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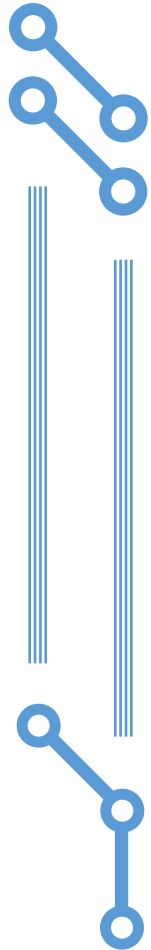
Enabling Granularity-customizable Geocast in Network Layer Using P4-based Software Defined Network

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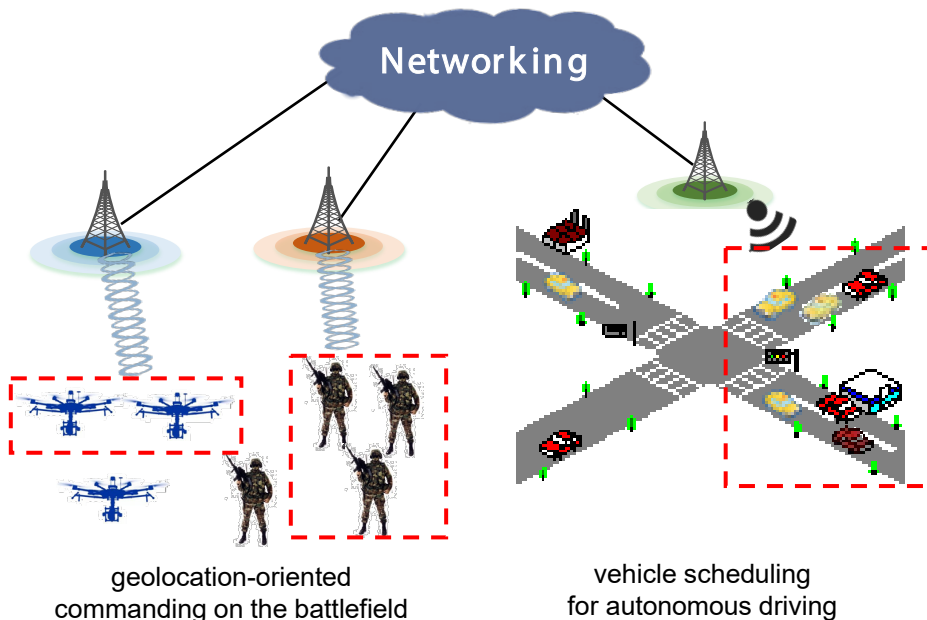
Background & Related Work

Design Details

Performance Evaluation

Conclusion

■ Usecases for geocast

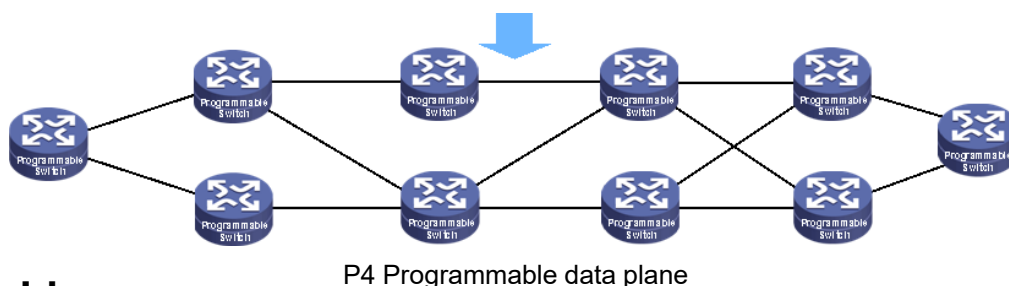
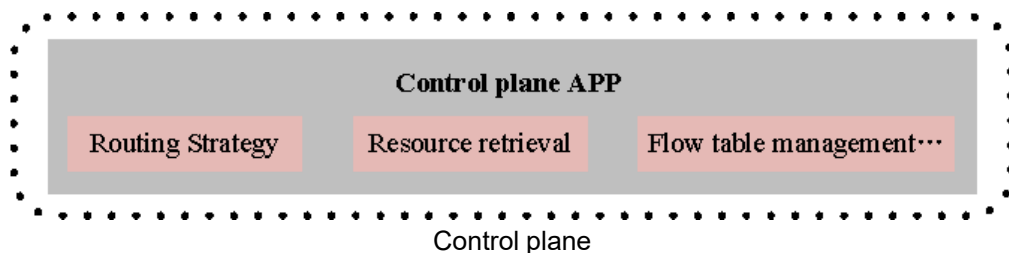


