OBF: A Guaranteed IP Lookup Performance Scheme for Flexible IP Using One Bloom Filter

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Background and Motivation

The current IP address system is facing more and more problems

1) Poor flexibility

- Low packet efficiency
- Address exhaustion
- Address fragmentation

2) Single semantics

- topology-semantic only (RFC0791)
- DNS delay
- High dynamic satellite network

Expectation for a flexible address structure

- be adaptive to futuristic scenarios requirements
- unleash more network abilities and possibilities

Background and Motivation

Flexible IP (FlexIP): Address Structure

For short address length only
- length: 1-byte (0-239)
- One segment, topology semantic

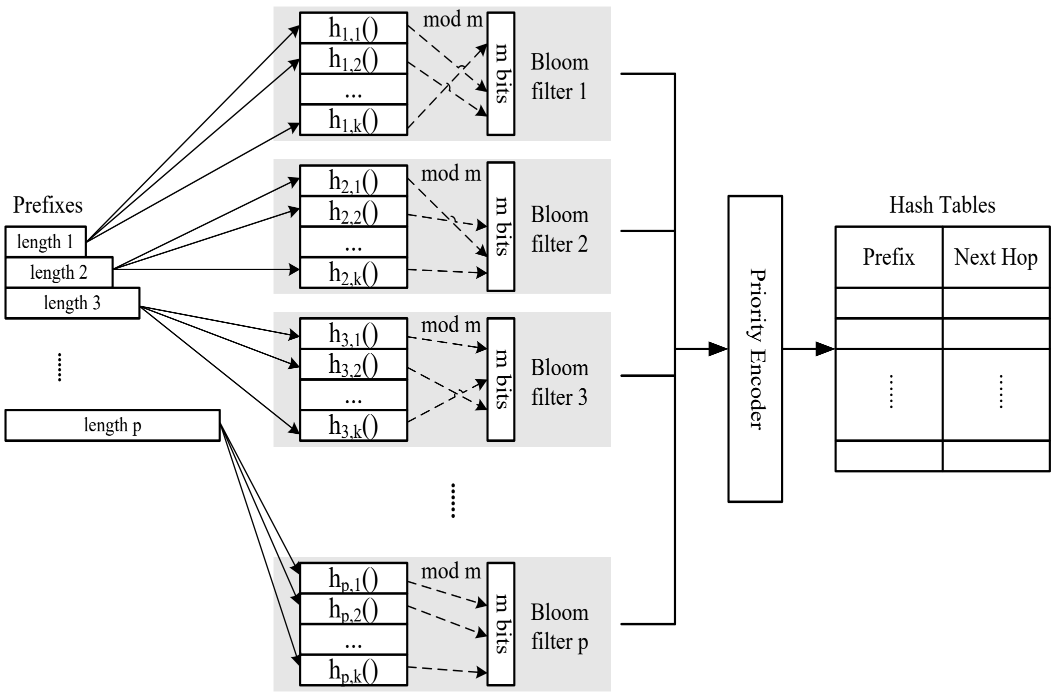
For extendable address length
- length: Any-byte
- One segment, topology semantic

For multi-segment address
- length: accord with each segment
- Multiple segments, topology semantic

For non-topology semantic address

Index	Type	Structure (default by topology semantic and 1 segment)
0x01	Restrained Space	topology address - address 1
0x02	Restrained Space	topology address - address 2
...	...	...
0xEF	Restrained Space	topology address - address 239
0xF0	Extendable Space	followed by address with 16-bit length
0xF1	Extendable Space	followed by address with 32-bit length
0xF2	Extendable Space	followed by address with 64-bit length
0xF3	Extendable Space	followed by address with 128-bit length
0xF4	Extendable Space	followed by address with 256-bit length
0xF5	Extendable Space	followed by address with X-bit length
0xF6	Hierarchical Segments	followed by address with 2 segments
0xF7	Hierarchical Segments	followed by address with 3 segments
0xF8	Hierarchical Segments	followed by address with Y segments
0xF9	Multi-Semantics	followed by Non-topological semantic address
0xFA - 0xFF	None	reserved

