TODA Protocol - A Ledgerless Blockchain

A new approach for distributed and fully decentralized value exchange protocol

Intro:

Most internet users have smartphones and can't afford mining machines. There is currently a need for a single class, secure strong governance *(decentralized)* value exchange that uses maximum distributed computing so it is efficient AND scales to millions of transactions per second when powered/powering billions of devices *(single class of machines)* while maximizing security and minimizing transaction fees *(to almost zero)*. The TODA protocol is geared to meet those needs, is fully distributed (BFT, *efficient yet redundancy x32)*, has a governance model which becomes more and more decentralized as it grows, and is optimized for mobile devices without computer desktops or server or the need for any centrally controlled system. It can also scale existing blockchains if they use its rails and nodes can optionally run on combination of mobile devices and nano-micro cloud instances, one representing each mobile device. *// this step might be necessary in early releases to increase social scalability, so it's highly recommended that implementation details take that into effect. See PoAW for details of how "more than necessary" cloud power does not make any difference, we call that CMR (Centralized Mining Resistant)*

Design overview:

In a fully distributed and decentralized system, Machines will need a map to efficiently navigate the network and locate objects. A virtual binary tree, we call it the Todatree, specifically a fully saturated BStree structure is a virtual structure that contains a reference to every object in the entire system that exist, will exist and objects that move from one place in the tree to another, they move using unique IDs from the tree as their identifiers and occupy points in the tree that are also unique to them and are empty when they aren't occupied by them. Given it is fully distributed, the reference is actually from the device pointing to the device and all the potential Machines that it could potentially interact with. We use it because it is extremely fast to compute at each Machines' level to locate a certain leafs' parent in a certain branch etc. and it is simplified to any computer scientist to comprehend it and imagine its navigation and the possibilities of things that can be done deterministically. *// This map/abstraction is needed because we envision at least 7 different cs disciplines to work with TODA protocol, so it's important that we not only make it easy for machines, but as easy as we could to the subject matter experts. At any point some deployments may succeed without this specific abstraction while still preserving the overall protocol instructions using DAGs, DHT CHORD or other.*

The smallest Unit is at the leaf's level we call it TODAQ or Quark. However the smallest unit that can not be divided by users but it can be transferred in its wholly by users we refer to its structure as atomic and we call it TodaNote or Toda File because it is actually a file when viewed by Machine's OS. It has an atomic structure, it has a unique number through its life and the quarks are necessary to actually form it within that tree structure, each quark has a unique number and can contribute along with a total of 2^32 Quarks to form one single

unique TodaNote and can not form another TodaNote. Quark numbers are like DNA they belong to the TodaNote and can not belong to 2 TodaNotes.

// This abstraction is similar to atoms made out of quarks and other sub-atomic elements, but you can not send half an atom on its own unless you are working on a nuclear reaction. So one set of 2^32 quarks can form one specific TodaNote with one unique number and not any other TodaNote

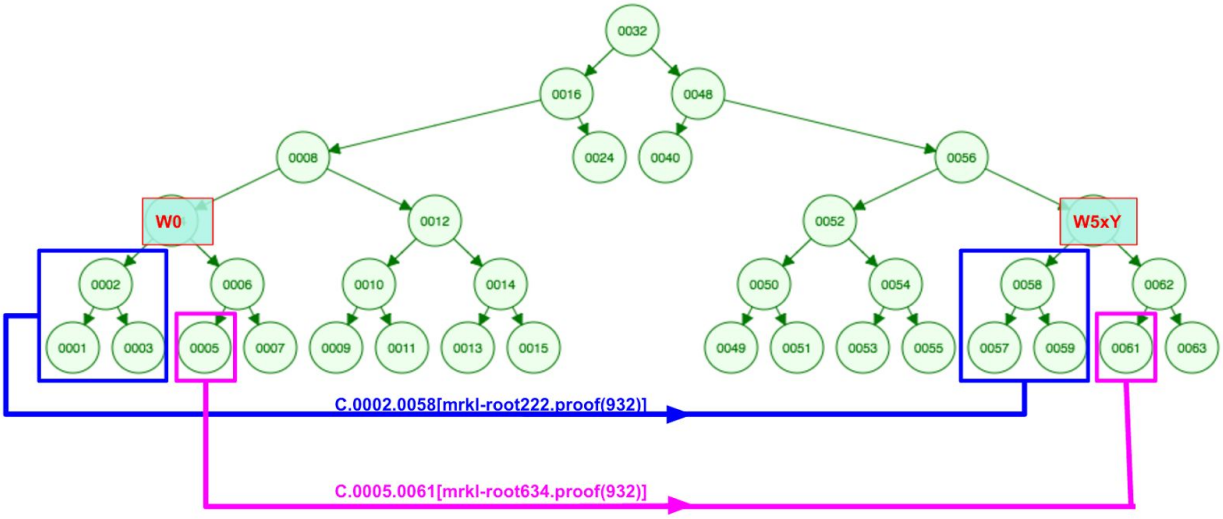
One application of TODA protocol, a value to be exchanged similar to a currency, and the provenance of each unit/TodaNote is from a sub-branch at level 96 the Provenance Virtual Branch *(technically 2^63 TodaNotes is the maximum limit to be initiated into the system hint: TodaNotes are at level 32)* - A TodaNote can travel within the Todatree when cryptographically signed by owner to another, and have a new location every block only when transacted. Every movement builds a chain of Machines/Wallets edited inside the TodaNote file *(also at level 96 in todatree, some implementation details may suggest level 64 which aren't concerned with the quarks, in those systems they either don't care about the ongoing supply/creation of TodaNotes or have them in a probabilistic function that results to similar outcome).*

