BlockQuick: Super-Light Client Protocol for Blockchain Validation on Constrained Devices

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Abstract

Today server authentication is largely handled through Public Key Infrastructure (PKI) in both the private and the public sector. PKI is established as the defacto standard for Internet communication through the world wide web, and its usage in HTTPS, SSL/TLS (Web PKI). However, in its application to Internet of Things (IoT) devices, using Web PKI infrastructure for server authentication has several shortcomings, including issues with validity periods, identity, revocation practice, and governance. Recently, different approaches to decentralized PKI (DPKI) using Blockchain technology have been proposed, but so far have lacked practicality in their application to devices commonly used in IoT deployments. The approaches are too resource intensive for IoT devices to handle and even the "light client" protocols have not been resource efficient enough to be practical. We present BlockQuick, a novel protocol for a super-light client, which features reading blockchain data securely from a remote client. BlockQuick requires less data for validation than existing approaches, like PoPoW or FlyClient, while also providing effective means to protect against eclipse and MITM attacks on the network. BlockQuick clients have low kilobyte RAM requirements, which are optimal for IoT devices and applications with embedded MCUs.

Introduction

Web PKI is the defacto standard for encrypted Internet communication. Today, most Internet traffic is being encrypted [mad18] using TLS, which relies on PKI for server authentication. This authentication uses X.509 certificates signed by third parties: the Certificate Authorities (CAs). Since Netscape [res01] brought SSL to the Internet with their first browser in 1995, the certification of servers has been in the hands of third parties. Since

1995, many improvements have been made to Web PKI, however, the following issues around governance, revocation, and handling of time in certificates persist [sch10] [hou16]:

Time. For the IoT, the current recommendations of the CA/Browser Forum to shorten certificate lifetimes [hou16b] are especially heavyweight. In contrast to personal computers, most IoT devices have more limited connectivity, power, and resources. In many use cases, in fact, the devices can be offline, e.g. in storage or on the shelf, for many years. When an IoT device connects for the first time to the Internet, it needs to establish two things: 1) The current time 2) Secure connectivity. This poses a chicken or egg problem: without the actual current time, the device can't validate Web PKI certificates in order to securely communicate, and without Web PKI certificate validation, it does not have a trusted source for time.

Previous solutions to this problem often trade-off security as a work-around. Such as:

- Falling back to read time from non-authenticated time sources [alr18] such as NTP [wic18], GPS [kar17]
- Accept insecure time from the same server that is offering the certificate to be validated [tsc15]
- Usage of a hard-coded factory build time timestamp when the real-time is not known

This problem is further amplified with ever shorter lived certificates. With shorter lived certificates, the certificates stored on the device, such as the root certificates or cached endpoint certificates, may well have all have expired. This issue is even more serious because many of today's resource-efficient IoT devices have very little non volatile storage - often less than the recommended minimum of Web PKI root certificates. Without a trustworthy understanding of time and potentially expired certificates, IoT devices are prone to man-in-the-middle attacks [sel15] and fake time servers [mal15].

Multiple Certificates. In addition to the issue of time, PKI has, by design, no method to detect duplicate identities. It is not possible for any peer of the system to know how many certificates represent the same identity. This enables attacks using alternative sets of certificates without the user, the victim, or the certificate authority knowing. [gre17]

Governance. There is a third issue stemming from the lack of governance structure of Web PKI. In Web PKI there are, at the time of writing, 3,625 valid intermediate certificates [cen19]. Each of these certificates can be used by their holders to create valid certificates for any domain. Unfortunately, misuse is [kim17] and has been common [ven14] [lav14].

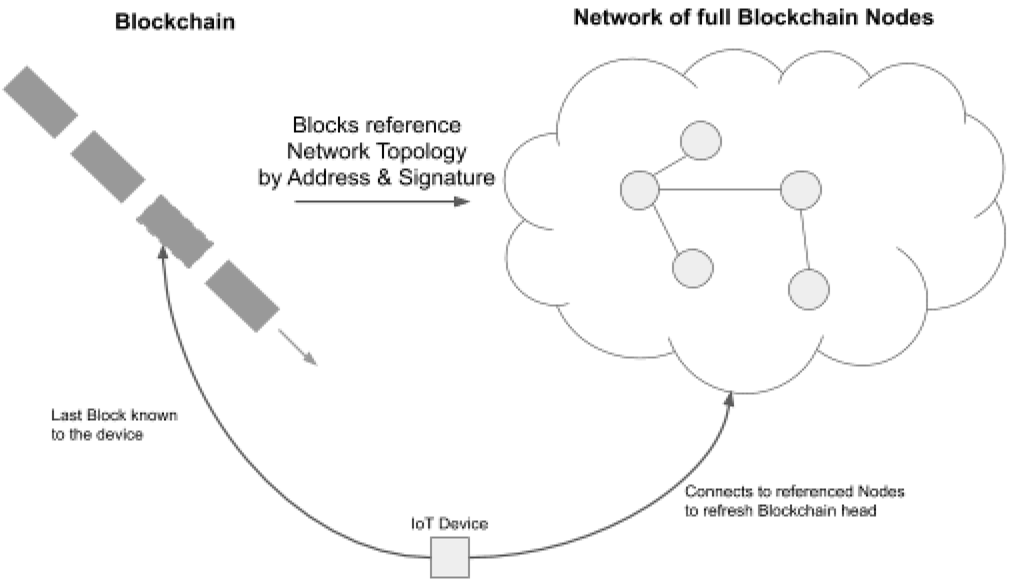
Revocation. Lastly, revocation is a necessary part of the certificate lifecycle and is defined in PKI via CRL and OCSP. Unfortunately, implementations vary especially on IoT devices. The features to enable the device to detect and respond to revocation are usually missing, and adoption from service providers to actually announce revoked certificates via these mechanisms is very low [liu15]. For many IoT use cases, Web PKI revocation is unfortunately non-functional.