Background and Motivation



The conventional Bloom Filter-based scheme(CBF)

Challenge for CBF-based FlexIP addressing scheme:

- Off-chip memory access
- Scalability
- Simplicity

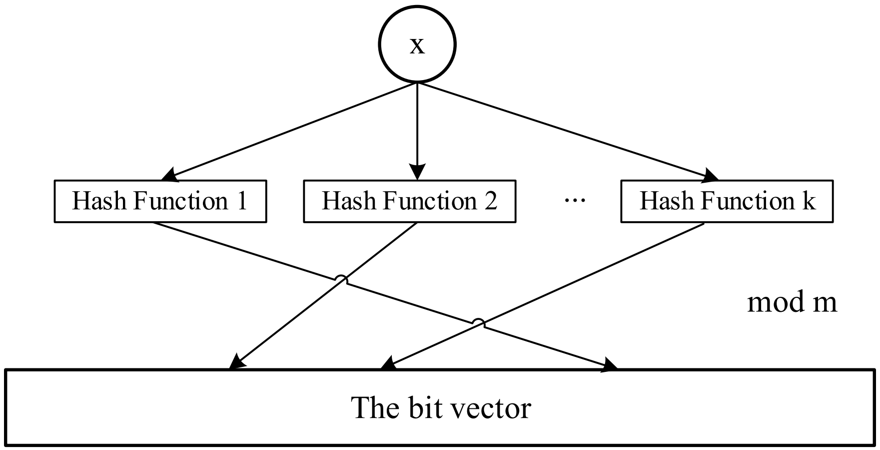
OBF: Off-chip memory access

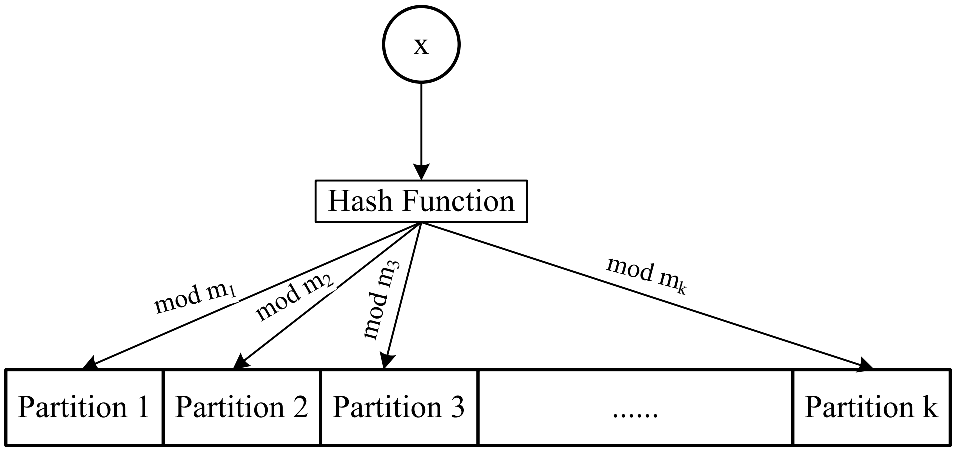
Original		Expanded		
Prefixes	Next hop	Prefixes	Next hop	
P1=0*	1	00*(P1)	1	Length 2
P2=1*	2	01*(P1)	1	
P3=10*	3	10*(P3)	3	
P4=111*	4	11*(P2)	2	
P5=11101*	5	11100*(P4)	4	Length 5
		11101*(P5)	5	
		11110*(P4)	4	
		11111*(P4)	4	

Worst-case off-chip memory access:
P → P/w

Controllable Prefix Extension (CPE)

