Security Analysis of the Lightning Network

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State of the Hash-Lock

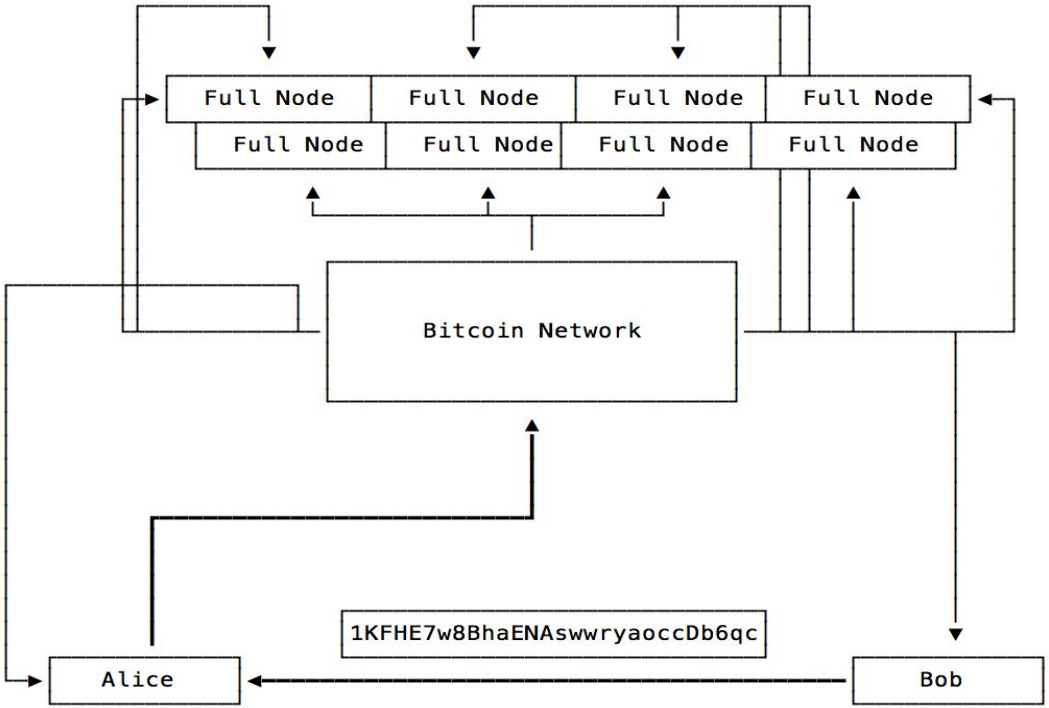
- In-progress Lightning Network specifications (lighting-rfc)
  - Basis of Lightning Technology (BOLT)
  - Specs cover: funding process, key derivation, p2p interaction, messages, etc.
- **4+** implementations being **actively developed** on Bitcoin's Testnet, e.g:
  - lightningd (c-lightning)
  - lit
  - eclair
  - lnd
- Testnet Lightning Faucet
  - Opens a **channel** instead of sending **on-chain**
  - Easy way for application developers to:
    - Get **testnet** coins
    - Starting **experimenting** with **Lightning**
- More thinking around **cross-chain** Lightning Networks

Outline

1. Lightning in 2 Slides
2. On-Chain Liveliness Assumptions
3. Peer-to-Peer Networking Layer
4. Onion Encoded Payment Routes (Sphinx)
5. Hash-Lock Decorrelation
6. Blinded Channel Outsourcing

Lighting in 2-Slides (½)