- **Atomic TodaNotes:** *// transaction fees and creation of new TodaNotes -*
    - Each unit/TodaNote contains its own history as a Machine chain of past transactions. If UserA sends UserB TodaNote C115, from the user's perspective, the TodaNote would look like this: C115_W(UserA).BlockNumber1111.MerkleProof1111.7854_to_W(UserB).BlockNumber88888.MerkleProof88888.569 *// To the machine, each TodaNote can only occupy certain location in the Machine which is a branch and therefore has a unique number derived from TodaTree in the entire system.*
    - TodaNote is the smallest unit that can be transacted by users *// In early implementations we are recommending the minimum suggested TodaNotes to be transacted to be 17, this increases the cost of malicious attacks and reduces the success rate significantly that way TodaNotes include the merkle proof of theirs and that of 16 others, using denominations almost any transaction can be expressed with up to 23 TodaNotes.*
    - TODAQ or Quark is the smallest unit non-divisible, it is mainly used for 0.04% of new quarks that are newly created / issued from provenance branch of TodaTree every transaction that can be sent to the transaction Machine of users who win the PoAW. 2^32 quarks = one TodaNote.
    - The Quarks are actually the leafs of the branch TodaNote in todatree*
    - Implementation recommendation would be using a hashcash like of next block's merkleroot concat of existing transaction hash to charge 1 entire TodaNote only 0.03% of the times which effectively be the same results but don't have to deal with splitting off the TodaNote at the user level. The Toda Protocol CORE Implementation uses this method. *// This method is not the most cashflow efficient as payer and payee must put 1 TodaNote per ~3333 TodaNote transacted. Also, because it is 0.04% of new*

TodaNotes are created per TodaNote movement, a single TodaNote will have to change ownership 2500 times so its impact aggregate is creating 1 new TodaNote

- **Map/Todatree**
    - Like a BST of height 256 *(Suggested tree model is based on fully saturated and balanced BST)*. The leftmost branch of level 160 can be viewed as a tree itself, and transactions within it can be processed more efficiently rather than the full tree, but we keep 256 by design for ease of future expansion, so each implementation can take on a branch of level 160, *// technically speaking you can have 2^96 branches at level 160 and therefore many implementations can benefit from interoperability*

Todatree simplified 256 to 5



This tree is used as a map so Machines know how to navigate the system and where to expect objects to be. *// Think of IPV6 but fully decentralized. This tree has more reference points than the estimated number of atoms in the universe* We call this tree the Todatree. We refer to level 96 as t96 and it is the level that represents the Machines *// some previous implementations suggested Machines are at 64 without TodaQuarks*

- T96 level is where all Machines are at.
- A higher level at T160 can be an implementation all on its own. It is wize for implementations to choose a unique T160. *// There are 2^96 160 to choose from*
- The ones on the far left are for Machines with TodaNote provenance but the ones on the far right of t96 are for Machines assignments like Wallets/Users/Smartphone.
- The very first 160 Machines on the left of Todatree level 96, have the denominations and are setup in a way where TodaNotes provenance of all the TodaNotes *// other branches can have units for smart contracts or whatnot*
    - Quarks are at the todatree leafs level t0 of that Machine, However not all quarks have same value, they all depend on the provenance Branch of TodaTree, each implementation

can have different branches for different denominations and different values. Initially we recommend denominations to be represented in left or right Machines such as W100 is where the TodaNotes, 20 to the left would 0.01TODA 20 to the right would be 100TODAs, 30 would 1000TODAs Denomination makes it easier to send small or large amounts, can be computed in a combination that will always be minimum 17 TodaNotes during one transaction. The average amount of files per transaction will depend on the economy using it, but will likely be between 20 and 30.

