HushRelay: A Privacy-Preserving, Efficient, and Scalable Routing Algorithm for Off-Chain Payments

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Bitcoin Blockchain Scalability Problem

- Bitcoin - too slow and too expensive!
- Scalability limited by 2 main factors -
  - *Average Block Creation Time* - 10 minutes to create and secure a block containing around 2000+ Bitcoin transactions.
  - *Block Size Limits* - Every block has a limit of 1MB (1,000 KB). Limit imposed to prvenet DoS attack.

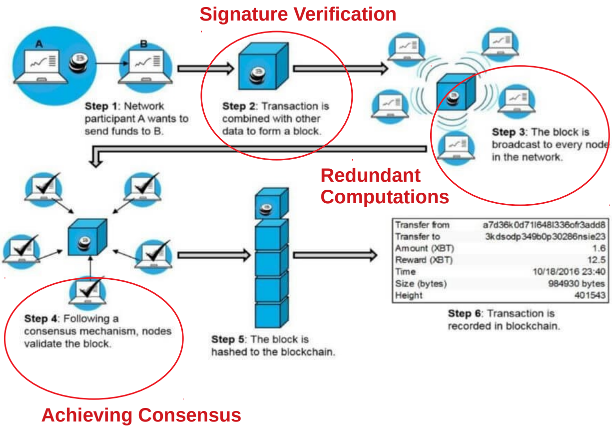

Photo Reference Link

Comparison Bitcoin Vs Conventional Payment Networks

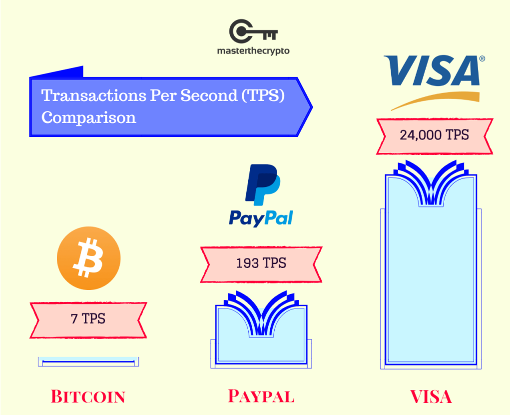

Figure: Processing speeds of Bitcoin compared to other centralized systems.

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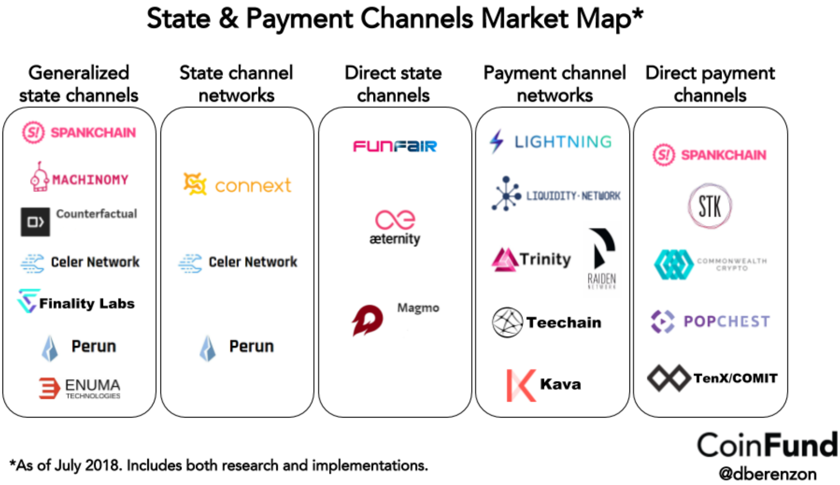
Layer 2 Solution, Off-Chain Transactions

Transactions are 'off-loaded' from the main blockchain to save space and reduce network congestion.