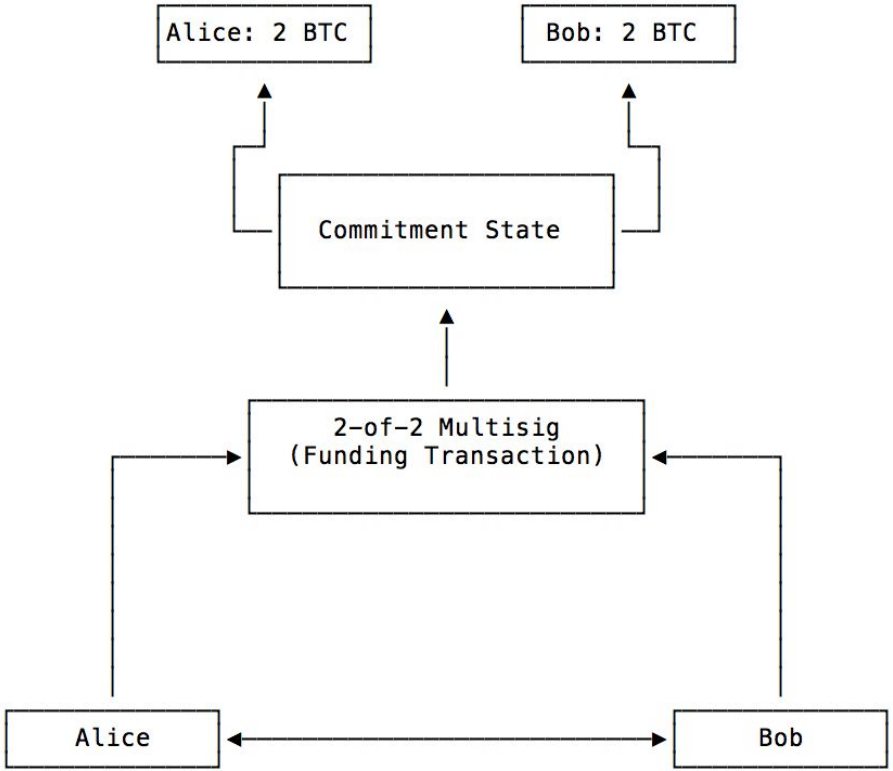
- “Vanilla” Bitcoin workflow:
- Alice ➡ Bob
  - Bob gives Alice **Bitcoin Address**
  - Alice **broadcasts** tx to network
  - **Entire** network **verifies payment**
  - Payment **confirmed** in block
  - Bob gets **coinz**
- Issues:
  - **Each** payment requires resources for **each** full-node
  - Confirmation times **unpredictable**
  - Global broadcast **doesn’t scale.**



Lighting in 2-Slides (2/2)

- Enter Lightning: **Off-Chain** Bitcoin payments

- Alice and Bob enter into a **contract**
- Contract creation:
  - Funds put into 2-of-2 multi-sig
  - **Before broadcast** transaction to *deliver* funds is signed
    - Requires malleability fix
  - Funding transaction broadcast
- Off-chain payments (sub-contract):
  - **HTLC**: Hash-Time-Lock-Contract
- Contract completion:
  - Closing transaction broadcast, final balance delivered
- On-chain footprint:
  - **2** transactions
  - All updates **point-to-point**
  - **Predictable** fees

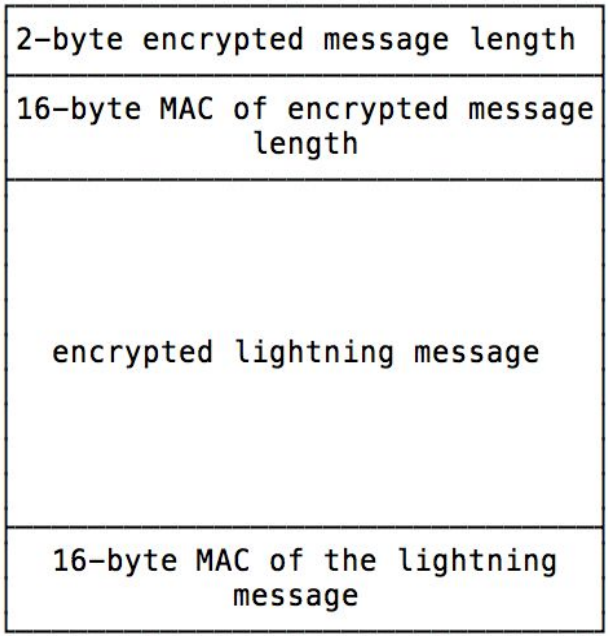


On-Chain Liveliness

- Security model of Lightning:
  - Relies on Bitcoin for **ordering of transactions**
  - Dependent on **time-based** windows of action (`T`)
    - Longer `T` (CSV delay) provides more security during **channel breaches**
    - Longer `T` also results in unavailability of funds for **unilateral closes**
    - In the optimistic case: higher `T`, as closures assumed to be **cooperative**
- Thundering herd failure mode
  - Massive **network-wide channel closure** clogs up chain
  - Depending on `T` (unique to each channel), and duration of backlog, adversaries may profit
- Possible solutions:
  - Time-stop
    - “Relative time-lock” stops ticking above “higher-water” mark
  - Consensus enforced transaction **dependency**
    - Covenant or op-code
  - Fee-based dependency: CPFP

Peer-to-Peer Networking Layer

- **All** communications between nodes **encrypted+authenticated:**
  - No protocol messages sent until **brontide** session initiated
- Brontide (BOLT #8):
  - Variant of the **Noise Protocol Framework** (brontide):
    - Framework for **Authenticated Key Agreement**
    - Init: series of **handshake** messages (ECDH+hashing)
    - Transport: **AEAD** cipher mode used for encryption
  - `Noise_XK_secp256k1_ChaChaPoly_SHA256`
    `<- s`
    `…`
    `-> e, es`
    `<- e, ee`
    `-> s, se`
  - Hash rachet for **key rotation**