DPKI. In response to these shortcomings, decentralized public key infrastructure based on blockchain technology has been proposed [but15] [sin17] [fro14] [pat18]. Deploying a public key infrastructure on a decentralized blockchain network has the benefits of alleviating all four PKI shortcomings: time, multiple certificates, governance, revocation. Though authors agree on these theoretical benefits, adoption of DPKI among IoT devices so far has been hindered by the absence of practical light client implementations [pac32] [mag18]. In this paper we want to introduce a new light client protocol that can be added to the Ethereum [but14] blockchain, allowing DPKI constructions to use Ethereum smart contracts without effectively locking out constrained devices.

Related light clients. In recent work, Bünz et.al. have proposed FlyClient [bun19], introducing a super-light client class of light clients for use in the Ethereum network. The super-light client needs to download only a logarithmic amount of block headers for validation, but requires the availability of at least one honest miner. In the context of IoT devices, this restriction seems unrealistic because many remote devices are easy targets for network manipulation such as eclipse attacks [hei15]. Individual devices can often be isolated when attackers intermediate cellular networks [sha15] [mey04] [rij15] or WiFi networks [van18] and run Man-In-The-Middle (MITM) attacks there [lee19]. Also, this is true for any mobile device that can be stolen and placed into a maliciously constructed network containing no honest miners at all. As such, a truly secure light client must have the ability to identify when no honest miner is available at all, e.g. when the clients' local network has been manipulated.

Contribution: BlockQuick

We introduce BlockQuick, a new super-light client protocol for Ethereum, and similar blockchains, that has sublinear - in fact near constant - bandwidth requirements for chain validation while being resistant to eclipse and MITM attacks. It enables a client to sync up to a relatively recent block (dependent on a chosen parameter $\mathbf{\Delta t}$) using a **consensus reputation table**. The amount of data that needs to be synced from blockchain nodes is independent of the block height (the total number of existing blocks), but depends on the historic majority change rate of miners within the consensus reputation table. We show that this means, for blockchains such as Bitcoin and Ethereum, only a fixed amount of data needs to be synced - Below 50kb for Ethereum and ~20kb for a further modified variant thereof.


Blockchain
Network of full Blockchain Nodes
Blocks reference Network Topology by Address & Signature
Last Block known to the device
IoT Device
Connects to referenced Nodes to refresh Blockchain head

Blockchain Additions:

The BlockQuick protocol can be added to existing blockchains as long as each mined block header contains the network peer information of the block miner (Internet address and public id) and a corresponding cryptographic signature of the header. In case of recoverable ECDSA signatures, as used in Bitcoin and Ethereum, the public key is already part of the signature and hence does not need to be an explicit part of the block header.

The additional required consensus rules for full nodes on the network are:

- Each block needs to have a cryptographic signature (and public key, if not included in the signature).
- Each block needs to contain an inklusion proof in form of a Merkle tree root of all previous block headers.
- Each miner should be reachable under the Internet address specified in the block.

BlockQuick Client Protocol

A client needs, at a minimum, a single last known blockchain block header hash. In an IoT use case, this might be a recent block header hash at the time of manufacturing. Additionally, the client needs either a list of seed nodes or a mechanism such as DNS to look seed nodes up. These seed nodes do not correspond to a list of trusted nodes - we will see how the protocol is able to trust data without needing to trust the nodes supplying the data.