OBF: Scalability





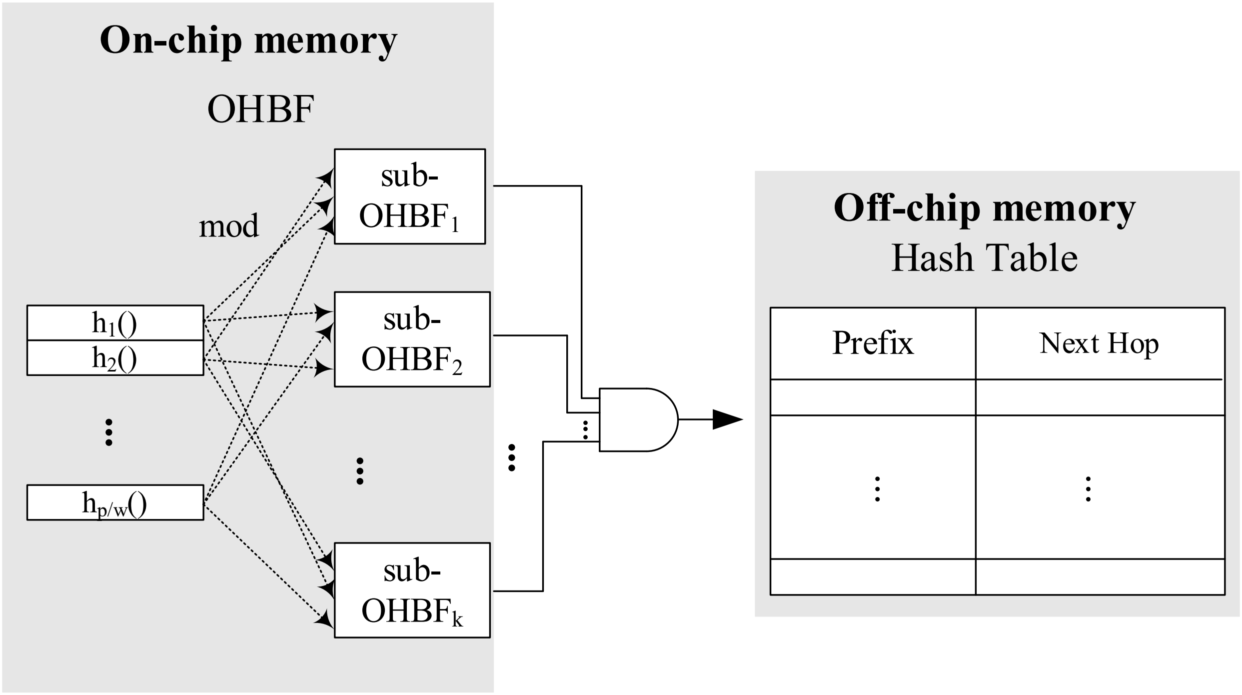
SBF: Multi-Hashing

OHBF: One-Hashing

The computation cost:

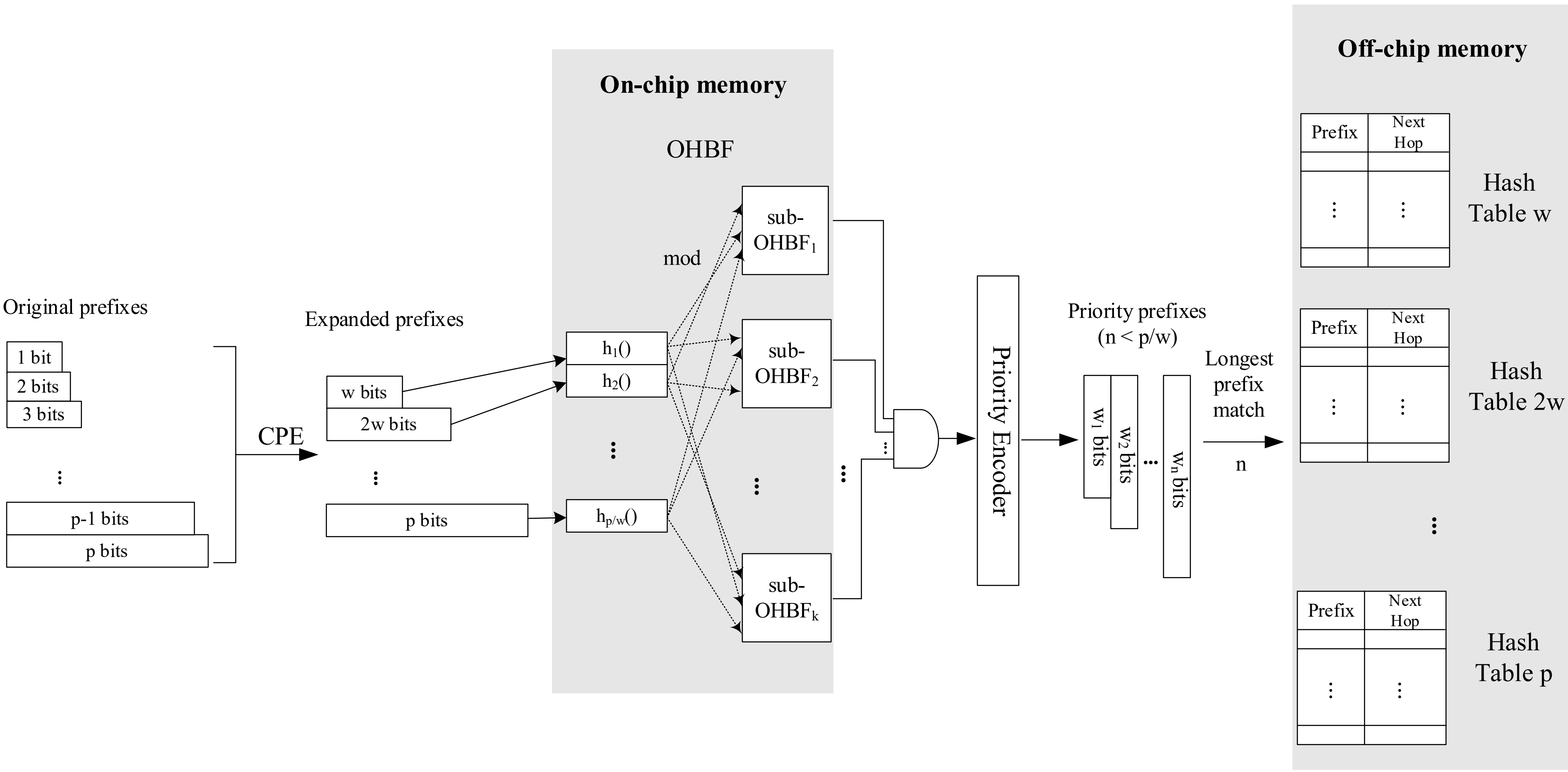
1 → 1/k

OBF: Simplicity



- each sub-OHBF uniformly loads all prefixes
- Only need to allocate enough on-chip memory space at the beginning

OBF: Configuration



OBF: Theoretical analysis

- **False positive probability**

$$f_{CBF} = \left(1 - \left(1 - \frac{1}{m}\right)^{nk}\right)^{k}$$

$$\approx \left(1 - e^{-\frac{nk}{m}}\right)^{k}.$$

$$f_{OBF} \leq \left(1 - \left(\sqrt[k]{\prod_{i=1}^{k}\left(1 - \frac{1}{m_i}\right)}\right)^{n}\right)^{k}$$

$$\approx \left(1 - \sqrt[k]{\prod_{i=1}^{k} e^{-\frac{n}{m_i}}}\right)^{k}.$$

If the distribution of m_i is concentrated in $\frac{m}{k}$ and m is large enough, then $\sqrt[k]{\prod_{i=1}^{k} e^{-\frac{n}{m^i}}} \approx e^{\frac{-nk}{m}}$.