Peer-to-Peer Networking Layer

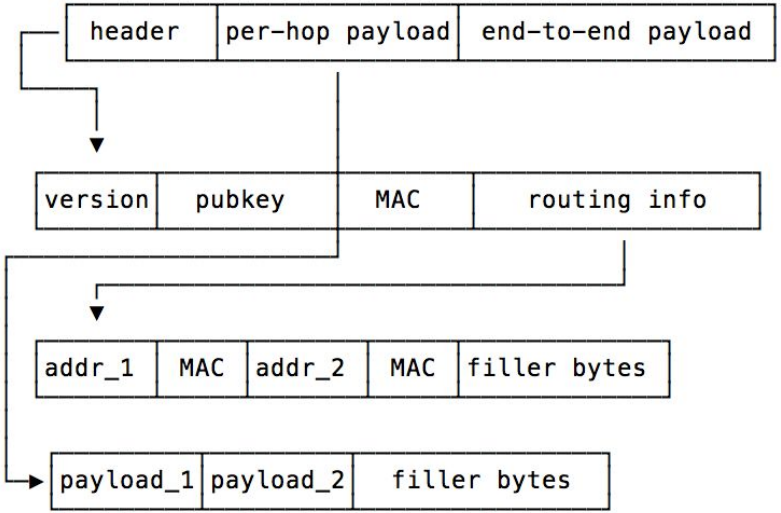
- Nodes identified on the network by **public key**
- **Bitcoin keys** and **node keys** used to authenticate information
  - Node Announcement:
    - Announces node existence: PubKey+sig, reachability
    - **Global features**
  - Channel Announcement (channel proof):
    - Channel ID: **location** of funding output in chain (8-bytes)
    - 4 keys: two multi-sig keys, two node keys
      - Verify: `2 <key1> <key2> 2 OP_CHECKMULTISIG`
    - 4 sigs:
      - Can be compressed to single key w/ **signature aggregation**
    - Verification can be sped up via **batch signature** verification
  - Channel Update Announcement:
    - Advertises **routing policy** for a **directed** channel edge
    - Signed by node advertising

Onion Encoded Payment Routes (Sphinx)

- Sphinx: compact, provably secure **mix-net** packet format
  - Used within lightning as basis for **onion routing**
  - **Fixed-sized** payload
  - Modified version in BOLT #4
- Security Features
  - Nodes don't know their **location** in the route
    - Packet remains **fix sized** during processing
  - Nodes don't how **how long** the route really was
    - All packets encode the **max hop** limit
  - Nodes only know their predecessor and successor
    - Received from downstream node, contains instructions to forward
  - All packets **indistinguishable** from all others
    - Packet is **re-randomized** at each hop
- Shared secret re-used to back-propagate **error messages**

Onion Encoded Payment Routes (Sphinx)