Consensus Reputation Table. The consensus reputation table is not centrally provided to clients but is constructed on each client based on the last known block header. For example, in a Proof-of-Work (PoW) system the client can construct the consensus reputation table by reading 100 previous block headers from the last known state of the blockchain. All past block headers of the blockchain can be validated on the client using the parent block checksum alone. Thus, clients can even fetch these block headers from untrusted nodes as the data can be validated using the existing block header and its contained parent block hash. Once the client has those past block headers fetched and validated, it creates the Consensus Reputation Table from the information in the headers as follows:

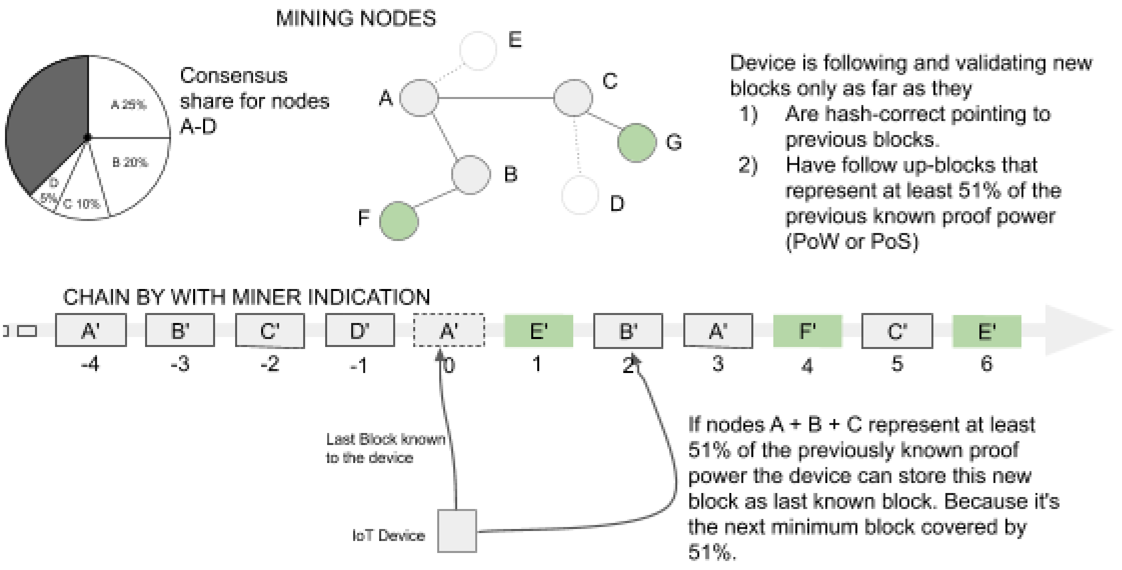
> The proposed light client protocol establishes a reputation system on the mining nodes in the network. The reputation of each mining node corresponds directly to the percentage of blocks that each mining node contributed compared to all mining nodes in a given time frame. The time frame is the consensus group's history length parameter **Δt**, with units in the number of blocks. In a PoW consensus, the percentage of mined blocks during the last **Δt** blocks corresponds to their proportional computational proof power among all participants. A miner who mined and signed 10% of the **Δt** recent blocks thereby shows to have 10% of the total computational power during that time frame, generalized for other consensus algorithms we call this their **consensus share**.
>
> As such, clients can cache a list of most reputable miners together with the most recent known good block for a quicker update mechanism. Each miner thereby is stored as a triplet of the peer's public key, its address, and its consensus share. The client needs to store at least N reputable miners so that the sum of their consensus share is >50% but should store more up to **Δt** miners, depending on local storage allowance.

Simple Connection Algorithm

If the client has an existing cached list of last miners, it tries to reach enough miners such that the sum of their consensus share is at least >50% in the Quick Update process:

Quick Update - For each miner M in the client's miner list:

(1) Client connects to the miner and fails if not found or not matching the stored public key.
(2) Client downloads most recent block headers from the miner.
(3) If the client successfully reached enough miners corresponding to >50% consensus share the client can stop.


MINING NODES
Consensus share for nodes A-D
A 25%
B 20%
C 10%
D 5%
E
A
C
G
B
D
F
CHAIN BY WITH MINER INDICATION
A'
B'
C'
D'
A'
E'
B'
A'
F'
C'
E'
-4
-3
-2
-1
0
1
2
3
4
5
6
Last Block known to the device
IoT Device

Device is following and validating new blocks only as far as they

1) Are hash-correct pointing to previous blocks.
2) Have follow up-blocks that represent at least 51% of the previous known proof power (PoW or PoS)

If nodes A + B + C represent at least 51% of the previously known proof power the device can store this new block as last known block. Because it's the next minimum block covered by 51%.

Slow Update - If less than 50% of the consensus share could be connected to the device assumes that a "long period of time" has passed and falls back to this slower update sub-routine:

(1) The client defines the current consensus group as the **Δt** last blocks from it's last known blocks. Based on this consensus group, the consensus share of each peer in that consensus group is calculated. E.g. if
Δt = 100 and miner A created 25 of the last 100 blocks his consensus share is 25%.
The data is either cached on the client or can be downloaded from any peer, validating the block-header data based on the existing block header hash on the client.

(2) Then the client downloads the most recent block headers from any peer

(3) The client further fetches incrementally the whole missing link of block-headers between last known block-header and the most recent header.

