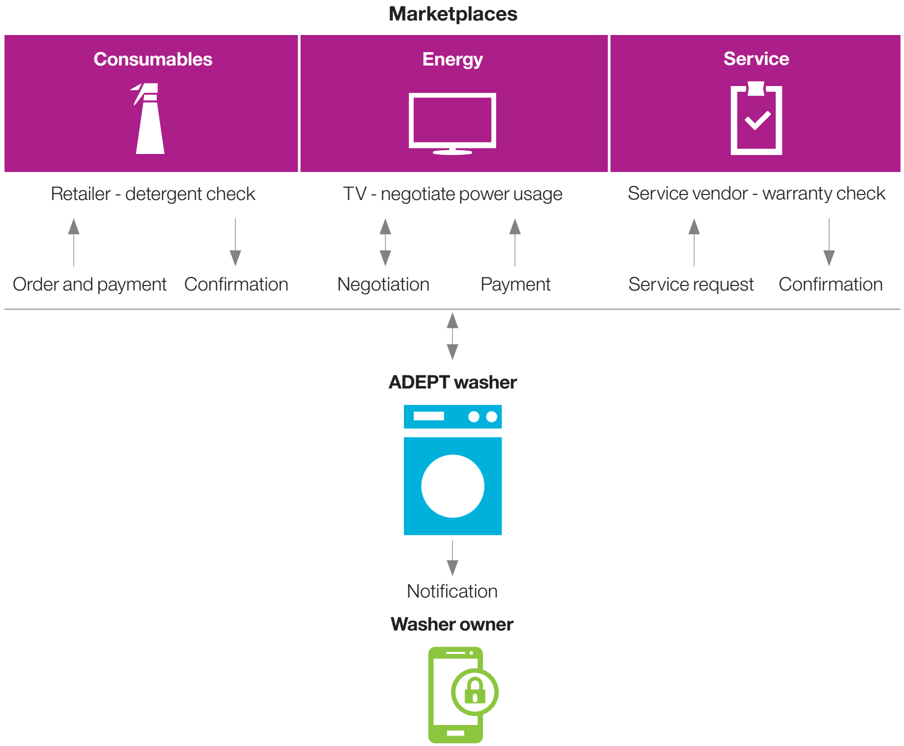
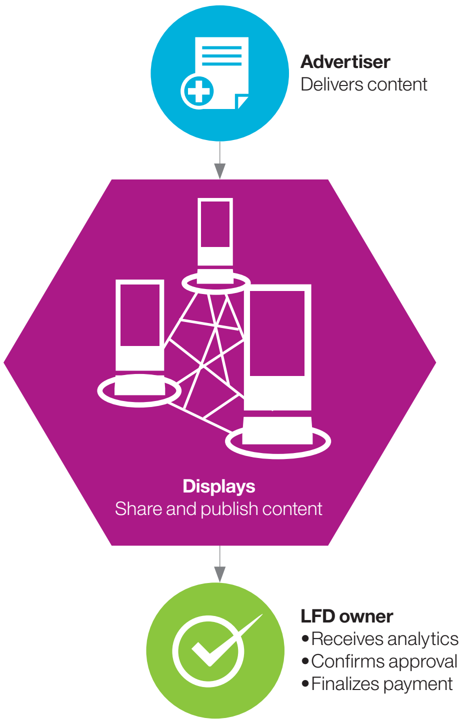


Figure 7

Large format displays participated autonomously in a decentralized advertising marketplace