- **Addressing Performance**

The maximum number of off-chip memory access per IP lookup is

$$H_{max} = \frac{P}{w} f$$

On average, the upper limit of the number of off-chip memory access for once successful IP lookup is

$$H_{avg} \leq h_{max} + 1 = \frac{P}{w} f + 1$$

In the worst case, the number of off-chip memory access is

$$H_{worst} = \frac{P}{w} + 1$$

OBF: Theoretical analysis

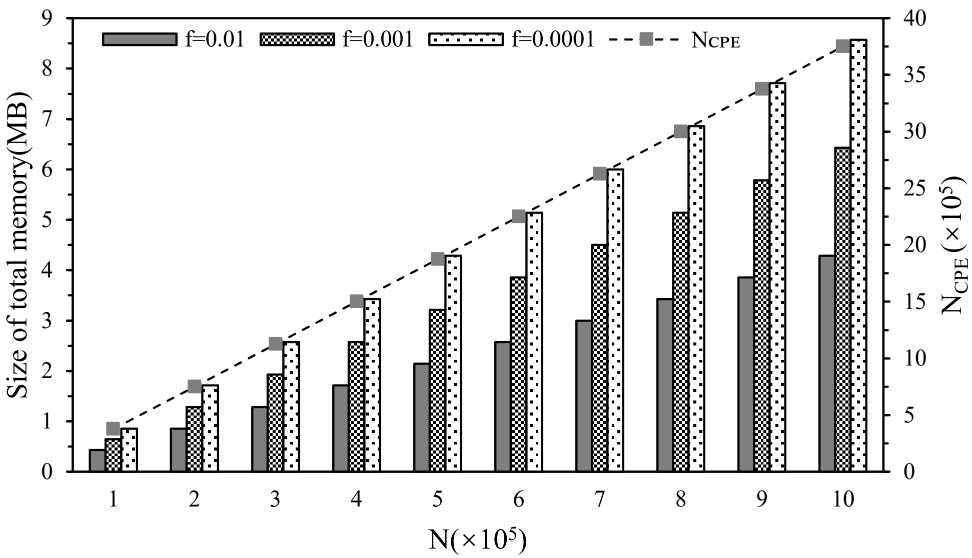
- **False positive probability**

On-chip memory, M is

$$M = -\frac{kN_{CPE}}{\ln\left(1 - f^{\frac{1}{k}}\right)}$$

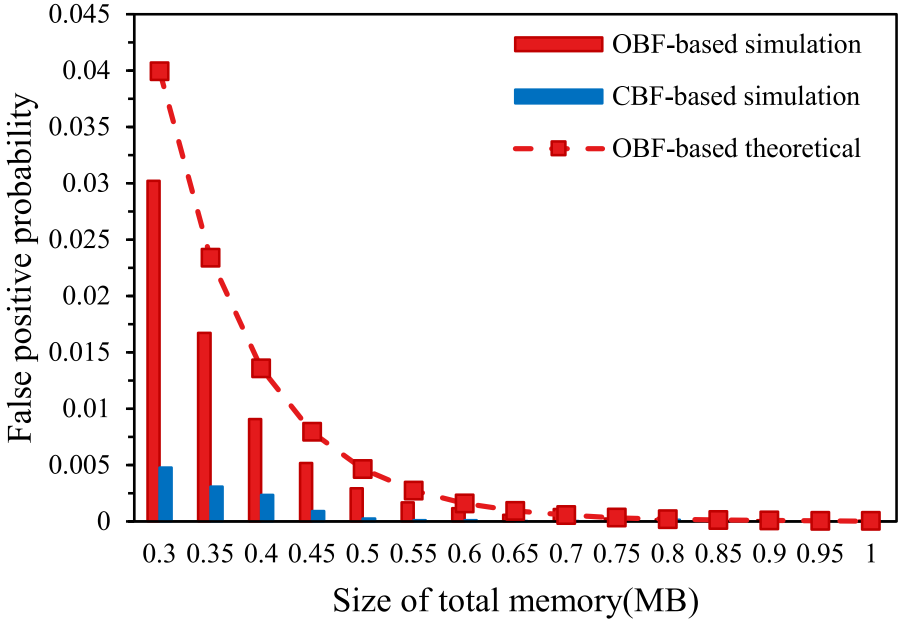
Under certain addressing scale and addressing performance