■ Existing solutions

- **IP-based approaches**
eg: Akamai, Quova, Maxmind, Geobytes, IPInfoDB, etc.
 - Poor performance on mobility.
 - High implementation overhead.
- **location-based routing protocols**
eg: GeoTORA, Geo-AKOM, DA-GSAF, EECSG, SMGSAF, etc.
 - Lack of flexibility.
 - non-IP, incompatible with the current Internet.

- **Geocast** is a one-to-many communication paradigm for sending the data packets to a designated area rather than an IP address.
- The existing solutions cannot cope with the challenges in **flexibility**, **mobility**, and **compatibility** in situations where users require a granularity-customizable geocast.
- **Question:** How can we flexibly implement geocast towards the designated area of customized granularity?

■ P4-based Software-defined Network (SDN)



Idea:

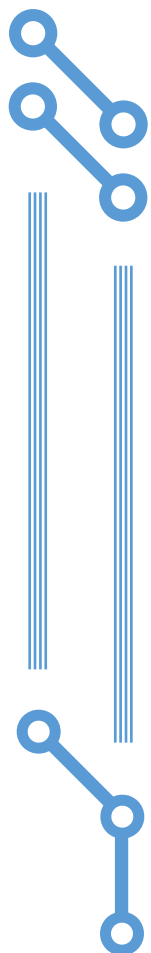
- Implementing granularity-customizable geocast at the edge of the network through embedding a novel network-layer addressing scheme using the programmable data plane.
- Enhancing the compatibility with the assistance of a mapping service on the control plane.

➤ Control plane

- Deploy service layer functions
- Provides convenience for network management

➤ P4 Data plane

- Provide flexibility to customize packet processing
- Protocol-independent



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■ Design goals

1. **Flexibility:** Users may require sending messages towards a customized fine-grained destination area when using geocast services. A flexible network-layer naming method is needed to identify the destination area of customized granularity.
2. **Mobility:** Geocast is usually applied in mobile scenarios. It is necessary to make network layer forwarding insensitive to the changes in the receiver's location.
3. **Compatibility:** Enabling an Internet-wide granularity-customizable geocast would be potentially valuable to improve the service capability of the Internet.

Solution designs

1. EMD-based subdivision and coding.
2. GeIP addressing.
3. GeIP-based packet processing with P4.
4. Geolocation Name Service (GNS system).

(1) EMD-based geographic subdivision & coding

1. The global region is subdivided hierarchically into multiple meshes by longitude and latitude interval.
2. Binary coding is used to generate multilevel subdivision mesh code (SMC).
3. Every subdivided mesh of customized granularity is named by a unique SMC.
4. SMC can identify a maximum fine-grained area of 4cm^2

Concept of *domain* & subordinate *subarea*.

1. A domain refers to a country-scale region.
2. A subarea refers to the area subdivided by the EMD subdivision method within a domain.

Note: When implementing the granularity-customizable geocast, the destination area is usually a fine-grained area within a certain subarea.