- Payment Channels
- State Channels

Various State Channel Projects



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Off-Chain Payments

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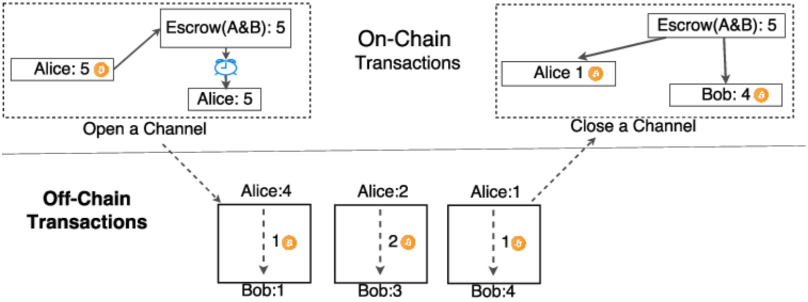
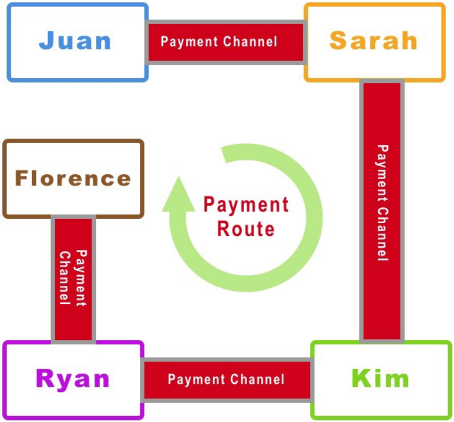


Avoids recording all the transactions, except opening and closing of channel, in the Blockhain.

Payment Network Example

Photo Reference Link



Problems that needs to be addressed in such Payment Networks:

- Routing
- Payment

There are several Payment Algorithms: ensures privacy of payer and payee, hides the payment value. Eg. HTLC [11], Multihop HTLC [8], Anonymous Multihop Lock [9] etc.

Here we deal with just Routing in PCN

Routing in PCN

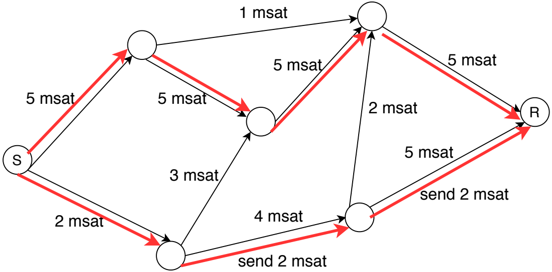


Figure: Transfer 7 msat from S to R

Hence splitting is inevitable.

Challenges faced

This is not like a conventional Routing Algorithm as S does not have sufficient information.

Since only opening of channel gets recorded on-chain, this is the information S has:

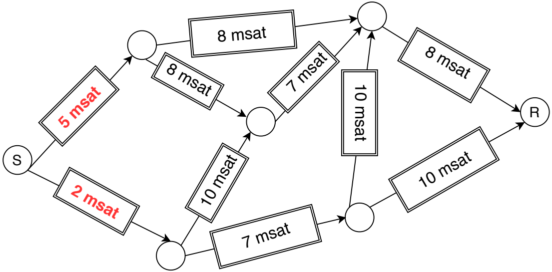
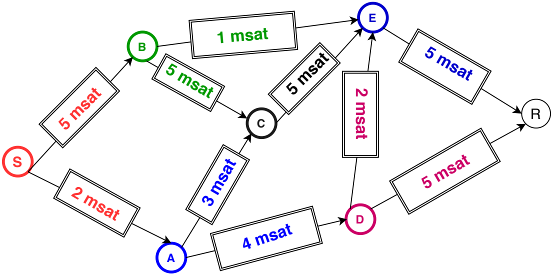


Figure: Except for its outgoing channel, S just knows the opening balance of rest of the channels

Each node has information of the residual capacity of their respective outgoing channel.



Inferences made

- Any routing algorithm designed for PCN must be *Decentralized*.
- Individual nodes take decision based on the information received from its neighbourhood.