From proof-of-concept to commercialization: A hybrid future

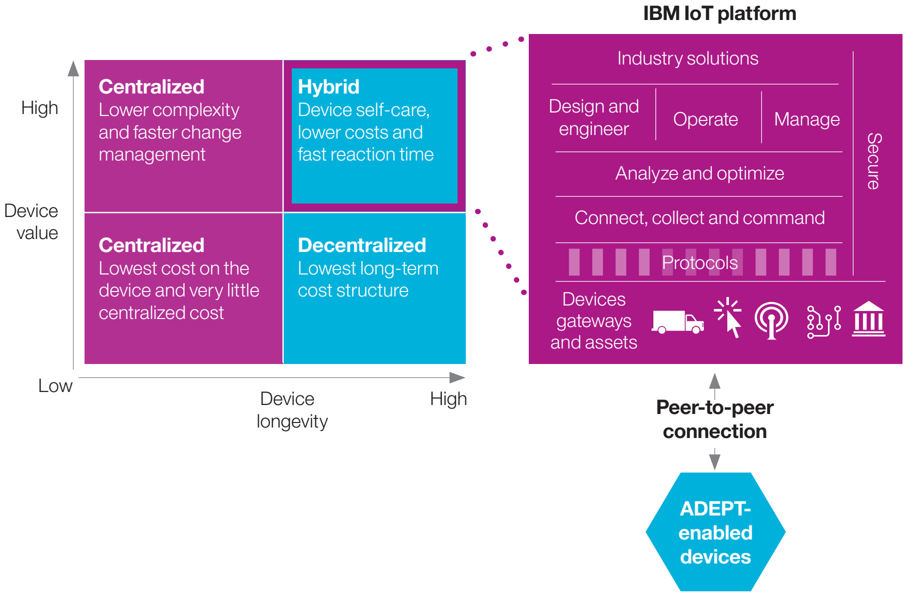
ADEPT shows great promise for tomorrow's IoT. As "Device democracy" notes, the humble work of transaction processing is the foundation of modern computing workload.[8] Thanks to major advances in both device technology and software, it is now possible to bring transaction processing, marketplaces and intelligence to virtually every device, anywhere.

Distributed systems like ADEPT can make businesses and consumers more efficient and open a huge range of economic opportunities. These technological changes could foretell the biggest revolution since the origin of general purpose computing and transaction processing systems.

Future commercial systems may exist as hybrid centralized-decentralized systems depending on the value, longevity and application of devices on the IoT. The feasibility of ADEPT paves the way for augmenting today's centralized IoT solutions with more decentralized capabilities (see Figure 8).

Figure 8

The feasibility of ADEPT paves the way for augmenting centralized IoT solutions with peer-to-peer approaches



The ADEPT PoC opens the door for the electronics industry to further explore the challenges and opportunities of potential hybrid models that can effectively augment today's centralized solutions.

Recommendations

Augment centralized with decentralized

As the IoT continues to grow, IoT practitioners must evaluate opportunities to augment existing IoT solutions with peer-to-peer models. Low-cost, high-longevity device applications are good candidates to begin the expansion to a more hybrid IoT. Industries where services are tightly controlled and economies that incur massive infrastructure costs from digitization are likely to benefit most from a hybrid model.

Collaborate for change

This report provides insights to IoT practitioners from a functional PoC of a decentralized IoT. But to develop commercially viable solutions, it is imperative that core technologies be made more robust to meet the challenges of a peer-to-peer network of hundreds of billions of devices. Actively engage with the IoT and blockchain communities to take critical steps to address these challenges.

Act now

Clearly, there are still significant scalability challenges associated with commercializing distributed systems, as well as security, coordination, intellectual property management, and identity and privacy issues. One strategy that does offer certainty, however, is not advisable: sitting on the sidelines and waiting for others to pioneer this technology. Choosing that seemingly safer option merely raises the likelihood that when today's risks have been resolved, it will be difficult to catch up with market leaders.

Are you preparing to benefit from the evolving IoT?

Companies across industries must grasp the scale of IoT transformation that will occur over the next decade and get ready for its impact. These questions can help to identify useful steps that practitioners and executives can take toward that goal:

- How will you forecast the infrastructure and maintenance costs necessary for your business to support and engage in the IoT?
- How can you evaluate the security of your IoT solutions today? How will they continue to protect the privacy of users, whether consumers or enterprises?
- What is your plan to help your IoT solutions survive the longevity of the devices they support?
- To what extent can your existing IoT benefit from a decentralized or hybrid model?
- What opportunities exist for your company to improve efficiency and collaborate across the IoT community to capitalize on hybrid IoT models ahead?

Related publication

Brody, Paul and Veena Pureswaran. "Device democracy: Saving the future of the Internet of Things." IBM Institute for Business Value. September 2014. www.ibm.biz/devicedemocracy

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Notes and sources

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