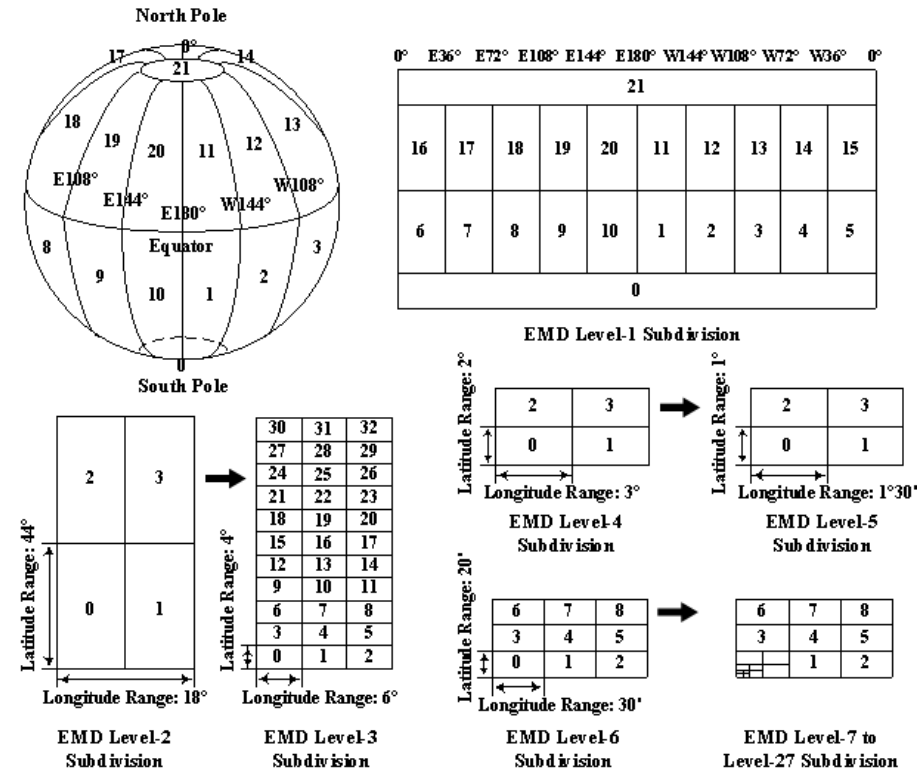


Fig.1 EMD (Extended model based on the Mapping Division) mesh subdivision and coding method

Level-1 (5 bits)	Level-2 (2 bits)	Level-3 (6 bits)	Level-4 (2 bits)	Level-5 (2 bits)	Level-6 (4 bits)	Level-7 to Level-27 (40 bits)
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Fig.2 Example of Subdivision Mesh Code (SMC)

(2) GeoIP addressing

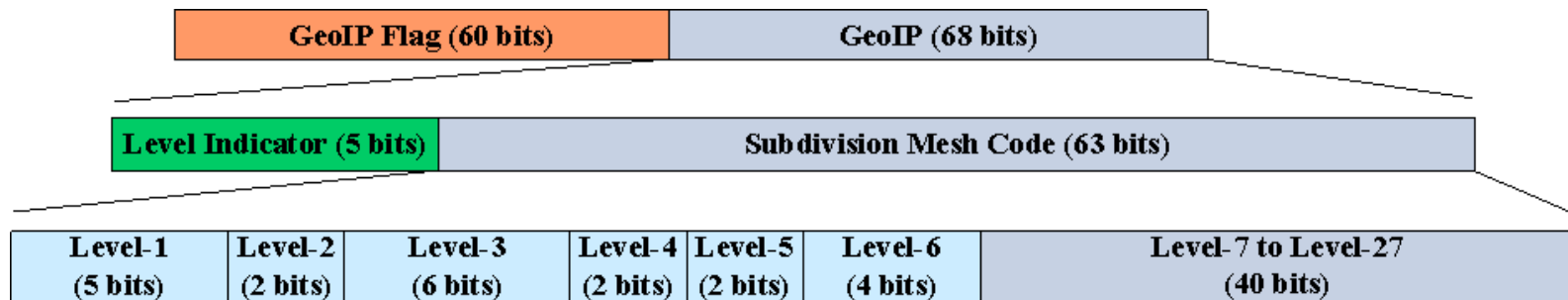


Fig.3 Structure of GeoIP

Level Indicator:

GeoIP is designed based on the SMC by adding 5 bits of binary code as the level indicator which is used to determine the level of SMC.

GeoIP Flag:

To make it compatible with the current IP-base network, GeoIP is implemented with the IPv6 namespace. Hence, an additional 60 bits of GeoIP Flag are added to the GeoIP for completeness.

Note: A GeoIP could uniquely represent a specific subdivided area. The GeoIP prefix of a domain is the same as the GeoIP prefix of its subordinate subarea. We assign the GeoIP of a subarea to the access point (AP) of that subarea to implement the granularity-customizable geocast.