- TodaNotes have a unique number for the life of them. Their number is that of the branch they come from, and their movements are branches they occupy belonging to other Machines, hence Machine chain is within each and every TodaNote is calculated at the system level as it is better from usability perspective to show Machine *(wallet chain / user chain)* chain than point occupied chain, especially if your Machine remembers other Machines and can give them names. Kinda like phone numbers, you remember the name of someone but they could have several phone numbers.
- Every block, the entire provenance range of W200 branches move to the right of the first Machine range of 200 by 200 every block. The reason for that is so when looking at any TodaNote number you can tell its provenance block by conducting a quick binary computation, so the provenance W of a TodaNote is linearly related to the block# so the calculation would be: Provenance Machine = (W(2^95 + (block# * (2^96))) - *// This is important to prevent unauthorized TodaNote creation/activation*
- **Merkle Tree** // see appendix
    - Generated every T seconds *// T can be 30 seconds initially but it is adjusted dynamically every X blocks, intent is to have majority of transactions requesting change of TodaNote ownership make it in the block they request, so average time for capability to re-spend is less than 2T*
    - The merkle root (root hash) is generated by every active validating Machine in the network shared across the network *// You only need 1/32 or about 3% of the network to be active for merkle tree to be built every block if there are no transactions and you would need over 50% if there are transactions.*
    - Every TodaNote is coupled with another TodaNote to potentially form L1 (*L1 for Level one)* of new merkle tree *// Merkle tree and Todatree are not the same, merkle tree gets created every block based on the provenance branch, basically the provenance branch, gets replicated every block with only up to the TodaNotes issued while those in branch not issued will always have static value until issued*
    - utilizing the previous Merkle root in a function to pseudorandomly select the Machines/managers of those TodaNotes (Group A) along with the merkle root prior (Group B). Each merkle root when inserted in the pseudorandom function can assign 32 managers. Hence a total of 64 managers (groupA + groupB) **can** work on building the merkle proof. *//"can" but don't have to*
    - Coupling of TodaNotes is deterministic from Toda Tree reference pointers. If TodaNote unique number X is even then it couples with X+1 otherwise X-1

    - The pseudorandom function using the TodaNote number can give the Managers Toda Note addresses
    - If a manager from Group A does not have merkle proof in subsequent block when it moves to Group B, then manager can not win the 0.1% even if manager generates the merkle proof then. Therefore Managers have an incentive to have before in anticipation of building it again with new values when TodaNote is being transacted *// If for example Managers of TodaNote22 build the merkle proof in block 333 but then in block 334 TodaNote22 isn't transacted, they have no incentive and won't likely build it*
    - Basically every Machine when acting as manager is able to run the pseudorandom function that provides the coupling for each and everyone of its TodaNotes that it is managing during any specific block.
    - Dormant or disconnected Machines, when they rejoin the network using gossip like protocol can get the update of last list of merkle roots
    - Every Machine when delivering the merkle proof can not win the 0.1% if it doesn't have the previous one *(therefore was online)* and if it didn't pass the entire data it received to Group B. This creates an ongoing incentive for Machines to receive and deliver on all the TodaNotes despite the value. This is important, without this, Machines are only incentivized to handle high denominations, and high value.
    - Every Machine is expected to have all Merkle roots in the system along with last TodaNote assigned and last Machine assigned during each Merkle root *// that's basically the only universally shared data if a Machine doesn't have this data, it will have hard time validating instantaneously receipt of transactions as it would be able to compare merkleproofs against historic merkleroots*
- **Beacon**
    - The Merkle root of last block is used as a beacon in existing block to generate pseudo-randomness that is deterministic and universal.
        - For example, the Merkle root is used in a function to tell each Machine which TodaNotes to manage during the existing block
        - To make the deployment secure consider each Machine to manage on average 32x the average amount of TodaNotes owned by Machines, this is constant # as each block the amount of Machines and and TodaNotes range activated are shared with everyone.
    - TodaNote does not change ownership on its own, there's a minimum of 17 TodaNotes transferring together
- **Wallet/Machine/Manager/Miner/Node** *// In Toda they can be synonymous*
    - While Machines have unique numbers in the Todatree, at the t96 level they can also be part of a branch at a higher level than t96
    - The Machine owning the TodaNote is the only one able to crypto-sign it to change its ownership