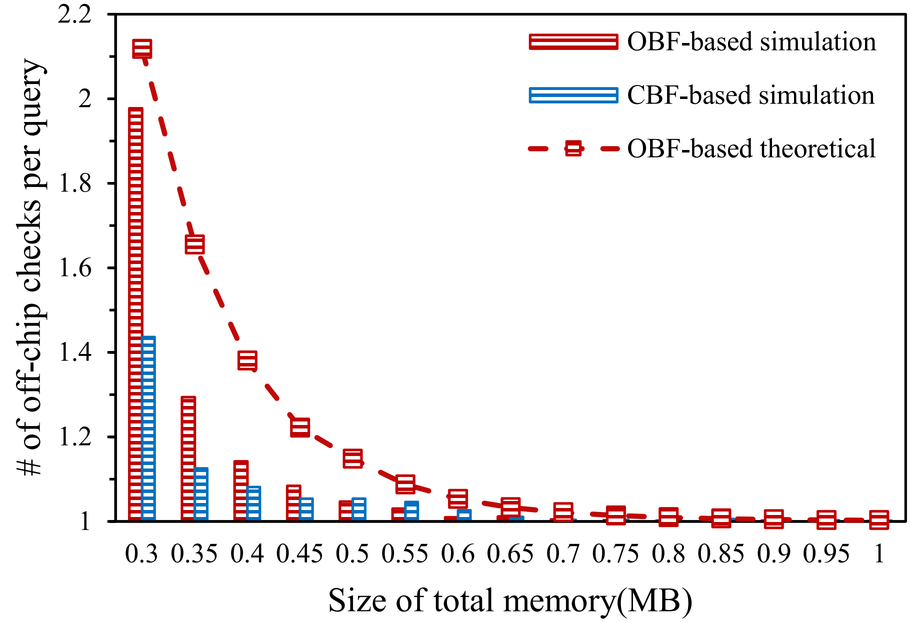
$$M_{min} = -N_{CPE} \cdot \ln \frac{\left(1 - e^{-\ln 2}\right)^{\frac{M}{N_{CPE}} \ln 2}}{(\ln 2)^2}$$



In theory, OBF-based scheme could achieve **1 off-memory access** per IP lookup with 100,000 FlexIP address under no more than **1 MB** on-chip memory.

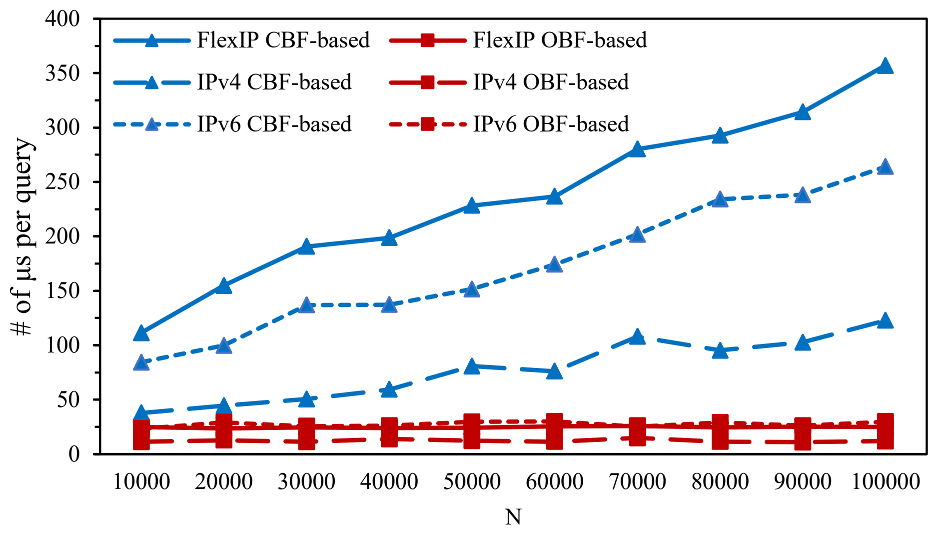
Evaluation: The Impact of False Positive