(3) GeoIP-based Packet Processing with P4

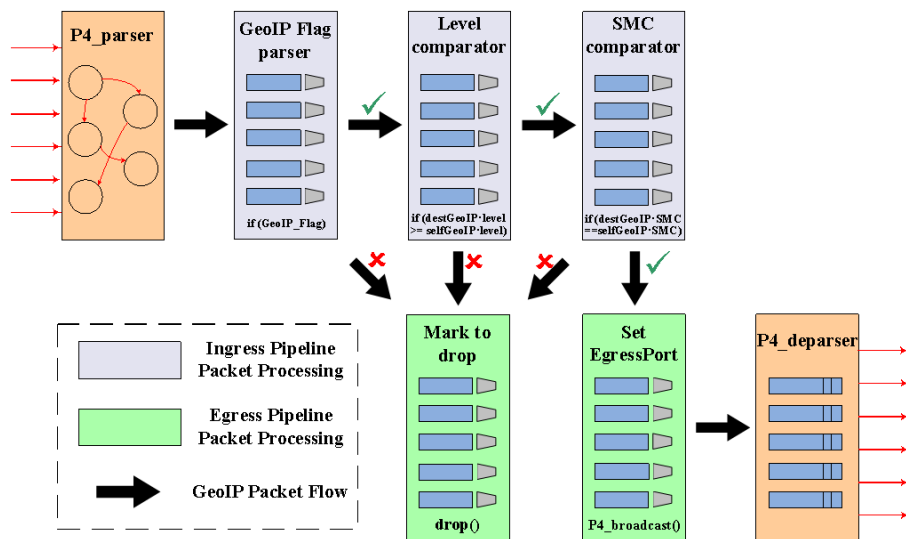


Fig.4 GeoIP packet forwarding of P4 pipeline

GeoIP packet forwarding:

- The GeoIP packet processing scheme is embedded in the wireless AP (say, a basestation, WIFI, WLAN card) by utilizing P4.
- GeoIP packets will be processed according to its GeoIP Flag, Level Indicator, and SMC.

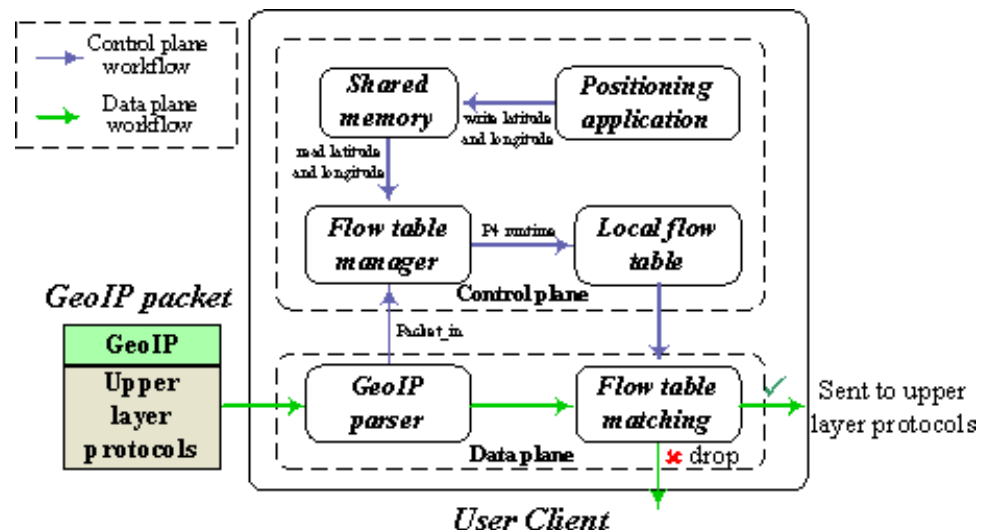


Fig.5 GeoIP packet receiving scheme

GeoIP packet receiving:

- Local control plane is used to provide dynamic flow table according to the user's location.
- Data plane performs the match-action to determine whether the packet should be delivered to upper layer protocols.

(4) Geolocation Name Service (GNS)

Idea: We refer to the design of DNS (Domain Name Server) system. The GeoIP can be regarded as the “Domain Name” and be resolved to an IP address.

Domain GeoIP Server (DGS):

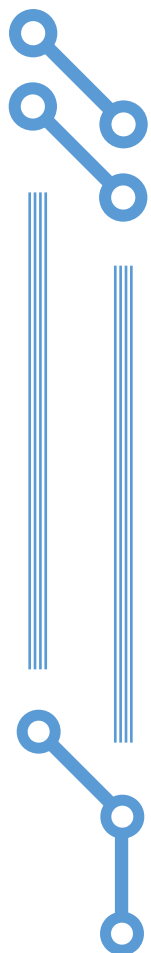
- Each domain has a DGS which is assigned a public IP address.
- DGS maintains the mapping entries for the GeoIP of each subarea in that domain to the IP address of the local wireless AP in that subarea.