(4) For each block-header in the range, starting at the last known block-header, the client assigns a score based on the known consensus share of the block miner or zero if the block miner is not known.
For example, in the above picture, block 1 mined by miner E receives a score of 0, since its corresponding miner E is not part of the previous consensus group.

(5) The score value of each new block is then increased once per miner from the known consensus group having a block in the following block list. The logic is that when a miner B created and signed a block on this candidate branch of the blockchain, it meant the miner must have trusted this branch.
So when the client sees block 2 mined by miner B, it receives a positive score of 25% and the score of block 1 is also increased to 25% - because it has now been confirmed by a miner who represents 25% of the consensus group.

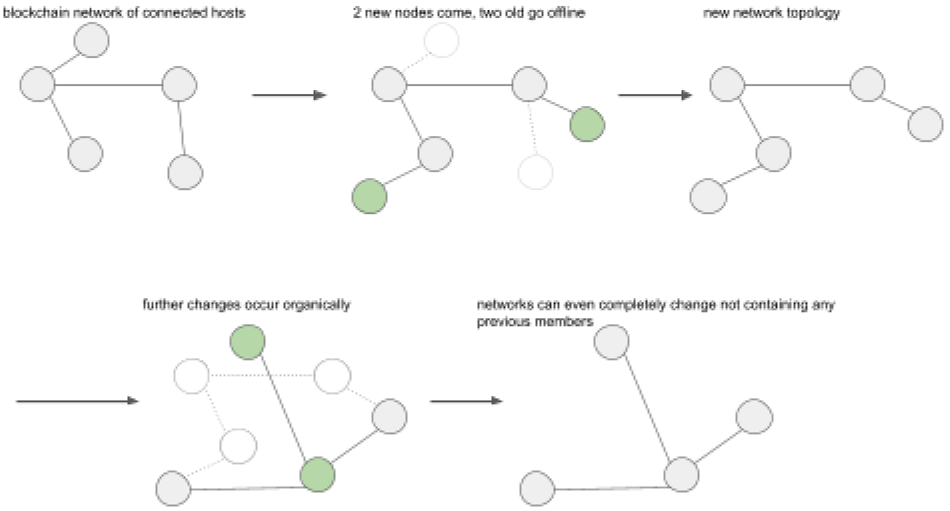
(6) If no block reaches the threshold score of >50%, the device will disconnect and assume manipulation.

(7) With each found block above the 50% threshold, the consensus group is updated to now include that block, allowing the consensus shares to adjust over time, mirroring the shift in the consensus group in the real world when miners shut down their operation or new miners start operation.

(8) Finally, when the >50% threshold has been established for some new blocks, but cannot be established for further blocks (e.g. because there are not enough further blocks), the client repeats the Quick Update process based on the new current consensus group. If the quick update process succeeds, the most recent block above the 50% threshold is now stored as the new most recently known block on the device.

During the execution of this algorithm, the client might encounter multiple different versions of the blockchain, potentially malicious forks and outdated versions. But unless an attacker manages to gain more than 50% of the consensus share by their private keys, the client will not accept a wrong chain. However, for outdated-but-valid blocks, it is important that the client always executes the Quick Update after a Slow Update in order to validate with multiple miners that this is still the most recent version of the blockchain.

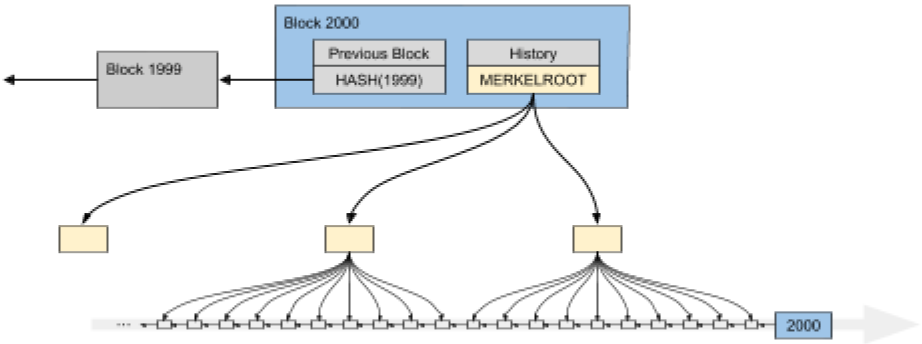
The present algorithm allows a device to follow the blockchain through gradual changes of the consensus group as long as the impact of the change within the $\mathbf{\Delta t}$ last blocks is below 50% of consensus share.


blockchain network of connected hosts
2 new nodes come, two old go offline
new network topology
further changes occur organically
networks can even completely change not containing any previous members