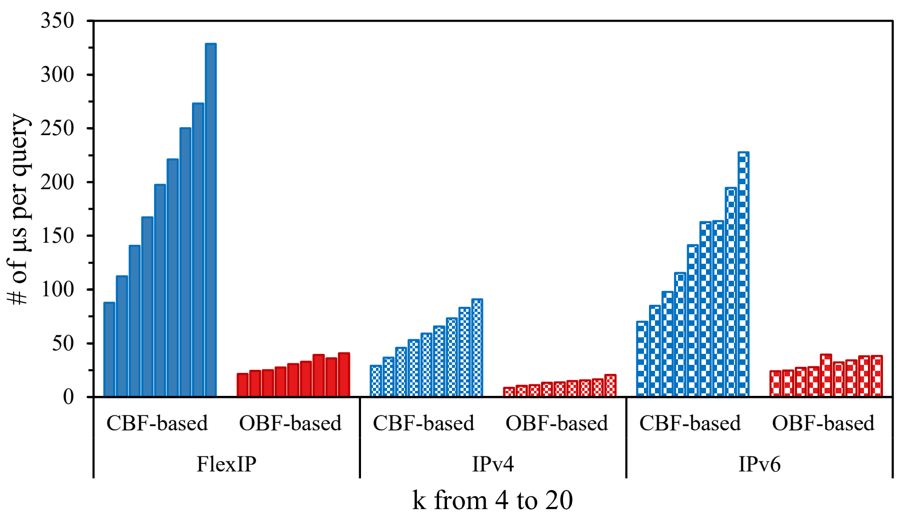




- The false positive probability gradually decreases as the total on-chip memory increases.
- The false positive probability of OBF-based is higher than that of CBF-based with the same size, but the addressing performance is not weaker.
- OBF-based limits the length of prefixes, and does not need to check all possible prefixes in one IP lookup.