Root GeoIP Server (RGS):

- Every RGS is assigned a public IP address.
- RGS records the mapping entries of each domain’s GeoIP to the IP address of its DGS.

Local GeoIP Server (LGS):

- LGS is deployed in each subarea of a domain. LGS could only be accessed by the users of the same subarea.
- It is responsible for recording the recently queried GeoIP-to-IP mapping entries to offload the query request in DGS and RGS.



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Design implementation

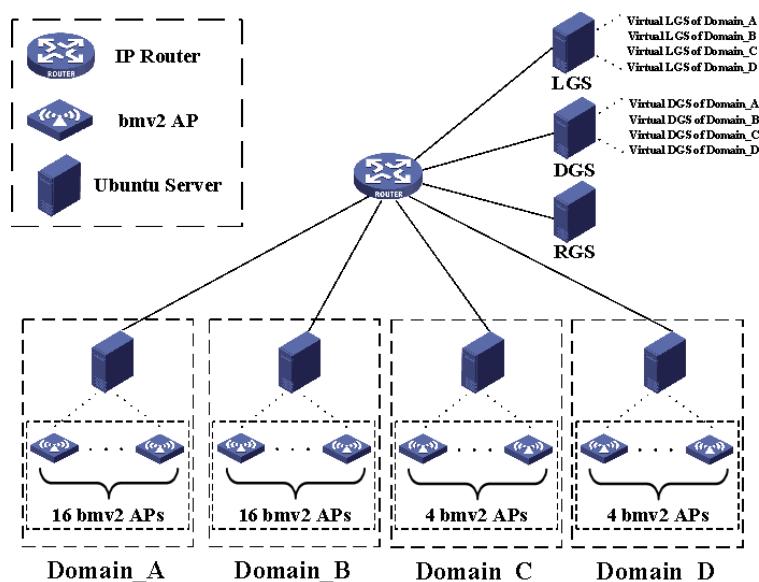


Fig.6 The topology of the prototype system

- **Programmable AP:** bmv2+WLAN card. Ubuntu 18.04 system, Intel(R) Xeon(R) CPU E3-1230 V2@3.30GHz*8 4 Cores, Memory 8G.
- **User Client:** P4Pi+Raspberry PI. BCM2711B0 CPU@1.5GHz 4 Cores, 8GB, Raspberry Pi OS 5.10.17 32bit.
- **GNS system:** MySQL+ONOS. Ubuntu 18.04 system, Intel(R) Xeon(R) Silver CPU 4214 @2.20GHz*48 12 Cores, Memory 62.6G.

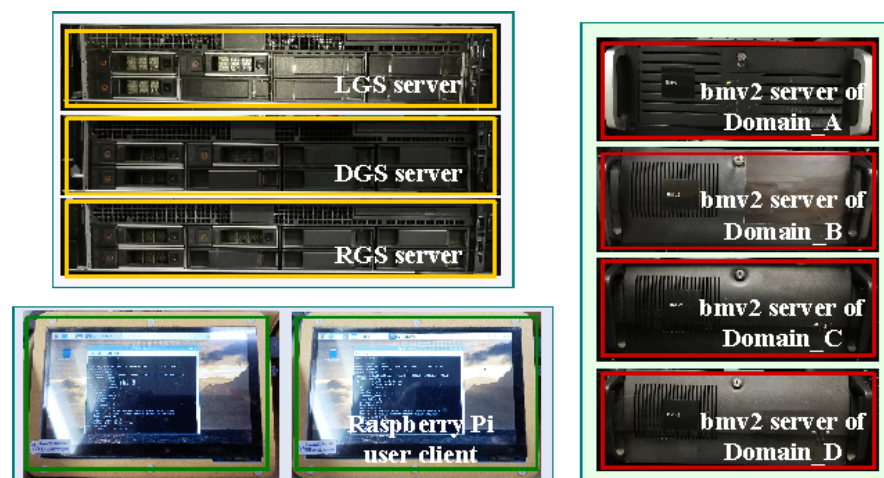


Fig.7 The hardware of the prototype system

Table.1 Settings of experiment

Parameter	Value
Number of Domains	4
Number of Subareas	40
Number of Programmable APs	40
Number of User Clients	100
Number of Servers in GNS	1 RGS, 4 DGSs, 4 LGSs
The Entry Lifetime of LGS	30 seconds
Flow Intensity of User Client	80%