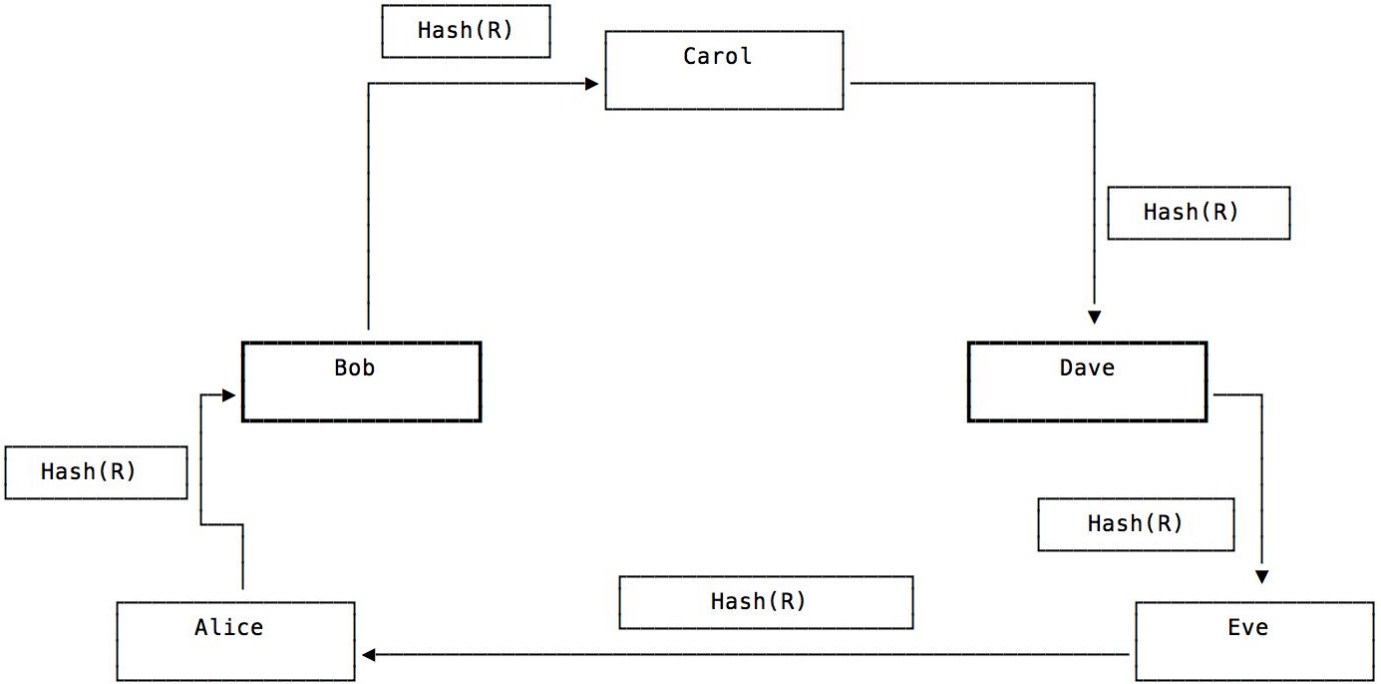
- Payments routed through network using **source routing:**
  - Gives sender **total control** over payment path
  - Authenticated per-hop payload:
    - Outgoing time-lock (#blocks or time)
    - Satoshis to forward (ensure proper fees)
    - Outgoing “realm” (Bitcoin, Litecoin, etc)
- Replay attack prevention:
  - Each Sphinx packet commits to the **payment hash**
  - HTLC’s past **absolute** are rejected
- Routes still subject to **traffic+timing** analysis
  - Poor path diversity weakens security



Hash-Lock Decorrelation

If **Bob** and **Dave** wish to **collude** then they've correlated the route.

This correlation mitigates our **unlikability**



Hash-Lock Decorrelation

- Problem:
  - The hash-lock (payment hash) is **identical** over entire route
- Solution:
  - **Decorrelate** the hash-locks via **re-randomization**
  - Similar to Sphinx's "One little trick"
- Construction (one of many):
  - Switch from hash-locks to "key-locks" (for path length y)
    - Sender calc's: Q_i = Q + R_i + R_i-1 + ... + R_y (multi-scalar mult)
  - `Q = G*q_i ->` Key-Lock from **incoming KTLC** (need the private key to settle)
  - `r ->` Scalar encoded within **payload**
  - `P = Q + r*G = G*q + G*r = G*q + R = G*(q+r),` used for **outgoing payment**
  - Once `p == (r+q)` is revealed: `calc p=r-q`
- Introduces new **causal dependency** into the payment contract:
  - Funds **must** be pulled in the **reverse** order

Blinded Channel Outsourcing

- Lightning requires parties to occasionally **monitor** the blockchain
  - **TEE** based schemes (e.g. Teechan) can help
  - Each “pay-to-self” output has a **relative time-lock** (CSV)
  - Delay acts as **adjudication** period
- Responsibility for watching the chain can be outsourced to a third-party
  - With `SIGHASH_NOINPUT` or MAST, can reduce storage to `O(log(N))`
    - `N = number_of_commitment_updates`
  - For now, we can at least make the process more **private**
- Blinded Channel Monitoring
  - Outsourcer shouldn’t be able to distinguish **which** channel they’re watching
  - Achieved by **randomizing** commitment keys on each update
  - Able to **collapse** the revocation state, saving disk-space
    - “Reverse” merkle-tree -- once you have parent, can **discard** children

Blinded Channel Outsourcing

- Incentivization:
  - Can **pre-pay** outsourcer for their work
  - Possibly add a **bonus** upon adjudication
- Sybil Resistance
  - Outsourcer doesn't know **which** channel (due to blinding)
  - Therefore, client might be feeding **garbage** data
- Possible solution:
  - **Linkable ring-signature** over some **subset** of channel graph
  - Linkability allows outsourcer to ensure **unique** service per user

- Think this stuff is interesting?
  - **Lightning Labs** hiring
    - Crypto Protocol Engineers
    - Mobile Engineers
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