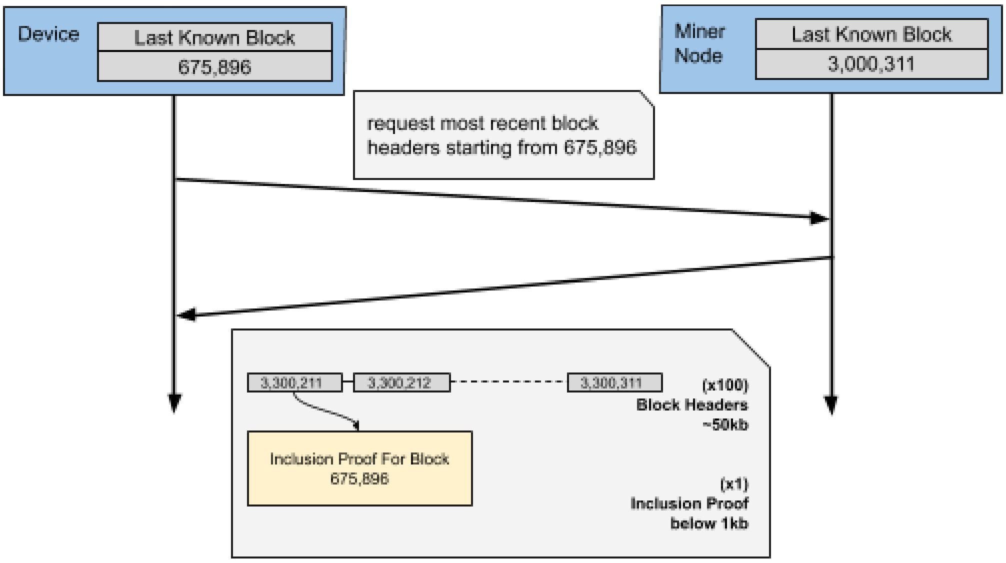
Sublinear Sync Size

The presented solution enables IoT devices to establish trust in a recent blockchain block, by operating on block headers and verifying the miner signatures. In existing blockchains, such as Ethereum and Bitcoin, an inclusion proof for previous blocks is given with the previous block hash of each block. Validating this inclusion proof though requires iterating all blocks linearly in this order. Given the current size of the Ethereum headers, especially for a device that has been offline for an extended period of time, the incremental check would take too much time and bandwidth to be realistic. E.g. given 3 years since the last known block, an average block header size of 500 bytes, and assuming one header every 15 seconds, a total of 6,307,200 blocks (~3gb) would need to be downloaded and checked by an IoT device. This is not feasible for the vast majority of IoT devices.

To address this, there are two necessary adjustments to Ethereum. First, merkelized inclusion proofs can be utilized as described by Crosby and Wallach [cro09] and Bünzel et.al. later [bun19]. With this addition in a new *historyRoot* field in each block, a client can validate the inclusion of any previous block based on the Merkle proof. The Merkle inclusion proof has only a logarithmic size. By using it, the device can skip all headers in between the devices last known block and the current most recent block.



Secondly, when a device connects to a miner, it not only requests the most recent block header, but it also provides its last known block header and **Δt**. This information allows the server/miner to determine whether there has been a "Majority Change" in the consensus group between the last known state on the client and current state of the blockchain. The server/miner can then calculate the minimum number of block headers that the device needs to synchronize.


Device
Last Known Block
675,896
Miner Node
Last Known Block
3,000,311
request most recent block headers starting from 675,896
3,300,211
3,300,212
3,300,311
(x100) Block Headers ~50kb
Inclusion Proof For Block 675,896
(x1) Inclusion Proof below 1kb

Using this approach, the number of blocks that needs to be fetched, even after a long period, is massively reduced. From any point in the blockchain known to the device, the server/miner node only needs to provide a Merkle proof to a recent block, plus the N following blocks required for the device to confirm these blocks based on its known, consensus group. So, in the example of bridging three years or 6,307,200 blocks, the device would fetch a Merkle inclusion proof of the logarithmic size of the total blockchain. We estimate an upper worst case using the [cro09] binary Merkle tree and 50 years, or 105 million blocks. The Merkle proof would thus require $\log_2(105{,}000{,}000)$ = ~26 nodes @ 32 byte each for SHA-256, totaling 832 bytes for the inclusion proof. Additionally, the most recent **Δt** block headers are required to build the new consensus group and to validate the approval of the current consensus group. At 500 bytes per header, and **Δt** = 100, those headers accumulate to 50kb, totaling the required data transfer at ~51kb.

Majority Change. Over the lifetime of a blockchain, the consensus group will have incremental changes. New miners come online and old miners stop their participation in the network. Over an extended period of time, this means that the consensus group that has been known to the device, and the consensus group of the current longest chain, might be significantly different. At some point, the difference might be so large that the last known consensus group won't be sufficient to confirm the recent blocks with >50% confidence because there are not enough known signatures present after a certain point in the chain. In this case, the device would not be able to accept the most recent **Δt** blocks directly as they can't be confirmed by its last known consensus group. In this case, the server needs to provide additional blocks around the time of the consensus group change in order to allow the client to reconstruct the gradual change of the consensus group. Effectively, this provides a first incremental sync to a new blockchain state that is still confirmable by the device's last known consensus group. If necessary, there can be an arbitrary amount of these incremental steps.