Results and analysis

Network layer overhead:

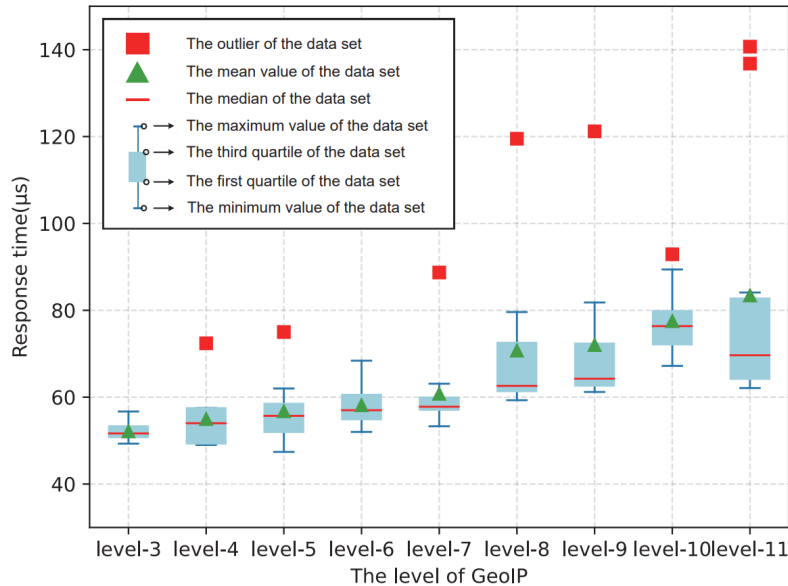


Fig.8 Response time for indexing different levels of GeoIP

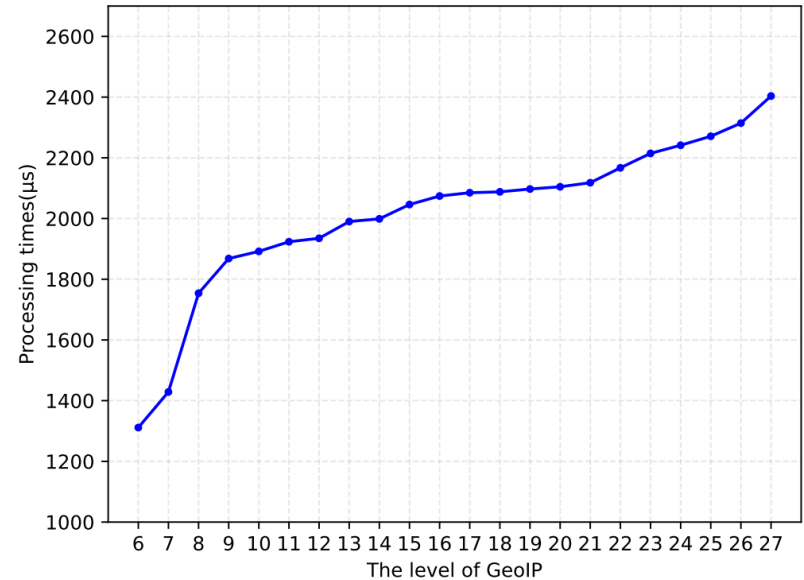


Fig.9 The average time cost for processing different levels of GeoIP in bmv2

- The overhead for querying entries indexed by multi-level GeoIP will not exceed 200μs.

- The average time cost for processing different levels of GeoIP will not exceed 2.5ms.