Related Works

Landmark Based Routing: SpeedyMurmur [3]

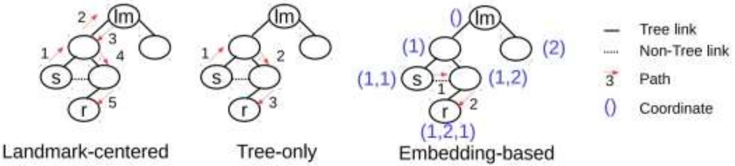


Fig. 1: Examples of different spanning tree routing schemes for landmark lm, sender s, receiver r.

Disadvantage

Wrong decision while deciding split!

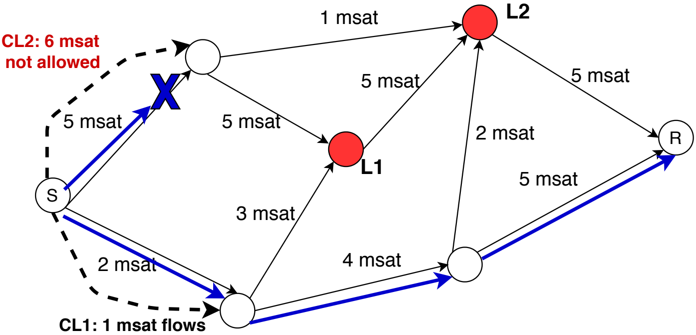


Figure: Transfer 7 msat from S to R: $c_{L1} = 1\ msat$ and $c_{L2} = 6\ msat$

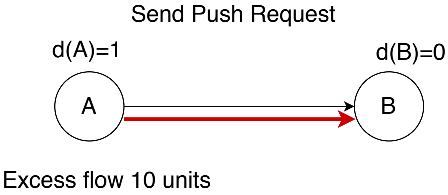
Our proposed solution: HushRelay

- Distributed in nature
- Allows optimal utilization of the available capacities present across multiple paths.
- Efficient and Privacy-Preserving

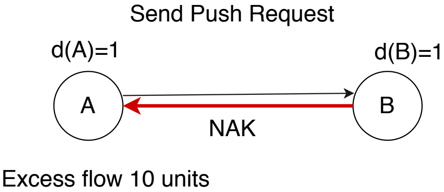
HushRelay: Basic Operations

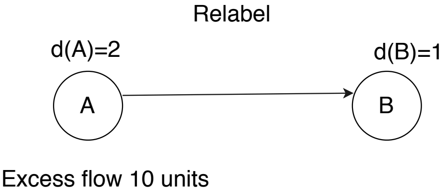
All the nodes acting as individual processing unit in parallel.

1) Try to push excess flow, Sending a Push Request



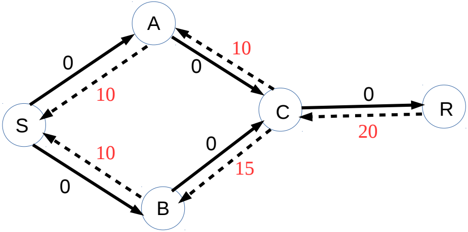
2) Incase of Negative Acknowledgement, Relabel





HushRelay: Example

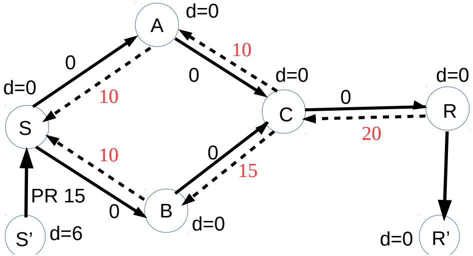
Given the PCN, transfer 15 units from S to R



(a) Initial state

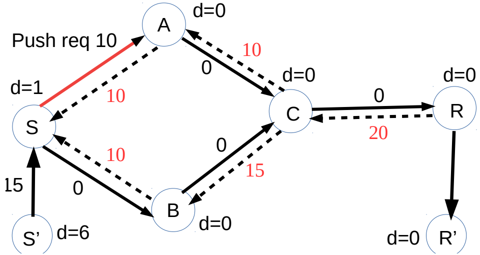
HushRelay: Initialization Phase

Dummy vertices S' and R' is added to the network with edges (S', S) and (R, R'). The edge capacities are as follows : $c(S', S) = 15$ and $c(R, R') = 15$. Each nodes is assigned a label of 0 except dummy vertex S'.