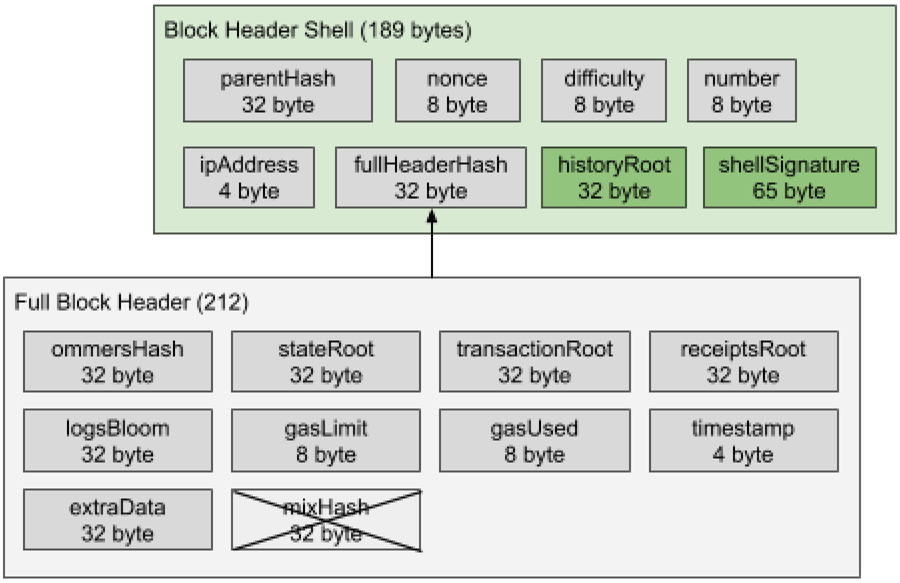
Given a blockchain state A known to the device, and a consensus group G_a at that point, then there can be a blockchain state B behind which >50% of the members of G_a, by consensus share, are not participating in the network anymore (not producing and signing blocks anymore). If such a blockchain state B exists, then the miner/server needs to provide the device the blockchain state immediately before B that was still signed by more than 50% of the devices known consensus group by consensus share. It is this amount of >50% consensus group changes that determine the total size of data required for the proof. For each majority change of the consensus group, there is at least one inclusion proof to that block, as well as **Δt** blocks around this change, necessary for the client to update its consensus group.

In a highly volatile blockchain, this could degrade to be linear to blockchain length, meaning that every **Δt** blocks a majority of the consensus group by consensus share has changed. However, when looking at all past blocks of Ethereum as a reference we can determine that while major changes in the consensus group were frequent within at the beginning of the blockchain, with growing adoption, the change of the consensus group has slowed down. During the last 5 million blocks there was no major consensus group change anymore, which means that a device would not need to sync any intermediate states.

Block Header Shelling

As discussed above, the total needed data transfer size using the BlockQuick algorithm linearlily depends on three factors: 1) block header size 2) consensus group history length **Δt** and 3) consensus change rate. While the consensus change rate is dependent on the economy of the blockchain and consensus protocol, the consensus group history length is defined by the client, based on security requirements.

The block header size is dependent on the chain implementation. In the case of current Ethereum [woo19], the header size is around 500 byte. However, Ethereum block-header size can be optimized by partitioning the full header into two parts: 1) An outer block header shell and 2) an inner full block header. The outer block header shell is reduced to only include the information required to validate using the BlockQuick algorithm: *parentHash*, *nonce*, *difficulty*, *number*, *ipAddress*, *historyRoot*, *shellSignature* as well as a 256 bit hash of the inner full block header (*fullHeaderHash*). The second partition - the full block header does not need to be transferred to the client during validation until the client is able to confirm a block. The client will need the full block header only from the most recent confirmed block to access *stateRoot*, transactionRoot, et cetera to perform further application-specific functions.



In the case of PoW, as pictured above, the relevant signature and difficulty are captured in the shell. This header partitioning applied on Ethereum would further cut the maximum required data by more than half. Using the same type of calculation as before, but now with block header size = 189, a consensus group history length **Δt** = 100, and no consensus majority change, we estimate 20kb of total sync size on average.

Summary

Empirical studies [lec11] have shown that misused private keys and stolen certificates are the most common risks in the PKI. We propose a new secure blockchain client that makes it feasible for all applications to implement DPKI solutions, replacing or complementing [bal17] Web PKI, while eliminating the risks introduced by third parties. By adopting the proposed approach, IoT devices are enabled to securely read blockchain information, including the current timestamp and registered DPKI information about domains, certificates, and ownership. Further using Ethereum Merkle proofs against the full block headers *stateRoot* allows the clients to validate each of these pieces of information against the last known good block.