Results and analysis

Comparison with the IP-based Approaches on mapping performance:

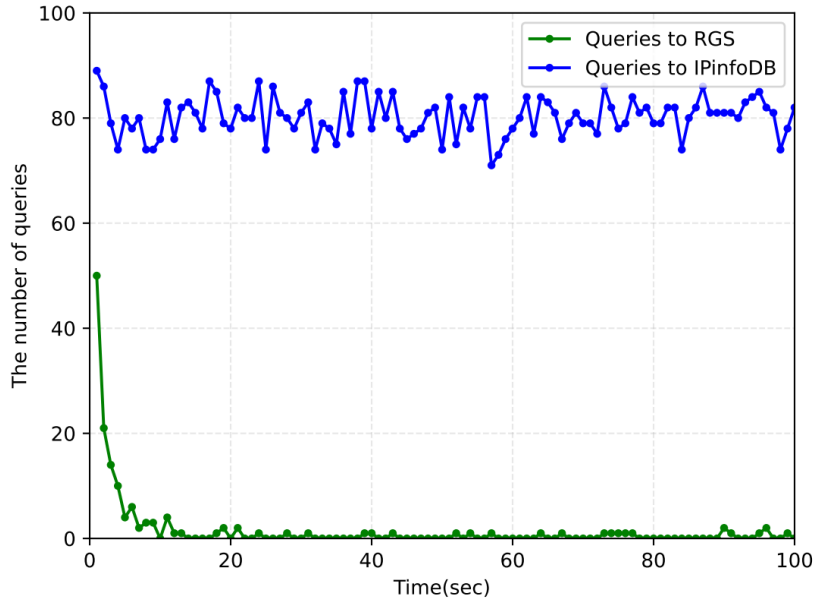


Fig.10 The number of queries to RGS vs IPinfoDB

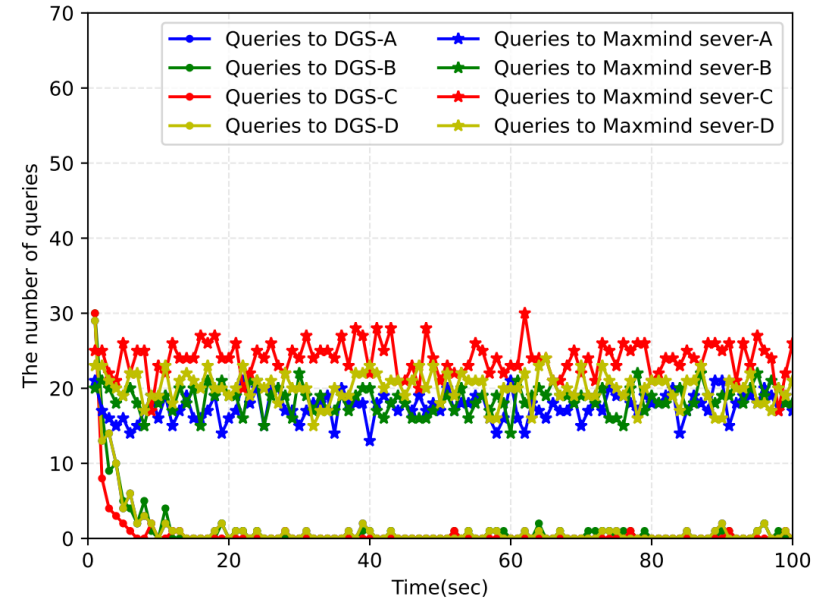
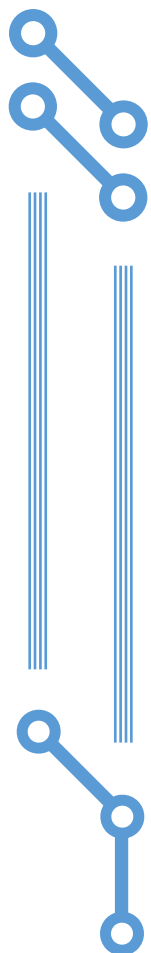


Fig.11 The number of queries to DGS vs Maxmind

- The query to RGS will not be necessary when the host of geocast and the packet receivers are present in the same domain.

- The hierarchical mapping system is beneficial to offload the query requests.



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- The global region is subdivided based on a geographic subdivision and coding method of EMD (Extended model based on the Mapping Division). Then we introduce the GeoIP as the name to identify the geographical areas of customized granularity.
- A GeoIP packet processing scheme is designed using the P4-based SDN to implement the granularity-customizable geocast at the edge of the network.
- A Geolocation Name Service (GNS) system is designed to make our design compatible with the current Internet by resolving a GeoIP to an IP address.
- The prototype system is built to implement and evaluate our design. Experiment results show that our design is feasible to provide granularity-customizable geocast at a relatively low cost.



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