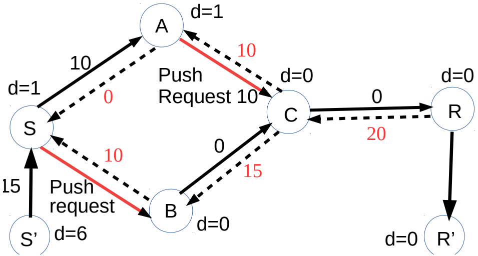
(b) Push request of 15 from S'

15 units pushed to S and d(S) set to 1. S sends push request to A.



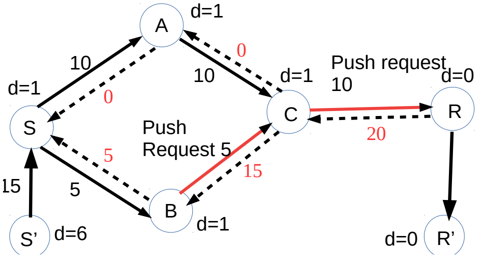
(c)

10 units pushed to A, set d(A)=1. Push request of 5 units to B by S and push request of 10 units to C by A



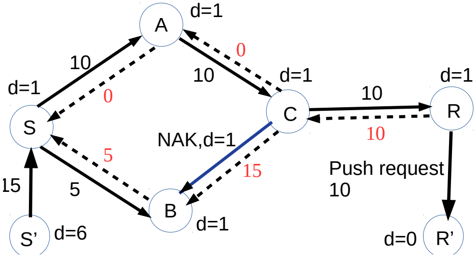
(d)

5 units pushed to B, 10 units pushed to C. Set d(C)=1 and d(B)=1. Push request of 5 units to C by B and Push request of 10 units to R by C.



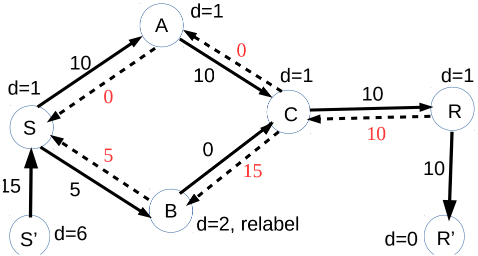
(e)

Negative Acknowledgement by C to B since both have same label, d(C)=d(B)=1. C cannot accept a request and generate a request at the same time. B pauses. C pushes 10 units to R. Set d(R)=1. R generates a push request for R'.



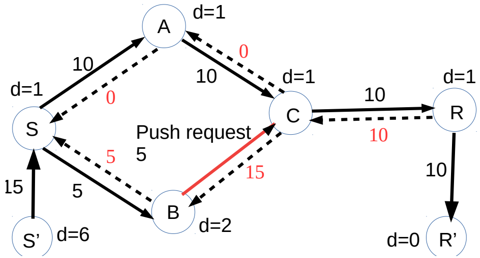
(f)

B performs relabel operation. Sets d=2 (max label of its neighbours + 1). R' accepts push request



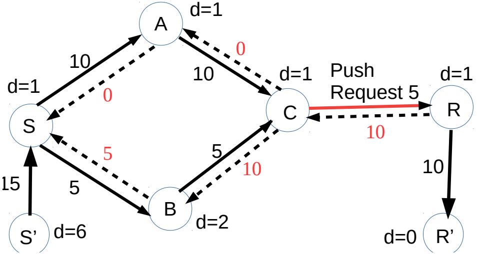
(g)

B sends a push request to C.



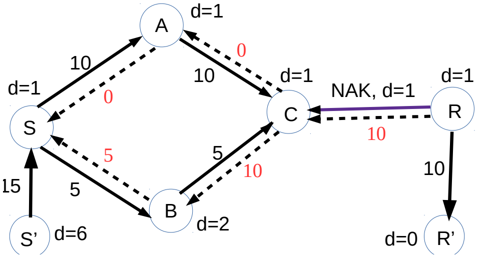
(h)

C accepts the push request. It won't be able to send push request to R as d(C)=d(R)=1.