- **TodaNotes**
    - Each TodaNote has a unique number at t0 level in Todatree that is atomic, so it is not divisible *// some implementation may suggest level 32*
    - Each TodaNote is a file, as TodaNote changes ownership, it keeps a stamp of the location it occupied in its own file, so anyone can compute the Machine chain it was owned by *// To keep the file small, we would only need the history of the first 3 Machines and last 9 along with the Merkle proof*
- **Decentralized and Distributed Consensus Mechanism**
    - For every TodaNote, at least 1 of 32 managers must testify its transfer for it to be transacted and those managers must be the ones selected by the pseudorandom function so everyone knows *(can compute)* who they should be during a certain block *// The selection is 32 if many provide different data, as long as 17 are providing the same, the Note gets accepted by receiver and transfer is complete. Given that transaction must be a minimum of 17 TodaNote, receiver can be satisfied with less than 17 per TodaNotes because information of transaction is propagated in the other Files.*
    - Testifying includes the check for authenticity of ownership proofs & signatures
    - PoAW (Proof of Actual Work) is basically racing with that TodaNote up the Merkle tree in that block and obtaining the merkle proof and delivering to payee.
    - The first to deliver to the new TodaNote owner the merkle proof gets the 0.1% reward in a probabilistic way *// Some implementations may choose pseudorandom function of next mrklroot to determine the receiver of 0.1% rather than the first. Approximately every 1000 files you testify during exchange and deliver the merkleproof first, you get one file/TodaNote*
- **Economical Incentive and DDOS prevention / PoAW (Proof of Actual Work)** *(Proof of Actual Work is the distributed computing needed to run the system with replication of 32x)*
    - The first validator Machine / manager for every TodaNote to get the correct Merkle root will collect the transaction fee of 0.1% *// Getting the merkle root involves building the branch of the Merkle Tree in a distributed way, starting with coupling with other Machines at L1 all the way to L(root) .. Please Note: Some implementation may choose to give not to "first" but based on a pseudorandom function of next block's hash / mrklroot. Each implementation has its pros/cons.*
    - Tx fees are split between payer, payee and new issuance via quarks of hashcash like to probabilistically transfer one coin every ~3333 times for paying and ~2500 for issuance. That's because initially we are suggesting payer 0.03%, payee 0.03% and new issuance of TodaNotes 0.04%. Those numbers seem to make economical sense for microtransactions.*// Effectively the cost of tx is approximately the aggregate cost of network, electricity and depreciation, implementation can set it to adjust automatically by bidding the lowest fees, if your bid is too high or your network or machine too slow you'll less likely receive the 0.1%. Basically the system runs itself*

and pays for itself. However, certain implementations may wish to have different fix percentages. Higher or lower may increase certain risks of successful attack vectors.

    - While newly issued Tx Notes are in quarks, the additional fees paid by payer and payee are easier if sent in a probabilistic formula where every ~3333 times an entire TodaNote of same denomination is sent from payer to validator and from payee to validator

- **Transaction stamp / Double Spending** *// also see distributed mrkl tree*
    - Payer and payee must cryptographically sign in-order for Notes to be transacted (yes receiver pays its network in Toda)
    - Up to 32 from the pseudorandomly selected Machines/Machines by a function of the last Merkleroot so it's deterministic and everyone knows who they should be for any active TodaNote for the duration of a certain block. If a TodaNote is transacted, they will all be replaced by a new set of 32
    - The first of the 32 selected Machines that comes back with the correct merkle proof (including new merkle root) will get the 0.1% transaction fee *// PoAW*
    - TODAQ or Quarks, are managed in a value as an extension to the TodaNote parent. Given that users can not send Quarks on their own but as part of transaction fee they can only receive Quarks.
    - Although TodaNote authenticity can be checked up instantaneously, in-order for TodaNote receiver to ensure every TodaNote received was not double spent, it must wait for the block to conclude and stamp transaction with Merkle root and retain Merkle proof for use in subsequent transaction. At the end of the block, the TodaNote transacted will have new managers that are pseudo-randomly chosen by a function of the merkle root, those new managers must certify ownership to only one owner and therefore new owner can easily check to see if TodaNotes are assigned to them and no one else.

Please Note: This summary was written by co-author Toufi Saliba and reviewed by co-author Dann Toliver of Toda Protocol that will also be credited to over 30 crypto contributors and reviewers including 3 Turing Award Winner and Globally renowned crypto folks, throughout its evolutionary iterations. Full list of credits will be made available. Although some components are either patented or in patent process, the Toda Protocol is open to re-use under CC BY-SA 4.0 // At the time this protocol is being written, an entire industry of Miners is emerging and will continue to fight every crypto that doesn't require mining. Toda can enable any existing blockchain to scale, miners can provide value as in routers, accelerators etc. Also Financial services to provide "true services" Toda will only encourage those implementations as long as users don't depend on them and can run without them. Basically governance must always be with users. Ask authors about some development in Biometrics and Proof Of Walk, if interested in helping out there as well.