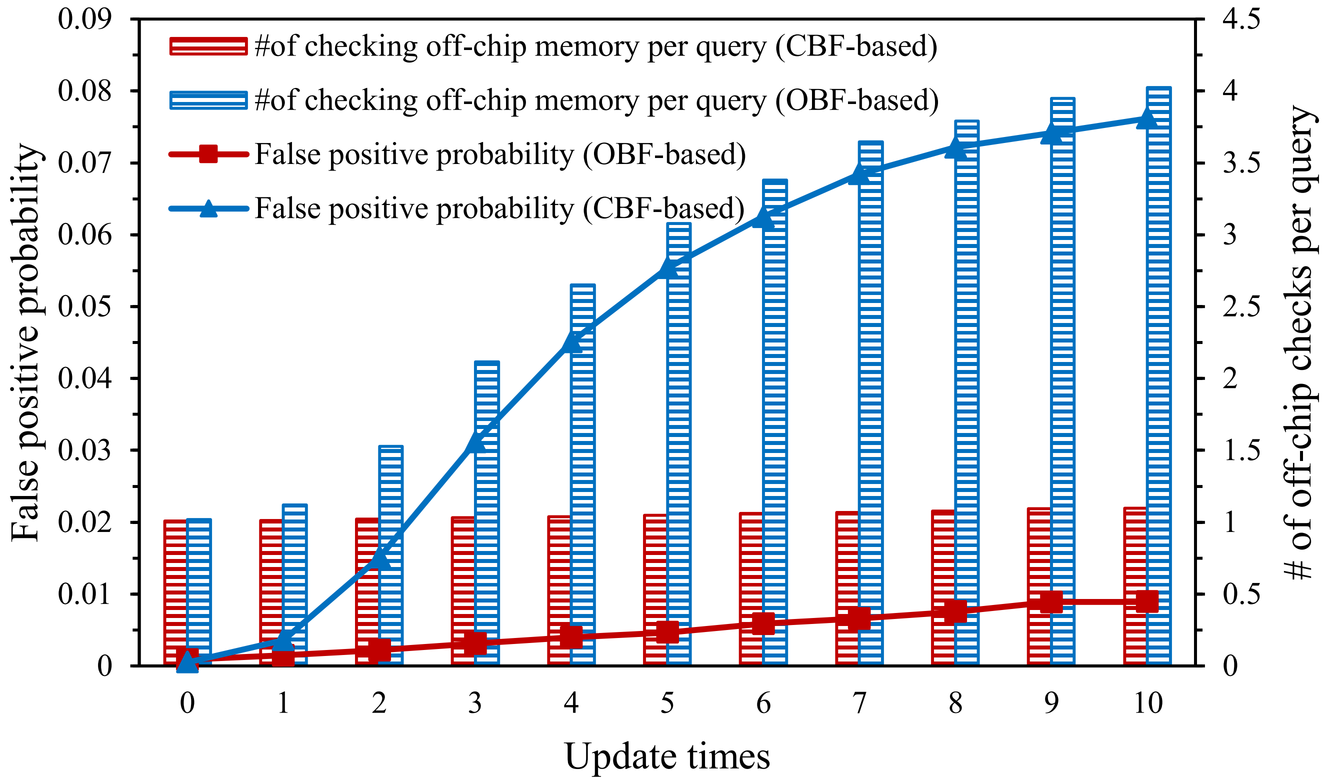
Evaluation: Scalability





- OBF-based performs much better than CBF-based in various situations, and the lookup speed is fast and almost remains constant.
- OBF-based uses one hash function to complete addressing, which also allows it to keep the lookup speed constant as the router table size increases.

Evaluation: Updates



- With the increase of update times, the performance of CBF-based decreases sharply, while the false positive probability of OBF-based increases slightly but still maintains close to 1 off-chip memory access per lookup.
- OBF-based only uses one Bloom filter without the problem of uneven memory allocation.

Evaluation: Lookup speed

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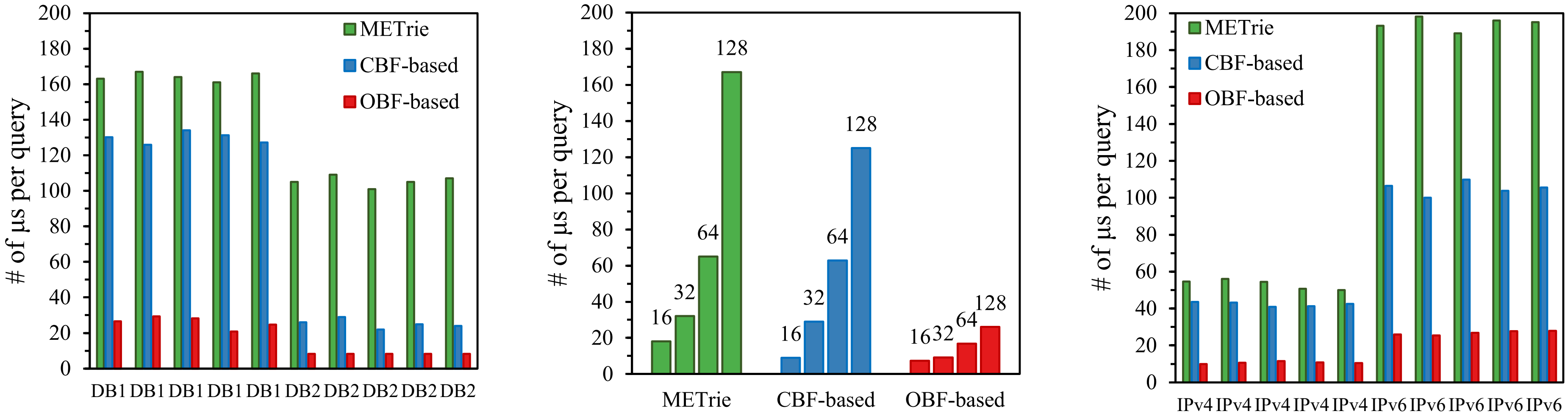

(a) FlexIP (b) Prefix length (c) IPv4 and IPv6

- OBF-based has the fastest lookup speed.
- OBF-based is not only applicable to FlexIP addressing, but also IPv4 and IPv6.

Thanks

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