We've shown a novel method to allow constrained devices typical to the IoT space to consume blockchain based data. This is the first building block to enable a more secure DPKI leveraging blockchain-based smart contracts. Devices are enabled to fetch block time and arbitrary state data from the Blockchain. In comparison to existing clients for the Ethereum network, we can demonstrate the magnitude of the impact:

Node Type	**Trust Model**	**Storage**	**Bandwidth**	**Duration**
geth --syncmode=full	Decentralized	~220GB[1]	>90GB[2]	days
geth --syncmode=fast	Decentralized	~130GB[3]	>90GB[2]	hours
geth --syncmode=light	Decentralized	~1.2GB[3]	~1.2GB[3]	minutes
BlockQuick	Decentralized	~20kb[3]	~20kb[3]	sub-second
Trad. Web PKI Client	Centralized	~20kb - 500kb[4]	~5kb[3]	sub-second

Although our solution is still larger than the typical handshake size of a traditional centralized Web PKI Client, it becomes feasible to execute on most hardware that is capable of Web PKI handshakes.

[1] Retrieved from https://etherscan.io/chartsync/chaindefault on May 10th 2019
[2] Estimated based on total block sizes https://etherscan.io/chart/blocksize on May 15th 2019
[3] As measured on May 10th 2019
[4] Range from minimal four AWS IoT certificates (20kb) and max all Mozilla NSS certificates (500kb) as of May 10th 2019
https://docs.aws.amazon.com/iot/latest/developerguide/managing-device-certs.html
https://www.mozilla.org/en-US/about/governance/policies/security-group/certs/

Potential Attacks

Chain Forks and Network Splits. In Ethereum, Bitcoin and other existing PoW networks, a fork chain can be created by a few malicious miners or even by a software bug. In the case of a fork chain, a blockchain client must still be able to connect to the blockchain, and to detect which of the forks is authoritative, and which of the forks should be ignored. From the perspective of a client device using the BlockQuick algorithm, the deciding factor is always the consensus share that each block can achieve.

It is for this reason that the threshold for accepting a block in BlockQuick is >50% of the known consensus share. This ensures that, from the device perspective during a network split, there is either no authoritative network or just one. For example, say there is a large network split e.g. due to atlantic network cables failing. In this case we have two new networks A and B. Each active miner and client sees either network A or network B, depending on their geographic location. Given a consensus reputation table from just before the fork we know that the consensus share S of the sum of all miners from A and all miners from B must have been 100%:

$$\sum_{m \in A} S_m + \sum_{m \in B} S_m = 1$$

From there it follows that there can be no split between A and B such that both sides share is bigger than 50%. We can differentiate three cases:

$$\alpha : \sum_{m \in A} S_m > 0.5 \rightarrow \sum_{m \in B} S_m < 0.5$$

Network A is authoritative with more 50% consensus share, clients will accept its blocks. Network B is a fork, and no block from B will be accepted by a client.

$$\beta : \sum_{m \in A} S_m < 0.5 \rightarrow \sum_{m \in B} S_m > 0.5$$

Network B is authoritative with more 50% consensus share, clients will accept its blocks. Network A is a fork, and no block from B will be accepted by a client.

$$\gamma : \sum_{m \in A} S_m = 0.5 \rightarrow \sum_{m \in B} S_m = 0.5$$

Neither network A nor network B can reach more than 50% consensus share and thus no network is authoritative.

While case γ is unlikely (exactly 50% of the miners would need to be both sides of a split), the scenario of exactly 50% consensus share on both sides can be made at mathematically impossible by choosing an odd number for $\mathbf{\Delta t}$. E.g. choosing $\mathbf{\Delta t} = 101$ would not allow a

50%/50% split (A=51 vs B=50 or vice versa in the worst case), making only one network the authoritative survivor.

Eclipse Attacks. Eclipse attacks as discussed by Heilman et.al. [hei15] were directed at node-to-node communication within full-nodes of the Bitcoin peer to peer network. For remote clients as found in super-light client use cases, network uplinks are typically even more scarce. A mobile IoT device will usually have a single uplink to the Internet, such as a cellular network or via WiFi networks in its vicinity. In these cases, eclipsing all connections that the device has to the outside world becomes much easier. Lee et.al [lee19] showed how, in a WiFi network, a device can be spoofed using crafted ARP packets, therebye routing all data traffic through the attacker. This way of monopolizing all network connections to the device allows for advanced manipulation, such as presenting the device with multiple different non-authoritative blockchain variants. PoW light clients, such as Ethereum geth that validate based on longest chain / highest difficulty, are prone to these attacks because they can only successfully choose "the best" chain given a set of alternatives. But, when all presented alternative chain versions are non-authoritative, the client will still accept one of them. The same is true for FlyClient as proposed by Bünz et.al. [bun19] - here a heuristic comparison of presented alternative chains is done. In the result, the FlyClient can decide which of these alternatives is most likely the correct chain. These clients can successfully solve the decision problem on which of presented alternatives is most likely the authoritative chain, but they fail to identify an abort criteria, when none of the presented chain versions are authoritative.