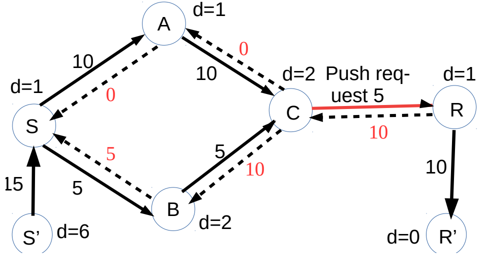
(i)

Negative Acknowledgement received from R. Hence C performs a relabel operation.



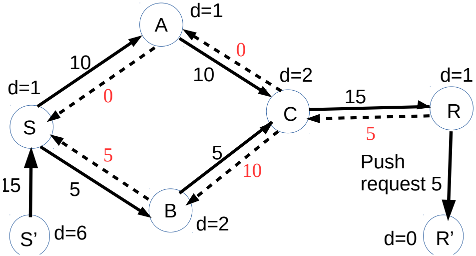
(j)

It sends push request of 5 units to R.



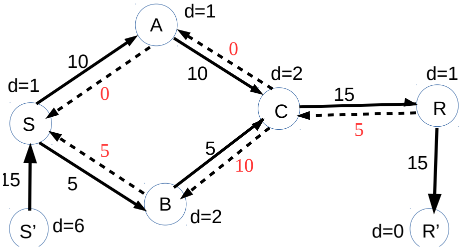
(k)

R accepts the push request, generate a push request of 5 units for R'.



(l)

Final State: Funds transferred to R



(m)

Complexity Analysis

n :Number of nodes in PCN, m: Number of payment channels

Under Asynchronous Implementation:
Message Complexity : $O(n^2 m)$
Runtime Complexity: $O(n^2)$

Analysis of *HushRelay* and *SpeedyMurmur*

HushRelay Source Code Link [1]

Table: SpeedyMurmur vs HushRelay - Performance Analysis on Real Instances

Network/Algorithm	SpeedyMurmur								HushRelay	
	Success Ratio Number of Landmarks				Time taken Number of Landmarks				Success Ratio	Time taken
	1	2	4	6	1	2	4	6		
Ripple Network	0.38	0.69	0.92	0.98	1.66s	2.2s	3.23s	4.74s	1	2.4s
Lightning Network	0.42	0.64	0.83	0.91	0.61s	0.69s	0.83s	1.94s	0.99	0.15s

On Simulated Instances

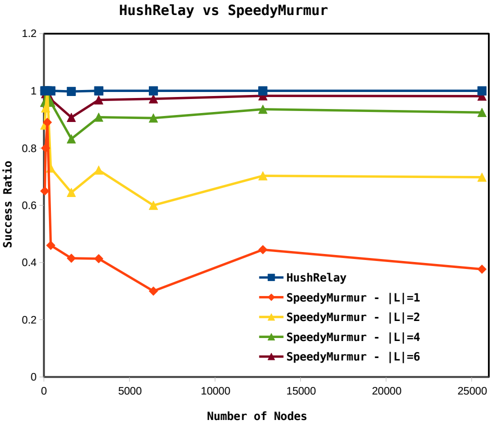


Figure: Success Ratio vs Number of Nodes

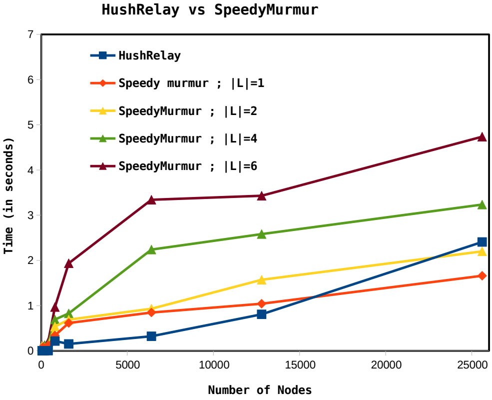


Figure: Time To Route vs Number of Nodes

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Thank You

Any Questions?