BlockQuick addresses Eclipse Attacks, and specifically the extreme case when a single actor monopolizes all connections, using the 50% consensus threshold. Let's assume an attacker constructs a forked blockchain with 10 blocks of wrong data entries. The authoritative version of the PoW chain would, in this case, grow quickly longer than this forked wrong chain. However, devices without a direct connection to the authoritative longer PoW chain would not be able to see the difference. In BlockQuick however, the PoW difficulty and length are not the primary deciding factors. Instead devices will iterate the blocks, in this case the 10 new blocks that the device is not aware of, and run the Slow Update mechanism. In each new block the device validates the cryptographic signature of the miner and compares these with the known miner identities in its **consensus reputation table**. Only if a block receives a consensus score of >50% is it accepted by the client. Receiving a chain with a lower total score results in an abort. Since all 10 new blocks from the example have been crafted and signed by the attacker, they, on their own, would not receive any reputation score and therefore would not cross the >50% threshold required for the client to accept these new blocks. Furthermore, since this is a forked chain, there are no other miners who would contribute on-top of this fork. Thus there are also no other later signatures that would increase the reputation score. Without additional signatures from existing reputable miners in the blockchain, it does not matter how much longer the attackers fork chain becomes (10s, 100s or 1000s of blocks), their reputation score will stay 0% and the BlockQuick client won't accept them. As a result, the attacked client device would reject the offered blockchain as non-authoritative and close the connection.

Discussion

Blockchain Time Source. As Adam Langley pointed out [lan14], today, secure time mechanisms have a circular dependendency between knowing the time and having the ability to interpret secure certificate validity dates. With BlockQuick there is now - for the first time we believe - a protocol to break this circular dependency. In our approach, the trust anchor that is stored on a computing device is a cryptographic hash of the last known good block header (SHA-3-256 / KECCAK-256 in current Ethereum). The benefit of using a cryptographic hash instead of a public/private key pair is that there is no individual entity that can be attacked to gain access to a private key part, and no third party that could go rogue with a private key.

BlockQuick can only be used for a rough understanding of time, however. Its precision is enough to validate certificates, but not precise enough for many other tasks. Ethereum, for instance, has a 15 second block interval - this is the minimum latency for our calculation. Clients can never confirm up to the most recent block - In the worst case, $\frac{\Delta t}{2}$ blocks are required past the next confirmed block, which in the case of $\mathbf{\Delta t}$ = 100 would lead to a mean latency of (15*100/2) = 750 seconds. For clients which need higher accuracy, it still solves the initial circular dependency on checking certificate validities. With this rough understanding of time, clients can now connect to a time server using standard PKI validation to improve the accuracy and trust-level of the retrieved time. Authoritatively accurate time servers could in fact be registered in blockchain data directly, using certificate pinning as discussed below.

Certificate Pinning. We have presented the foundation for constrained devices to securely read recent blockchain data. We propose to solve aforementioned PKI issues by complementing Web PKI with pinning certificates in a distributed blockchain, such as Ethereum. Pinning a certificate is a means of storing a certificate hash which then can be used to validate the concrete identity of a certificate. This combination solves the aforementioned problems of PKI: Time, Revocation, and Multiple Identities as the blockchain storage becomes the authoritative registry for the currently valid certificate for any entity. For Governance there are alternatives in development such as ENS [joh19] but the description of a complete solution in the form of a smart-contract structure is an ongoing research area.

Too-fast consensus share changes. The BlockQuick algorithm detects wrong blockchain branches based on the consensus group score. When the score does not grow above the threshold of 50%, the algorithm discards the branch. This puts a limit on the maximum change rate of a consensus group. If any block exists immediately after which the majority of the consensus group has changed (e.g. 51% of all miners suddenly stop mining), the BlockQuick algorithm would not consider the chain authentic. Should there be a catastrophic event leading to such a sudden loss of the majority, the blockchain would effectively stop for the client. This is a new theoretical limitation directly resulting from the design. Our testing on Ethereum history though showed that neither chain ever had such an event so far. It is future work to closely investigate the likelihood of such an event.

Selection of Δt. Increasing the size of Δt also increases linearly how much data has to be fetched for validation. A larger size of Δt reduces consensus group fluctuations stored on the devices, but also keeps consensus shares of nodes up that have not produced blocks in a long time. Higher fluctuation can lead, in the worst case, to a consensus share change that is at too fast a rate for the devices to follow. Implementations thus may choose different Δt values as appropriate. Additionally, the blockchain consensus may be extended to enforce changes rates of less than 50% within a given Δt timeframe. This might also render small Δt values practical. It is future work to investigate this further.

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